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PARALLEL MANIPULATOR WITH PNEUMATIC MUSCLE DRIVE

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Abstract: *A parallel delta manipulator of six degrees of freedom with a pneumatic muscle drive was presented in this paper. A solid manipulator model was explained as well as a prototype of this device was presented. Drive units of the manipulator, which consist of two pneumatic counter-rotating muscles connected via belt spur drive and produced by the author of this paper, were characterized. The author presented a scheme of the control system and explained its elements. A kinematic model of the manipulator that is essential in the steering process, was shown. Some unique features of the device, such as high overload of pneumatic muscles, were outlined in this paper as well. They allow applying the manipulator when operating with items of unknown or irregular shapes. Possible collisions of the effecter with the items transferred will be effectively damped by the drives.*

Keywords: parallel manipulator, pneumatic muscle, kinematics of industrial robots.

1. Introduction

Industrial manipulators, both those of serial structure as well as with a closed kinematic chain, are one of the main elements of flexible production lines. Electric or hydraulic drives are applied in the majority of cases in those devices. (Laski, Pawel Andrzej et al., 2014) The author suggested application of parallel pneumatic muscles to the drive. Such drives are characterized by high flexibility and overload capacity as well as its natural abilities to move smoothly.

2. Solid model of the manipulator

A parallel delta manipulator of six degrees of freedom was presented in this article. Its construction was shown in Fig. 1. The device consists of a stationary base, six identical and independent arms and a moveable platform. Each arm is built of an active part that is connected with a drive unit, and of a passive part connected with the platform. The mobility of the operating platform of the manipulator is six. It might be calculated using the formula (1)

$$w = 6n - \sum_{i=1}^{5} i p_i \tag{1}$$

where: w – manipulator's mobility, n – number of moveable manipulator elements, i – pair class appearing in the kinematic chain, p_i – number of kinematic pairs of i-class. Each arm of the manipulator is driven by an independent drive unit, which consists of two pneumatic counter-rotating muscles, belt spur drive, bearing unit and an angle encoder. Linear movement of pneumatic muscles is changed into rotary movement of the active arm element with the use of the belt spur drive.

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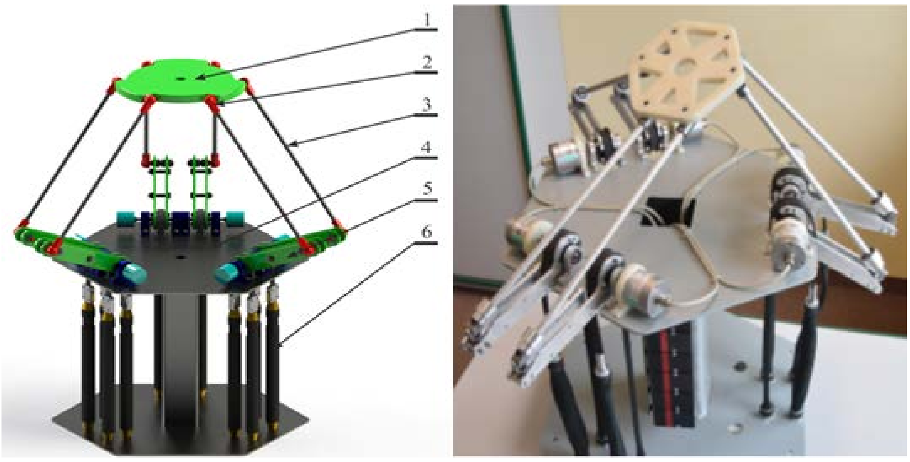

Fig. 1: Manipulator construction – general overview; 1 – operating platform, 2 – joint 3 – arm (passive element), 4 – base, 5 – arm (active element), 6 – drive unit

3. Kinematic model of the manipulator

The task of the manipulator is to move the operating platform against the stationary base. The platform movement constitutes the resultant of six controlled simultaneous movements of arms. As a result of such a movement, manual operation of the manipulator consisting in changing the angular position of each drive regardless of the others, is difficult or even impossible. That is why, in order to control the manipulator, determining and solving the inverse kinematics problem is essential. The problem consists in indicating drive articulated coordinates, knowing the setpoint position and orientation of the operating platform. The solution of the inverse kinematics problem was conducted in two stages. In the first one, knowing the setpoint position and orientation of the operating platform, the coordinates of points located in the upper joints of particular arms were determined. The correlations that allowed to determine those coordinates are presented with the following formula (2).

$$\left\{\begin{array}{l} C_{i,x} = P_x - R_2 \sin\zeta_i\left(\cos\alpha\sin\gamma + \cos\gamma\sin\alpha\sin\beta\right) + R_2\cos\beta\cos\zeta_i\cos\gamma \\ C_{i,y} = P_y + R_2 \sin\zeta_i\left(\cos\alpha\cos\gamma - \sin\alpha\sin\beta\sin\gamma\right) + R_2\cos\beta\cos\zeta_i\sin\gamma \\ C_{i,z} = P_z + R_2\cos\zeta_i\sin\beta + R_2\cos\beta\sin\alpha\sin\zeta_i \end{array}\right\} \tag{2}$$

where: i – joint number (arm), $C_{i,\mathrm{x}}, C_{i,y}, C_{i,z}$ – coordinates of i-joint, ζ_i – location angle of the joint on the platform, R_2 – radius of the circle, where the following joints are located $P_x, P_y, P_z, \alpha, \beta, \gamma$ – setpoint location and platform orientation.

