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Synchronous Drive Omnidirectional Minirobot

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Abstract. This paper presents an omnidirectional minirobot with conventional wheels that uses a synchro drive principle. The minirobot contains three pairs of conventional wheels and two D.C. motors. The transmission from the D.C. motors to the minirobot's wheels is achieved using geared mechanisms: three for steering and another three for displacement. The actuation and control system of the minirobot is described.

Introduction

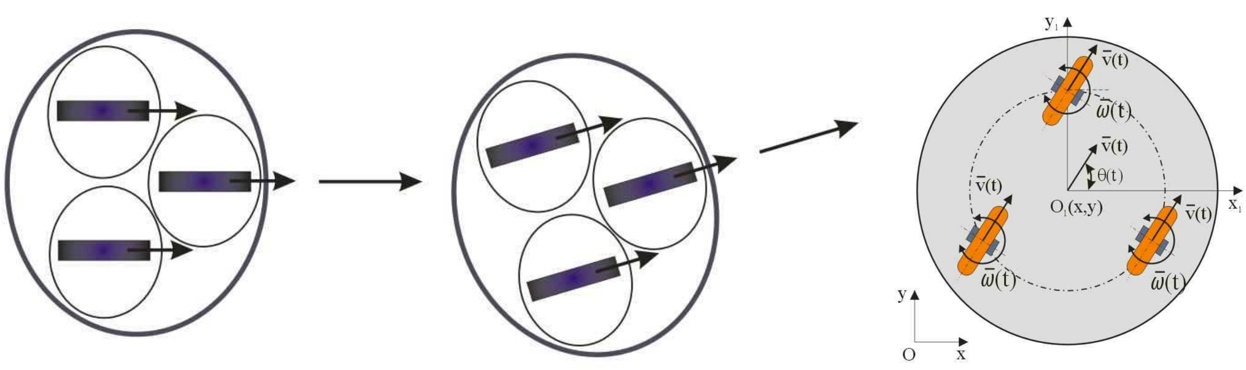
The term *omnidirectional* is used to describe the ability of a mobile system to move instantaneously in any direction from any configuration that it is in. The omnidirectional robotic platforms have vast advantages over conventional designs in terms of mobility in congested environments, being capable of easily performing tasks in such congested environments with static and dynamic obstacles and narrow aisles. These environments are commonly found in factory workshops, offices, warehouses, hospitals and elderly care facilities.

Depending on the type of wheels, the omnidirectional robots can be divided in two categories: robots with special wheels (so-called *omnidirectional wheels*) and robots with conventional wheels. Usually, an omnidirectional robot has three or more of these types of wheels.

In our previous work, different prototypes of omnidirectional platforms with special wheels were proposed [1], as well as with conventional wheels [2,3,4,5].

In this paper we introduce a new omnidirectional minirobot based on a synchronous drive principle.

In the literature, there are presented some omnidirectional robots with classical wheels that use the synchro-drive principle [6,7,8,9]. They have three or four pairs of wheels that are all driven and all being steered [10,11,12]. The wheels are rotated together so they always point in the same driving direction (Fig. 1). This can be accomplished, for example, by using a single motor and a chain for steering and a single motor for driving all three wheels. All of the wheels turn and drive in unison. Therefore, overall a synchro-drive robot (also known as synchronous drive robot) still has only two degrees of freedom [13,14,15,16].



a) b)

Fig. 1 The synchronous wheels configuration

The three / four wheeled synchronic drive principle has some benefits with respect to other wheel configurations. The main benefits are:
- 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; the 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 robot control;
- the possibility of symmetric design.

An omnidirectional minirobot was developed having three pairs wheels which can be steered so that the minirobot can displace in any direction.

The developed omnidirectional minirobot

Generally, a synchronous drive robot can be built by using centred orientable wheels or off-centred orientable wheels.
The required mechanical synchronization can be accomplished in a number of ways, the most common being a chain, belt, or gear drive. Chain and belt-drive configurations experience some degradation in steering accuracy and alignment due to uneven distribution of slack, which varies as a function of loading and direction of rotation. In addition, whenever chains (or timing belts) are tightened to reduce such slack, the 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 being very important in clean-room applications.

Mechanical design
The omnidirectional minirobot that is presented in this part has three pairs of conventional wheels.
The minirobot 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. Two D.C. motors are placed on the platform: one for driving and another one for steering. The transmission from the D.C. motors to the robot's wheels is made using geared mechanisms (composed of cylindrical gears with straight teeth): three for steering and another three for forward displacement. A picture of the developed prototype is presented in figure 2 [3].

