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A DELTA TYPE CLOSED KINEMATICS CHAIN WITH PNEUMATIC MUSCLE ACTUATOR MANIPULATOR

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Abstract: *In this paper electropneumatic with closed kinematic chain, three degrees of freedom with pneumatic actuators muscle delta type manipulator is presented. The paper presents the components and design of proposed control system with the results.*

Keywords: Parallel pneumatic manipulator, Pneumatic muscles, Simple and inverse kinematics.

1. Introduction

The need for rehabilitation of persons with disabilities requires the involvement of substantial resources as well as highly qualified personnel. The main objective of the robot design was to create construction with corresponding to human limbs movements. It was assumed that the structure will be characterized by a gentle start and stop, and high overload (Takosoglu et al., 2012). Moreover, the design should have a low weight. The proposed construction delta type robot with closed kinematic chain is usually driven by electric rotary actuator. The authors have proposed replacing the rotary drives by the pairs of pneumatic muscles working alternately. Pneumatic artificial muscles are characterized by considerable dynamics and at the same time allow you to perform gentle movements. The work of robot relies on the introduction by a qualified person (physiotherapist) selected movement trajectory and play repeatedly with the specified parameters by a person who is rehabilitated. The relatively low cost of implementation of the parallel manipulator based on the pneumatic muscle actuators allow for its use in the home.

The manipulator constructed in accordance with a delta structure includes a movable platform connected to the fixed base by three kinematic chains acting simultaneously. Each chain includes rotary drive actuated by a combination of a pair of pneumatic muscles acting antagonistic. The ends of the muscles were connected with the fixed base. To pass movement to the working platform are used three parallelograms ended by spherical joints. Single kinematic chain of 3-RSS manipulator contains the rotary type joints (R) and spherical type joints (S).

2. Inverse and Forward Kinematics

To control the robot in real time is necessary to solve the tasks of simple and inverse kinematics. Determination of the current position and orientation of the robot working platform is based on the measurement of angular displacement of arm and feedback in the control system while driving (Laski & Dindorf, 2007). Fig. 1. shows a diagram of a robot with visible local coordinate systems necessary to solve the tasks of kinematics.

For considered manipulator kinematics equations requires a designation of parameters according to the notation of DH (Denavit-Hartenberg) for working platform and arms. Tab. 1 includes the kinematic parameters of the work platform, while the Tab. 2 contains the parameters for the manipulator arm.

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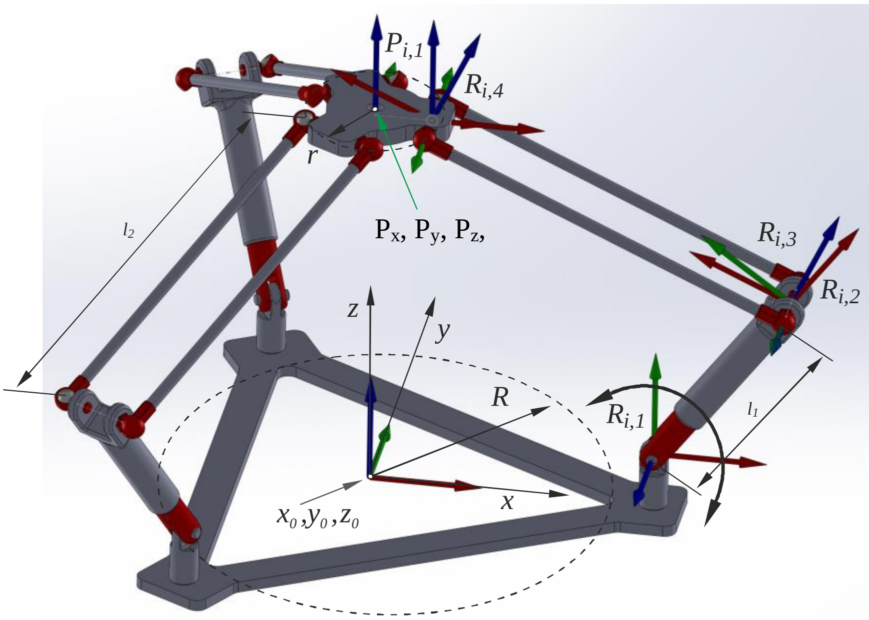

Fig. 1: Kinematic diagram of the delta type manipulator.

