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Design of a Synchro-Drive Omnidirectional Mini-Robot

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Abstract. Using the synchro-drive principle, the paper presents a new omnidirectional mini-robot with conventional wheels. The synchro-drive principle is achieved applying geared mechanisms: three for steering and another three for displacement. The mini-robot uses two DC motors and three pairs of conventional wheels. The first DC motor controls the rotation of three pairs of the wheels around the horizontal axis thus generating the driving force (traction) to the mini-robot. The second motor controls the rotation of three pairs of the wheels around the vertical axis hence generating their orientation.

Introduction

In comparison with conventional design robots, an omnidirectional robot has great advantages in terms of mobility in congested environments. Omnidirectional robots can change direction without changing the position or orientation of robots thus being capable of easily performing tasks in congested environments when facing static and dynamic obstacles and narrow aisles.

These environments are usually found in factory workshops, offices, warehouses and hospitals.

Omnidirectional robots fall in two categories. This classification is done according to the type of the wheels: robots with special wheels – the so-called omnidirectional wheels and robots with conventional wheels.

In the synchro-drive (synchronous drive) mobile robot, the wheels are rotated together, and therefore they always point to the same driving direction (all wheels steer and drive synchronously), (Fig. 1). All wheels turn and drive in unison [1–3].

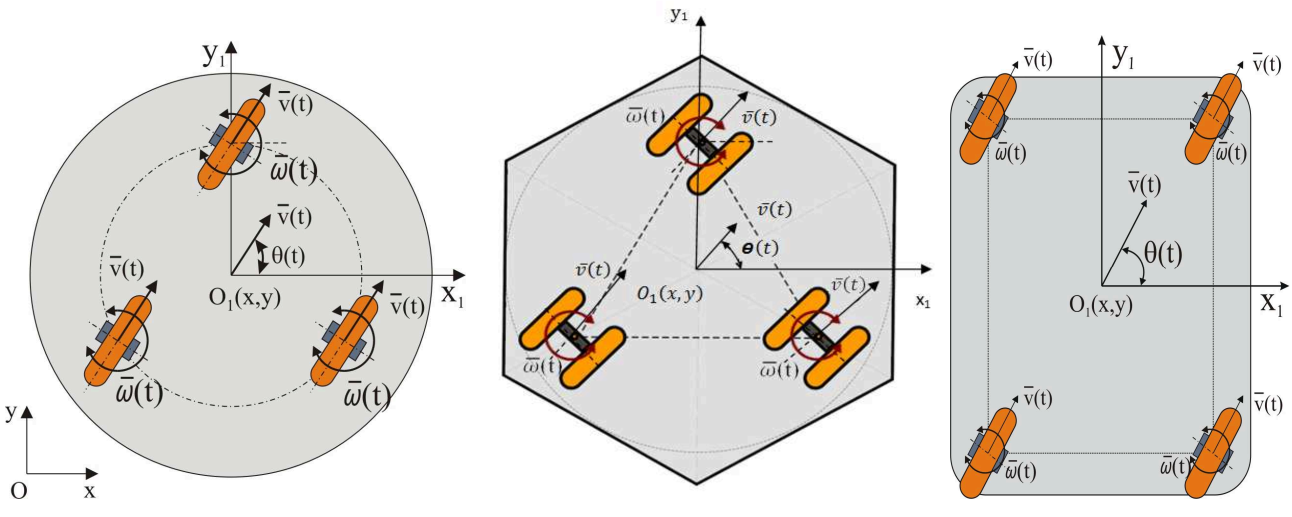


Fig. 1. The configuration of synchronous wheels [3]

The platform does not rotate as the wheels steer; thus, it remains in the same orientation regardless of its direction of movement. This can be accomplished by using a single motor and a chain for steering and a single motor for driving all wheels.

Some omnidirectional robots with classical wheels use the synchro-drive principle and are discussed in literature [4–10]. They have three or four wheels/three or four pairs of wheels all driven and being steered [11–13].

The synchro-drive principle has some benefits with respect to other configurations of wheeled robots. The main benefits are as follows [7], [9]:

- only two motors are necessary: one motor rotates all wheels together to produce motion, the other motor turns all wheels to change direction;
- no suspension needed; three wheel configuration ensures the ground contact of each wheel;
- the mechanical guarantee of straight line motion;
- the robot can move to a certain position and rotate in place to achieve a certain orientation;
- the independent control of the rotation and forward displacement of the robot simplifies the overall control over the robot;
- the possibility of symmetric design;
- excellent traction;
- zero turning radius and high manoeuvrability.