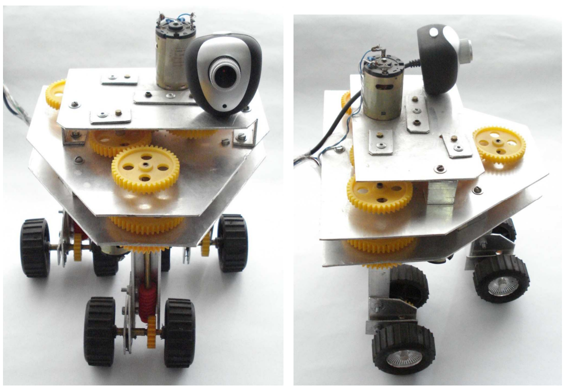


Fig. 2 The picture of the developed omnidirectional minirobot

Steering and drive systems
For driving, the minirobot has in its structure three identical geared mechanisms. The kinematic scheme of one of these mechanisms is given in figure 3 [5].

The following annotations are used in this scheme: n_{m1} – the drive motor rotation frequency; n_R – the wheel rotation frequency, Z_1 = 10; Z_2 = 50; Z_3 = 20; Z_4 = 40; Z_5 = 40; Z_7 = 20 – gear number of teeth, Z_6 = 1 – worm gear number of threads. Another three identical geared mechanisms are used for steering.

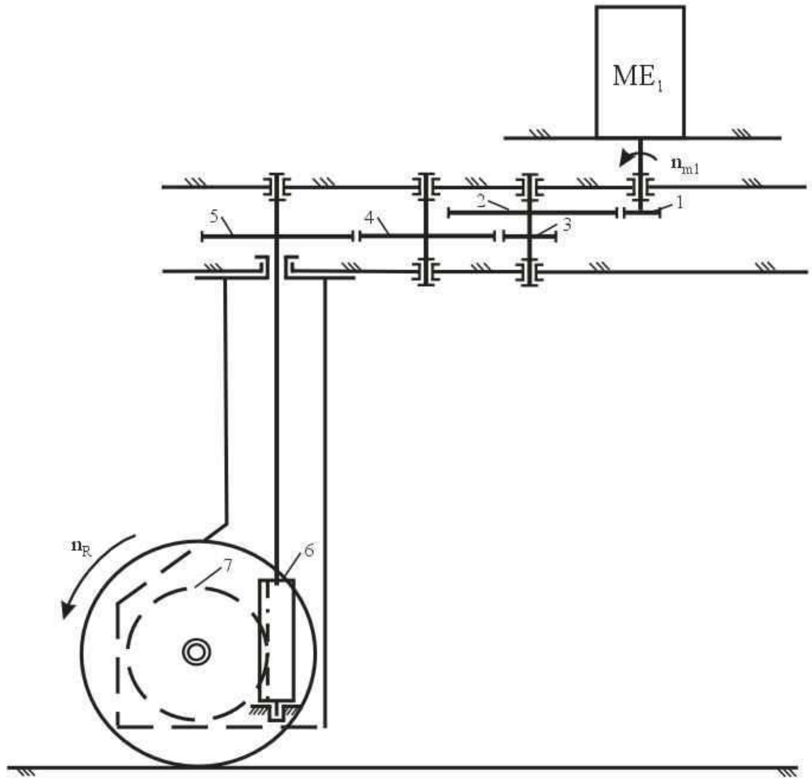


Fig. 3 The structural scheme of a drive mechanism

The kinematic scheme of one of these mechanisms is shown in figure 4. The following annotations are used in this scheme: n_{m2} – the steering motor rotation frequency; n_{ax} – steering axle rotation frequency, Z'_1 = 10; Z'_2 = 50; Z'_3 = 10; Z'_4 = 30; Z'_5 = 50; gear number of teeth.