Subsequently, taking advantage of the Denavit – Hartenberg parameters, dependencies, which allowed to calculate configuration coordinates, with a known position of the upper joint, were determined for each arm. Those dependencies are functions of three variables and for each arm they create a system of three equations with three unknown quantities that is presented with the following dependency (3)

$$\left\{\begin{array}{l} f_{i,x}\left(\theta_{i,1},\theta_{i,2},\theta_{i,3}\right) = -Wsp_{i,x} + R_1\cos\varepsilon_i + l_1\cos\left(\pm\left|\varepsilon_0\right| + \varepsilon_i\right)\cos\theta_{i,1} - l_2\sin\left(\pm\left|\varepsilon_0\right| + \varepsilon_i\right)\sin\theta_{i,3} + l_2\cos\left(\pm\left|\varepsilon_0\right| + \varepsilon_i\right)\cos\left(\theta_{i,1} + \theta_{i,2}\right)\cos\theta_{i,3} \\ f_{i,y}\left(\theta_{i,1},\theta_{i,2},\theta_{i,3}\right) = -Wsp_{i,y} + R_1\sin\varepsilon_i + l_1\sin\left(\pm\left|\varepsilon_0\right| + \varepsilon_i\right)\cos\theta_{i,1} + l_2\cos\left(\pm\left|\varepsilon_0\right| + \varepsilon_i\right)\sin\theta_{i,3} + l_2\cos\left(\theta_{i,1} + \theta_{i,2}\right)\sin\left(\pm\left|\varepsilon_0\right| + \varepsilon_i\right)\cos\theta_{i,3} \\ f_{i,z}\left(\theta_{i,1},\theta_{i,2},\theta_{i,3}\right) = -Wsp_{i,z} + h + l_1\sin\theta_{i,1} + l_2\sin\left(\theta_{i,1} + \theta_{i,2}\right)\cos\theta_{i,3} \end{array}\right\} \tag{3}$$

where: i – joint number (arm), $\theta_{i,1}, \theta_{i,2}, \theta_{i,3}$ – articulated coordinates of a particular arm, $\varepsilon_0, \varepsilon_i$ – position angles of the arm on the base, R_1 – radius of the circle, where the following arms are located, l_1, l_1, h – geometrical dimensions of the arms and base. $\theta_{i,1}$ is, however, an articulated coordinate of the drive of the i-arm. The system was solved with the use of the Newton-Raphson method. (Blasiak, 2015) As a result, a set of three solutions was achieved. Each solution included three articulated coordinates. From a mathematical point of view, those solutions are correct. However, they need to be verified as far as their physical correctness is concerned and later, the proper solutions need to be chosen. (Blasiak & Pawinska,

2015) Fig. 2 presents the trajectories of manipulator drives for two set trajectories of the operating platform: helix and circle, with stable orientations.

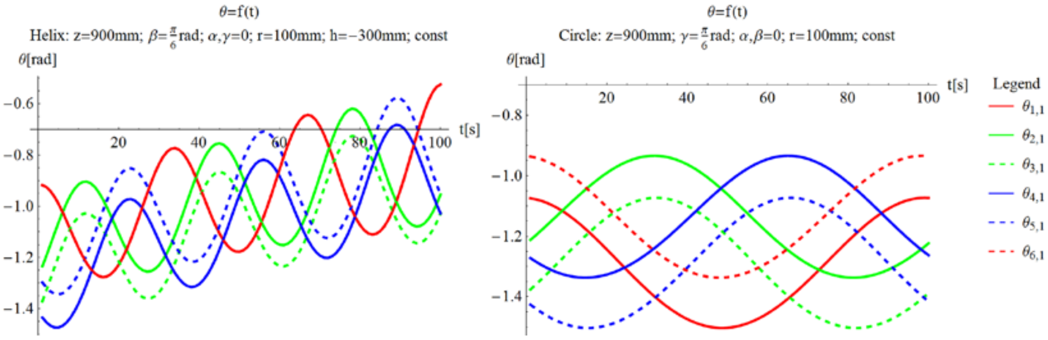

Fig. 2: Trajectories of particular drives for set displacements of the operating platform.