The main disadvantages of the synchronic drive principle include complex design and implementation.

Generally, a synchronous drive robot can be accomplished using centered orientable wheels or off-centered orientable wheels. The required mechanical synchronization can be achieved in several ways, the most common of which are those by chain, belt or gear drive [1], [5], [7], [8], [13].

Chain and belt-drive configurations experience some degradation in steering accuracy and alignment due to the uneven distribution of slack that varies as a function of loading and a direction of rotation. In addition, whenever chains (or timing belts) are tightened to reduce such slack, individual wheels must be realigned.

These problems are eliminated with a completely enclosed gear-drive approach. An enclosed gear train also significantly reduces noise as well as particulate generation; the latter is very important for clean-room applications.

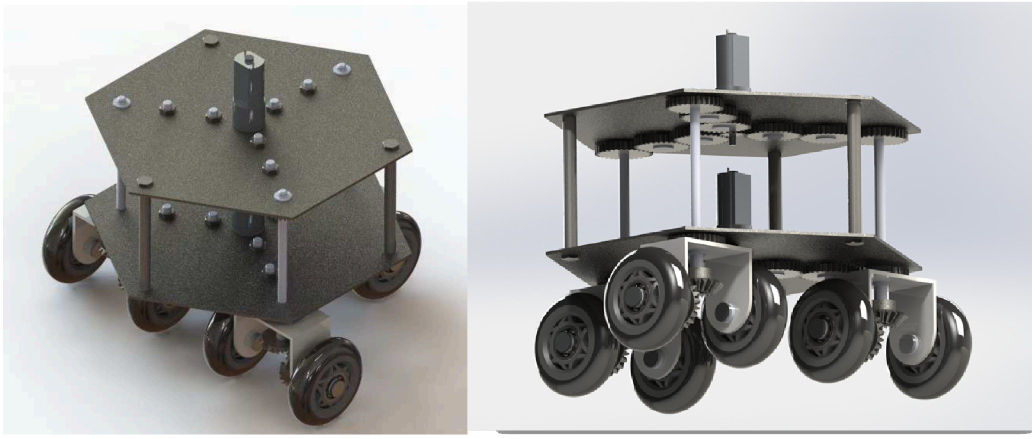
Synchronization can be also implemented electronically if robots have motors dedicated to each wheel.

Our previous work [9], [14–16] shows that the mini-robot synchronously has a platform placed on three supporting elements. At the base of each supporting element,-there is a pair of conventional wheels driven by a worm gear. Transmission from DC motors (one for driving and one for steering) to mini-robot wheels is made using geared mechanisms (composed of cylindrical gears with straight teeth): three for steering and another three for forward displacement.

This paper presents a new omnidirectional mini-robot using conventional wheels based on the synchro-drive principle. Compared to the previous model, a new mini-robot has the center of gravity near surface locomotion which gives high stability and has a simple structure using a cylindrical and bevel gear.

The Developed Omnidirectional Mini-Robot

Mechanical Design. The developed syncro-drive mini-robot discussed in this part of the paper uses three pairs of conventional wheels and two DC motors disposed in hexagonal tiered platforms (Fig. 1). The transmission from D.C. motors to the wheels of the mini-robot is achieved using geared mechanisms: three for steering and another three for displacement. Two platforms are made of hexagonal steel and have the side length of 114 mm. The mini-robot weights 1864 grams and is 220 mm in height. The wheels are 64 mm in diameter. The pairs of the wheels used by the robot can rotate at 360 degrees. The synchro-drive mobile robot may follow any trajectory. Figure 2 shows a picture of the developed prototype.



a) b)

Fig. 2. The developed omnidirectional mini-robot

Drive and Steering Systems. For driving, the structure of the mini-robot has three identical geared mechanisms that use cylindrical and bevel gears with straight teeth. A structural scheme for one of these mechanisms is given in Figure 3. The following annotations are used in this scheme: M_{e1} – driving motor; n_{m1} – the rotation frequency of the driving motor; n_R – wheel rotation frequency; 1, 2, 3, 4 – cylindrical gears, 5, 6 – bevel gears. The gear number of teeth is: $Z_1 = 14$, $Z_2 = 32$, $Z_3 = 32$, $Z_4 = 32$, $Z_5 = 20$, $Z_6 = 20$.