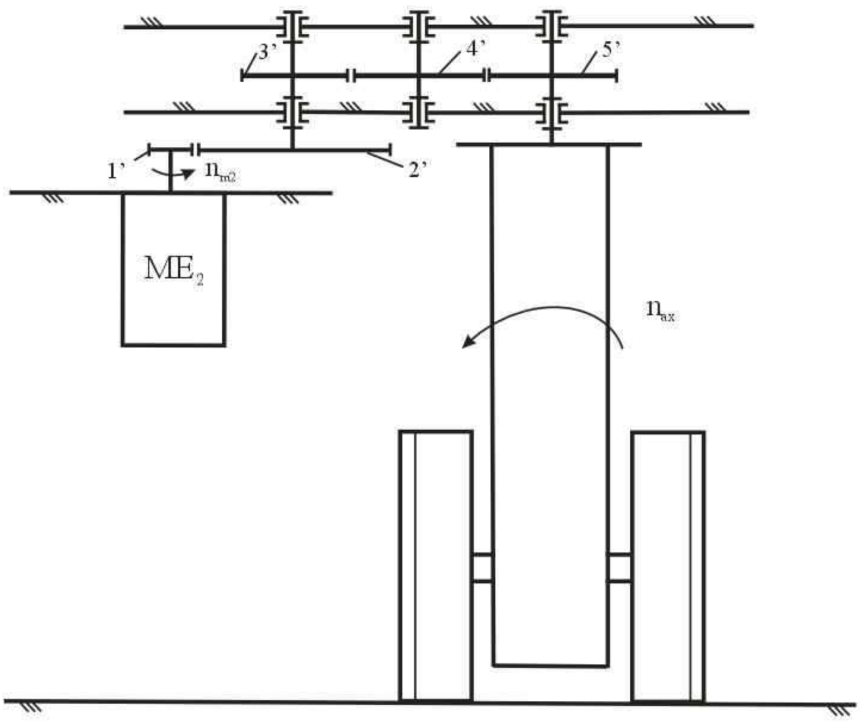


Fig. 4 The structural scheme of a steering mechanism

The minirobot contains three pars of active steered standard wheels. Figure 5a shows the wheels in the 0 degree position - in this position the robot will move right. The figure 5b shows the wheels turned 45 degrees. All wheels have turned an equal amount.

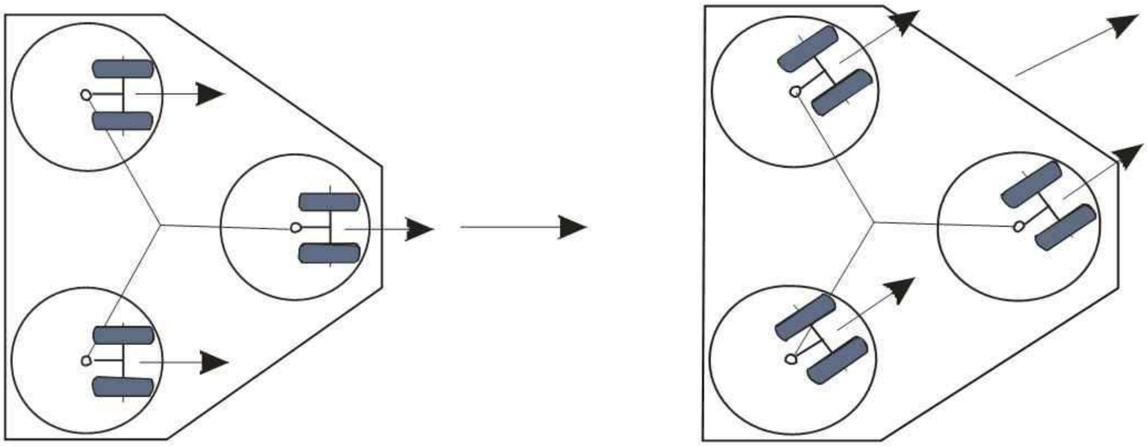


Fig. 5 The active steered wheels in the 0 degree position and turned 45 degrees

The forward kinematics for synchro drive minirobot

Let us define three reference frames: 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 robot chassis and the local reference frame $\{O_W, X_W, Y_W\}$attached to the wheels (Fig. 6).

The orientation of the three castor active wheels with respect to the reference system of the center of the minirobot $\{O_R, X_R, Y_R\}$ or with respect to the global reference system $\{O_I, X_I, Y_I\}$ is given by the angle θ. The robot's position is given by the x and y coordinates of the minirobot's mass center with respect to the coordinates system $\{O_I, X_I, Y_I\}$.