4. Operating space of the manipulator

Operating space of the manipulator determines a set of all points in the space that a robot is able to produce. This space, however, differs for various orientations of the operating platform. The operating platform presented in this paper was determined via discretization of points for zero orientation of the operating platform, i.e. for angles $\alpha, \beta, \gamma = 0$. (Laski, P A et al., 2014) A set of points surrounded by park position of the manipulator with dimensions bigger than the maximal width of the robot arms was randomly generated. Subsequently, out of that set of points, points for which it was possible to solve the inverse kinematics problem were chosen. What is more, the results of such calculations, which are articulated variables of the manipulator arms, need to fulfil the geometric conditions. (Janecki & Zwierzchowski, 2015) The operating space of the manipulator under consideration was presented in Fig. 3.

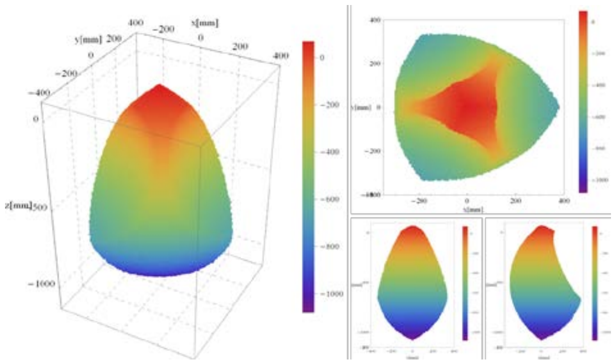

Fig. 3: The operating space of the manipulator determined for zero orientation of the effecter, in configuration of the robot with the platform pointed downwards.

5. Control system of the manipulator

The main element of the control system of the manipulator is a computer with real time system produced by *Speedgoat*. This device is equipped with AC & CA transducers (Takosoglu, J E et al., 2014). The system operation was divided into two stages. (Takosoglu, Jakub Emanuel et al., 2009) The first one is dedicated to solving the inverse kinematics problem and indicating new articulated coordinates. Solution of six systems of non-linear equations is required. The control system in the second stage generates proper signals that control the drive units (Andrs et al., 2012). Each control system consists of two counter-rotating pneumatic muscles. 3/2 proportional pressure valves, model tecno plus, manufactured by HOERBIGER were proposed to operate the pneumatic muscles. Those valves have piezoelectric control, which ensures quick response time. 16-bit absolute encoders of Posital Fraba, model OCD-S101G-1416-S060, served to measure the drive angular position. The scheme of the control system was presented in Fig. 4.

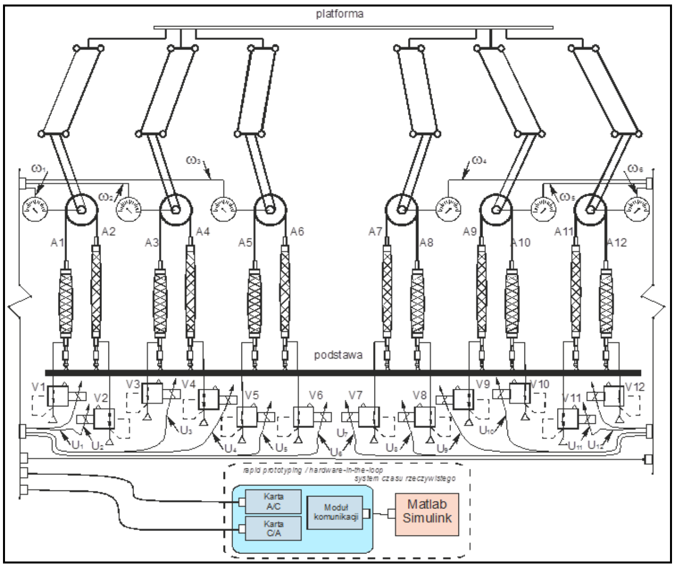

Fig. 4: Scheme of the control system of the manipulator

6. Conclusions

The manipulator of six degrees of freedom and with a closed kinematic chain was presented in this paper. The author presented the manipulator construction and the kinematic model, explained the operating space as well as showed the control system of the manipulator. The construction of the manipulator of six degrees of freedom allows free space orientation of the transported items. Artificial pneumatic muscles were applied as drives. The features of the applied drives provide the manipulator with high dynamics. They enable smooth start and stop as well as eliminate results of collisions of the manipulator with the surrounding areas. Due to the application of pneumatic drives, instead of electric, it is possible to use the manipulator in hazardous environment with danger of explosions or fire. A drawback of the applied drives is the difficulty of controlling them that results from their non-linear characteristic. From the research of a single muscle pair, it might be concluded that positive results of the drive positioning are obtained when using PID or Fuzzy Logic controllers.

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