Three pairs of the wheels are mounted on U-shaped frames. Only one wheel from each pair is driven by the DC motor through gears 1-2-3-4-5-6.

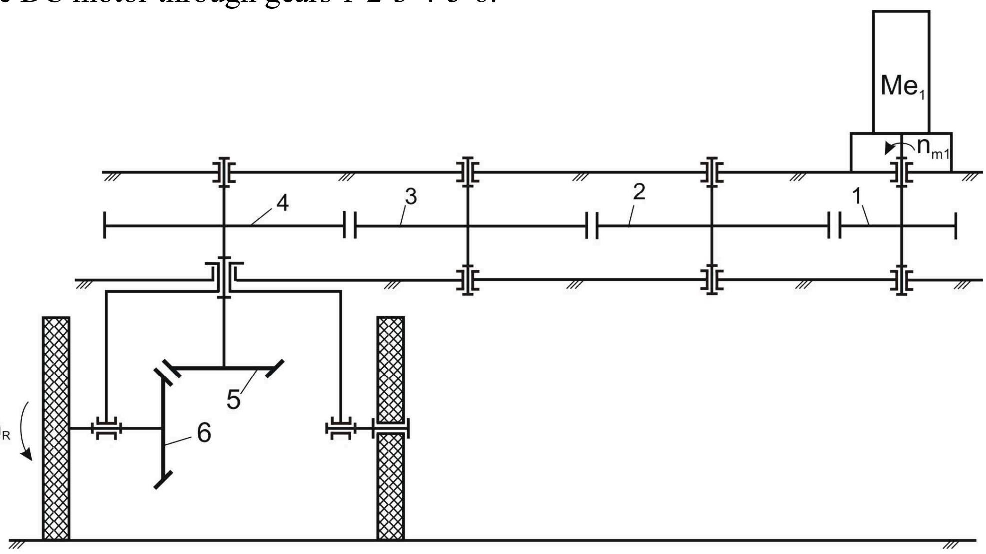


Fig. 3. Structural scheme for a driving mechanism

The rotation frequency of driving wheels n_R is given by the following relation:

$$n_R = n_{m1} \frac{z_1}{z_4} \cdot \frac{z_6}{z_5}. \tag{1}$$

The travelling velocity v of the mini-robot can be determined with reference to the following relation:

$$v = \omega_R r = \frac{\pi n_{m1}}{30} \frac{z_1}{z_4} \cdot \frac{z_6}{z_5} \cdot r \cdot \tag{2}$$

where ω_R is the angular velocity of the wheels, r is the radius of the wheels (r = 32 mm).

For steering, another three identical geared mechanisms (cylindrical gears with straight teeth) are used. Figure 4 shows the structural scheme for one of these mechanisms. The following annotations are used in this scheme: M_{e2} – steering motor; n_{m2} – the rotation frequency of the steering motor; n_s – the rotation frequency of steering ($n_s = n_{U\ shape\ frame} = n_{4'}$); 1', 2', 3', 4' – cylindrical gears. The gear number of teeth is: $Z'_1 = 14$, $Z'_2 = 32$, $Z'_3 = 32$, $Z'_4 = 32$. The orientation of U-shaped frames is obtained by pivoting motion where two wheels are rotating in opposite directions.