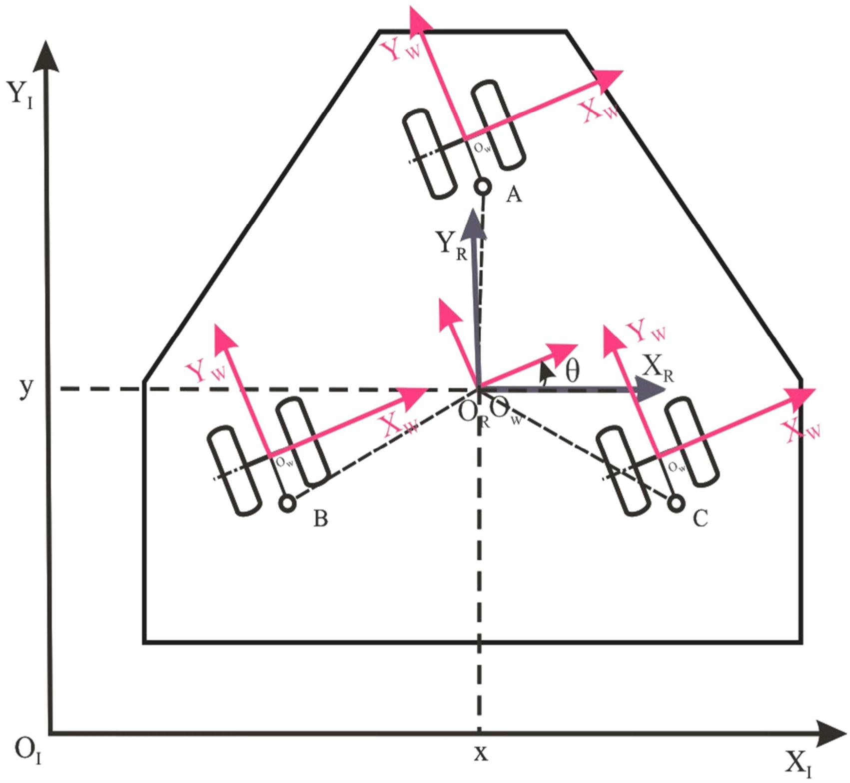


Fig. 6 The orientation coordinates frames

Let *x(t)* and *y(t)* denote the omnidirectional minirobot coordinate at time *t* in some global coordinate system and let the minirobot orientation (heading direction) be described by $\theta(t)$. The triplet (x,y,θ) describes the kinematic configuration of the robot. The motion of a synchro-drive minirobot is constrained in a way such that the translational velocity *v* always leads in the steering direction θ of the robot, which is a non-holonomic 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) denote the translational velocity of the minirobot 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):

$$x(t_n) = x(t_0) + \int_{t0}^{tn} v(t)\cos\theta(t)dt \tag{1}$$

$$y(t_n) = y(t_0) + \int_{t0}^{tn} v(t)\sin\theta(t)dt \tag{2}$$

$$\theta(t_n) = \theta(t_0) + \int_{t0}^{tn} \omega(t)dt \tag{3}$$

Translational velocity of the minirobot *v* is $r\dot{\varphi}$ where *r* is the radius of the wheels and $\dot{\varphi}$ is rotational velocity of the wheels.

Electronic architecture

The electronic components for the omnidirectional minirobot that are required for the drive and command of the two D.C. motors are presented in the following. The base or fixed system given in figure 7 is composed of a PC and a radio module. The communication between the PC and the radio transceiver is done trough a PmodRS232 serial to TTL convertor. The user interface that runs on the PC is implemented in Matlab and enables the control of the minirobot along a given trajectory or its remote control using a joystick.