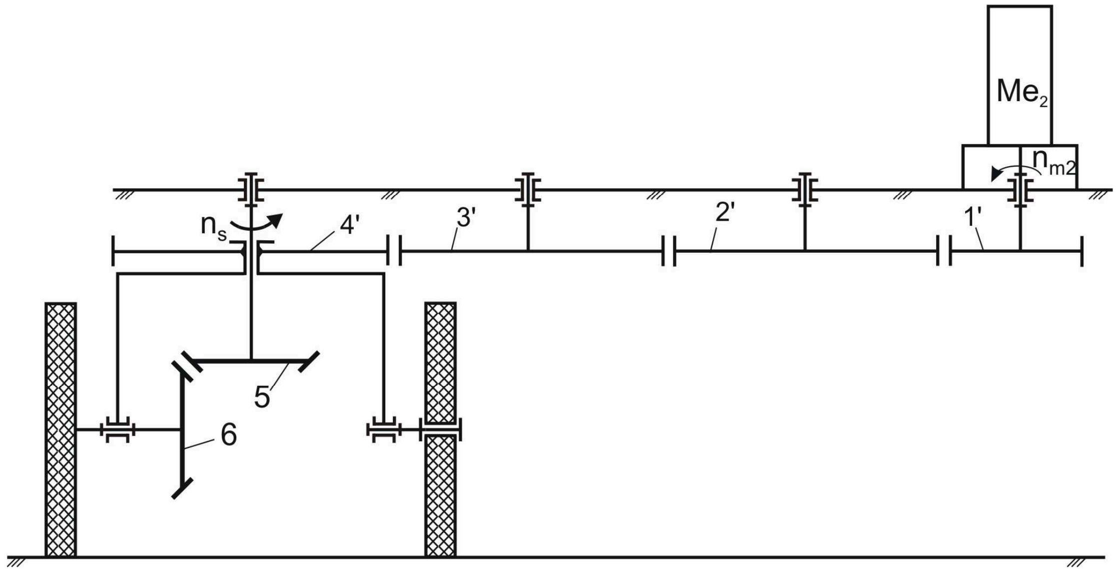
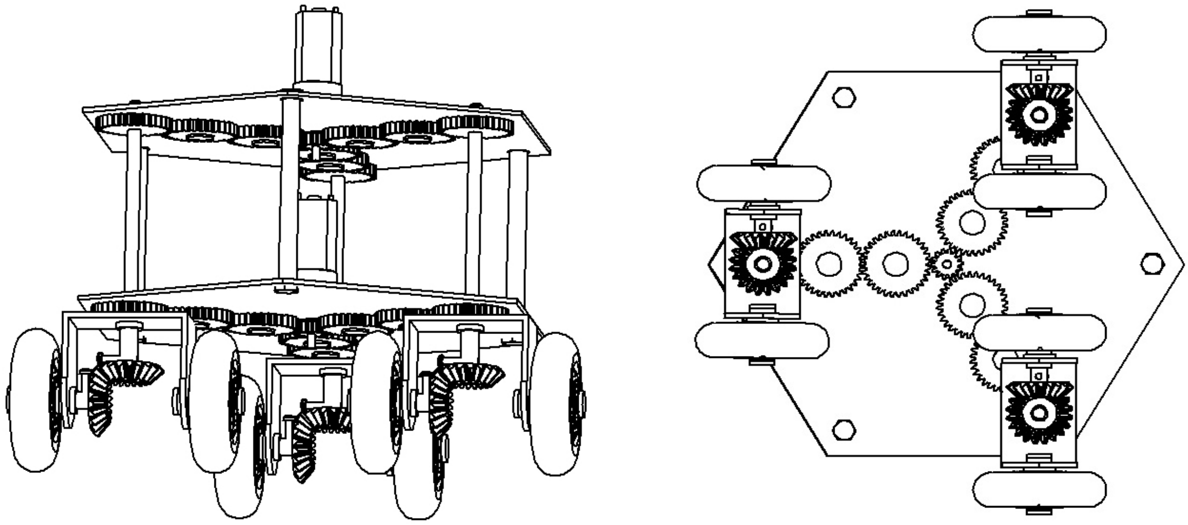


Fig. 4. Structural scheme for a steering mechanism

The rotation frequency of steering n_s is given by the following relation:

$$n_s = -n_{m2} \frac{z'_1}{z'_4}. \quad (3)$$

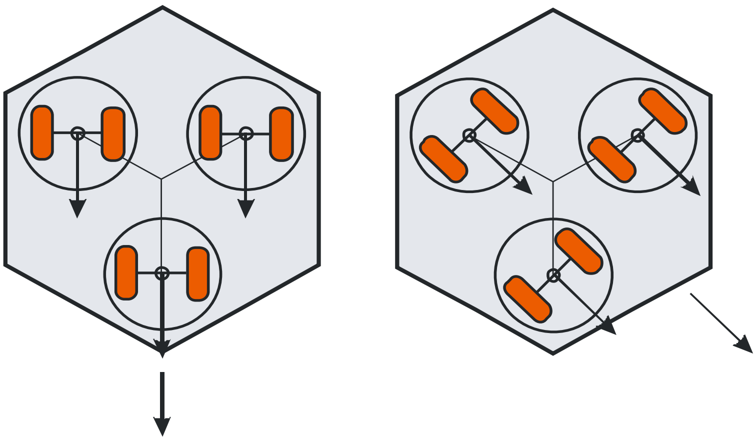
Three mechanisms used for driving and steering wheels can be identified in the following Fig. 5.



a) b)