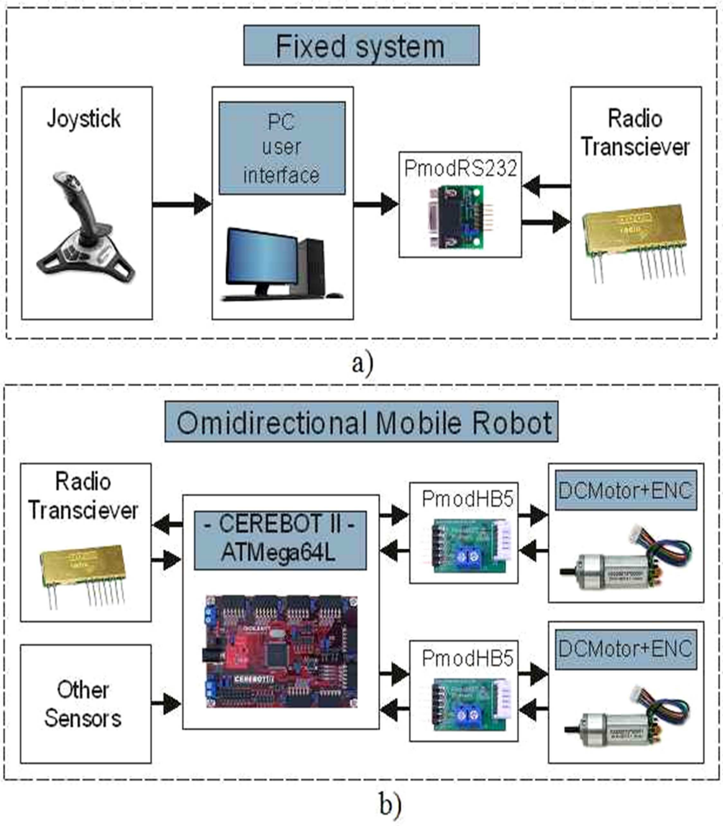
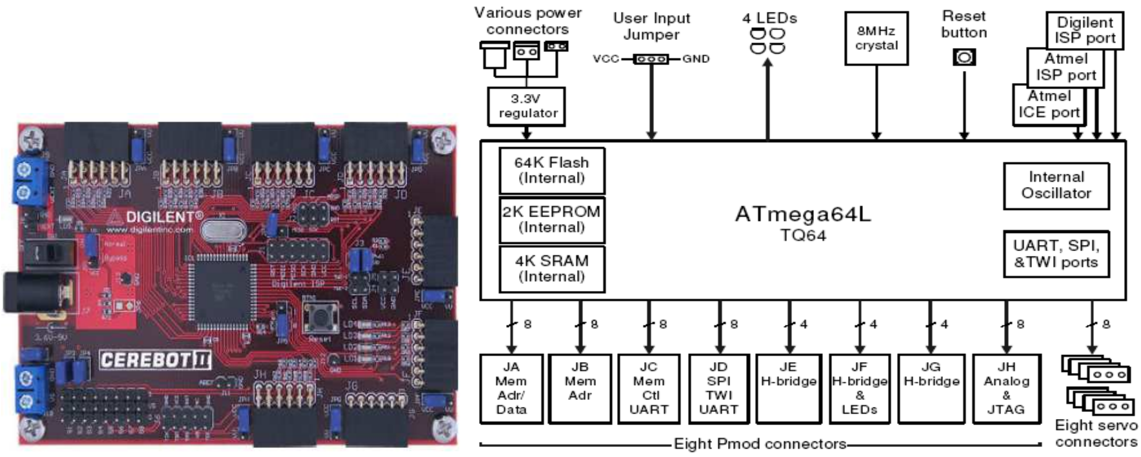


Fig. 7 The flow chart for controlling the robot

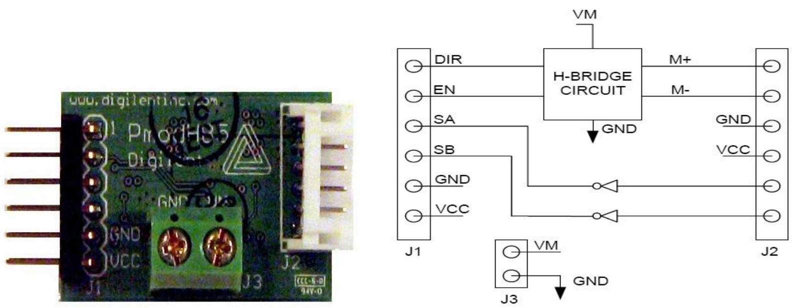
The control of the rotation frequency of the DC motors which actuate the minirobot is done using the electronic circuitry from the robot's structure. The hardware component consists of a Cerebot II circuit board [17], dedicated for robotics applications, and a few additional peripheral modules (Fig. 8, Fig. 9).



a) b)

Fig. 8 The Cerebot II board: a) photo; b) block diagram;

In order to read the encoders two Pmod HB5 H-bridge peripherial modules were used.



a) b)

Fig. 9 The H-bridge Pmod module - the block diagram (a) and the photo (b)

The software implemented in the microcontroller interprets the reference values (φ, θ), received via radio communication and uses them in the control loop.

The testing process of the omnidirectional minirobot

The testing of the minirobot was performed in laboratory conditions. The following figure shows images from the testing process of the prototype.