Fig. 5. Driving and steering mechanisms

Figure 6a shows three pars of active steered standard wheels in 0 degree position, and Figure 6b displays the wheels turned at an angle of 45 degrees. All wheels have turned an equal amount.



a) b)

Fig. 6. Active steered wheels of the mini-robot

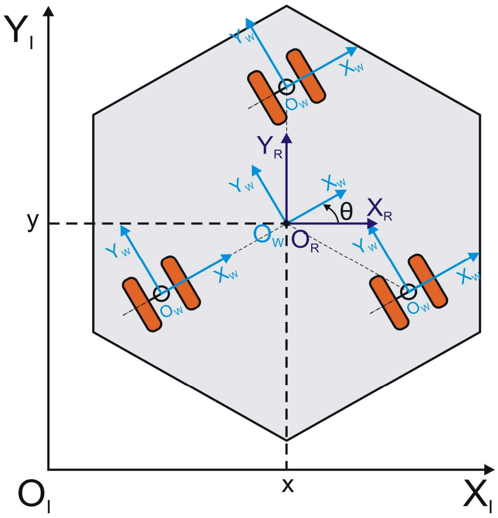


Fig. 7 The frames of orientation coordinates in the position of 0 degrees and turned at an angle of 45 degrees

Forward Kinematics for the Synchro-Drive Mini-Robot. The analysis of kinematics in this category of robots can be solved by [9] defining three reference frames, including the global reference frame $\{O_I, X_I, Y_I\}$ attached to the plane, the local reference frame $\{O_R, X_R, Y_R\}$ attached to the mini-robot chassis and the local reference frame $\{O_W, X_W, Y_W\}$ attached to the frame with wheels (Fig. 7). The orientation of the three pairs of wheels, with respect to the reference system of the center of the minirobot $\{O_R, X_R, Y_R\}$ or to the global reference system $\{O_I, X_I, Y_I\}$, is given by *angle* θ. The position of the mini-robot is presented by the x *and* y coordinates of the mass center of the mini-robot considering the system of coordinates $\{O_I, X_I, Y_I\}$.

Let $x(t)$ and $y(t)$ represent the coordinates of the mini-robot at time t in some global coordinate system, and let the orientation of the mini-robot (heading direction) be described by $\theta(t)$.

The kinematic configuration of the mini-robot is described by the triplet (x, y, θ). The motion of the synchro-drive mini-robot is constrained in such a way that translational velocity v always leads to the steering direction θ of the robot, which is a nonholonomic constraint.

Let $x(t_0)$ and $x(t_n)$ denote the x-coordinates of the robot at time t_0 and t_n respectively. Let v(t) denotes the translational velocity of the mini-robot at time t and ω(t) – its rotational velocity. Then, $x(t_n)$ and $y(t_n)$ can be expressed as a function of $x(t_0)$, $y(t_0)$, v(t) and θ (t), [10, 9]:

$$x(t_n) = x(t_0) + \int_{t0}^{t_n} v(t)\cos\theta(t)dt\,; \tag{4}$$

$$y(t_n) = y(t_0) + \int_{t0}^{t_n} v(t)\sin\theta(t)dt\,; \tag{5}$$

$$\theta(t_n) = \theta(t_0) + \int_{t0}^{t_n} \omega(t)dt\,. \tag{6}$$

The translational velocity of mini-robot v is $r\dot{\varphi}$ where r is the radius of the wheels and $\dot{\varphi}$ is rotational velocity of the wheels.

Control over the rotation frequency of DC motors that actuate the mini-robot is done using the electronic circuitry from the structure of the robot. The hardware component consists of Cerebot II circuit board [17] dedicated for robotics applications and a few additional peripheral modules.

This mini-robot has been successfully tested on plane surfaces under laboratory conditions. Currently, we are using the developed prototype for both educational and research purposes. Our feature work focuses on making the third level (turret), which is useful for a robot to make various operations. Also, it requires sensors to avoid obstacles found on locomotion surface.

Summary

For the synchronous drive mini-robot, the most significant advantage is that omnidirectional movement can be achieved by using only two actuators (driving actuator, steering actuator) and three wheels or three pairs of conventional wheels. The proposed synchro-drive mini-robot has three pairs of the wheels and two DC motors. Three-pair configuration ensures good stability and traction.

Transmission from motors to the wheels of the mini-robot is achieved using geared mechanisms: three for steering and another three for displacement. Since the mechanical structure guarantees synchronous steering and driving motions, less control effort is required for motion control. The developed mini-robot-can be displaced in any direction.

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