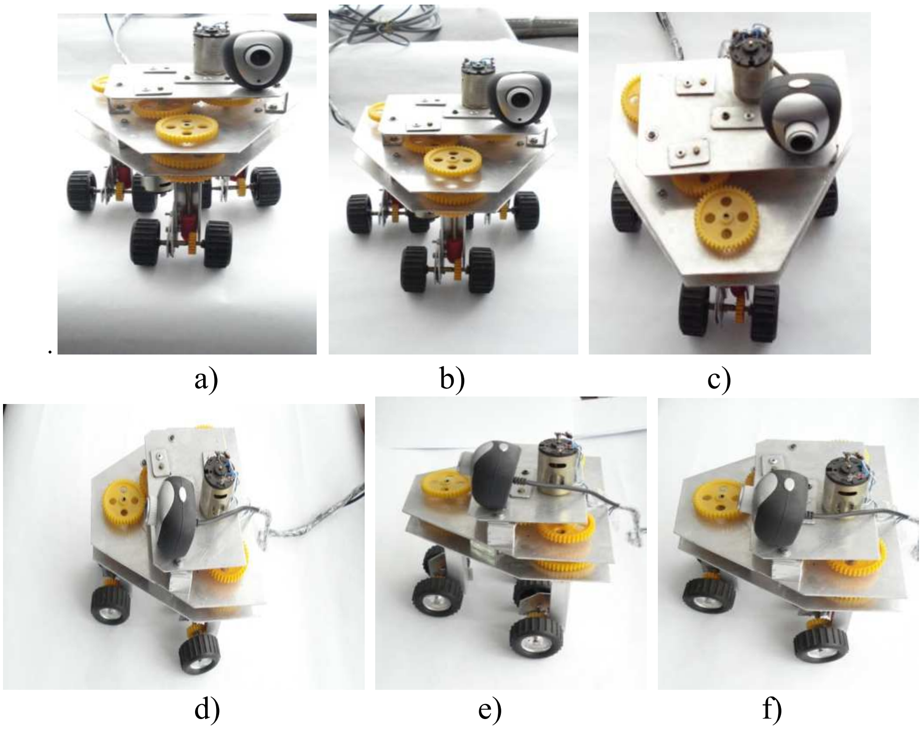


Fig. 10 The testing process of the prototype

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

$$n_R = n_{m1} \frac{z_1}{z_2} \cdot \frac{z_3}{z_5} \cdot \frac{z_6}{z_7} \tag{4}$$

The travel speed v of the minirobot can be determined with the following relation:

$$v = \omega_R r = \frac{\pi n_{m1}}{30} \frac{z_1}{z_2} \cdot \frac{z_3}{z_5} \cdot \frac{z_6}{z_7} r \cdot \tag{5}$$

where: ω_R is the angular velocity of the wheels, r is the radius of the wheels.

The theoretical travel speed of the minirobot is 0.112 (m/s), using a power voltage of 6 (V) and n_{m1} = 4750 (rpm). For the same input data, the measured travel speed is 0,1 (m/s).
The angular velocity of the steering axle ω_{ax} is given by the following relation:

$$\omega_{ax} = \frac{\pi n_{m2}}{30} \frac{z'_1}{z'_2} \cdot \frac{z'_3}{z'_5} \tag{6}$$

For a rotation frequency of the steering DC motor, n_{m2} = 1500 (rot/min), a steering angle of $\frac{\pi}{2}$ is performed in t = 0,3 (s).
Most significant advantage of the synchronous drive minirobot is that the omnidirectional movement can be achieved by using only two actuators and three pairs of conventional wheels. Since the mechanical structure guarantees synchronous steering and driving motions, less control effort is required for motion control. The three - pairs configuration ensures good stability and traction.

Summary

The omnidirectional minirobot contains three pairs of active castor wheels and two D.C. motors. The transmission from the motors to the minirobot's wheels is achieved using geared mechanisms: three for steering and another three for displacement. The hardware component for control consists of a CEREBOT II motherboard developed by Digilent and a few additional peripheral modules. The minirobot weights 900 grams, has a high of 200 mm, a width of 160 mm and the wheels have a radius of 45 mm. This prototype has been successfully tested on plane surfaces. The minirobot is not energetically autonomous, being supplied from a voltage source. The minirobot's autonomy can be increased by eliminating the powering wires and replacing them with accumulators. Currently we are using the developed prototype in both educational and research purposes. Our future work will be focussed on the study of an improved omnidirectional system involving replacement of the pairs of steered wheels with three active split offset caster drive (ASOC) modules.

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Synchronous Drive Omnidirectional Minirobot

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