Tab. 1: DH parameters for the working platform.

Coordinate system	Rot_{z,θ_i}	$Trans_{z,d_i}$	$Trans_{x,a_i}$	Rot_{x,α_i}
$P_{i,1}$	ζ_i	0	r	0

Tab. 2: DH parameters for the next arms i-te; $i = 1,2,3$.

Coordinate system	Rot_{z,θ_i}	$Trans_{z,d_i}$	$Trans_{x,a_i}$	Rot_{x,α_i}
$R_{i,1}$	ξ_i	H	R	$\frac{\pi}{2}$
$R_{i,2}$	$\theta_{i,1}$	0	l_1	0
$R_{i,3}$	$\theta_{2,1}$	0	0	$\frac{\pi}{2}$
$R_{i,4}$	$\theta_{3,1}$	0	l_2	0

To solve the equations of kinematics (0.1) and (0.2) were used numerical procedure based on the Newton-Raphson method for nonlinear equations using Gaussian elimination. Platform joint i – ty (i = 1, 2, 3)

$$\begin{Bmatrix} Wsp_{i,x} = P_x + r\cos(\zeta_i) \\ Wsp_{i,y} = P_y + r\sin(\zeta_i) \\ Wsp_{i,z} = P_z \end{Bmatrix} \quad (1)$$

Arm i – te (i = 1, 2, 3)

$$\begin{Bmatrix} f\left(\theta_{i,1},\theta_{i,2},\theta_{i,3}\right) = -Wsp_{i,x} + \cos\left(\xi_i\right)\left(l_1\cos\left(\theta_{i,1}\right) + l_2\cos\left(\theta_{i,3}\right)\cos\left(\theta_{i,1}+\theta_{i,2}\right) + R\right) + l_2\sin\left(\theta_{i,3}\right)\sin\left(\xi_i\right) = 0 \\ f\left(\theta_{i,1},\theta_{i,2},\theta_{i,3}\right) = -Wsp_{i,y} + \sin\left(\xi_i\right)\left(l_1\cos\left(\theta_{i,1}\right) + l_2\cos\left(\theta_{i,3}\right)\cos\left(\theta_{i,1}+\theta_{i,2}\right) + R\right) - l_2\sin\left(\theta_{i,3}\right)\cos\left(\xi_i\right) = 0 \\ f\left(\theta_{i,1},\theta_{i,2},\theta_{i,3}\right) = -Wsp_{i,z} + H + l_1\sin\left(\theta_{i,1}\right) + l_2\cos\left(\theta_{i,3}\right)\sin\left(\theta_{i,1}+\theta_{i,2}\right) = 0 \end{Bmatrix} \quad (2)$$

Dimensions:

- l_1, l_2 - arm lengths,
- R - the radius of the circle on which are arranged arms,
- $\xi_1 = 0^o; \xi_2 = 120^o; \xi_3 = 240^o$ - angles of the distribution of arms on a circle,

- r - radius of the circle on which joints of platform are distributed,
- $\zeta_1 = 0^o; \zeta_2 = 120^o; \zeta_3 = 240^o$ - angles of joints of platform placed on the circle.

2.1. Workspace analysis

One of the most important traits of robots is the range and shape of the workspace. Fig. 2 shows the space of designed delta type robot. In comparison to the open-chain robot kinematic with similar geometric dimensions the workspaces are much smaller.

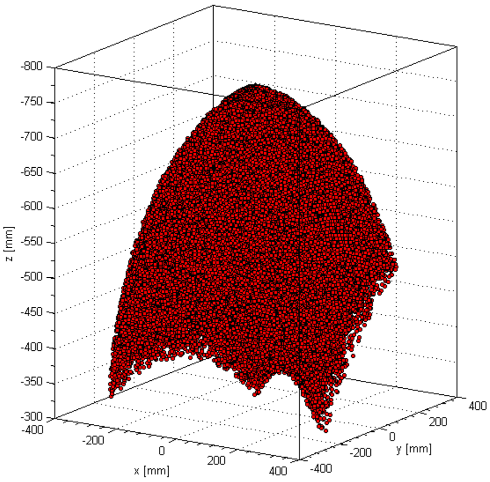

Fig. 2: Working space of delta type manipulator.

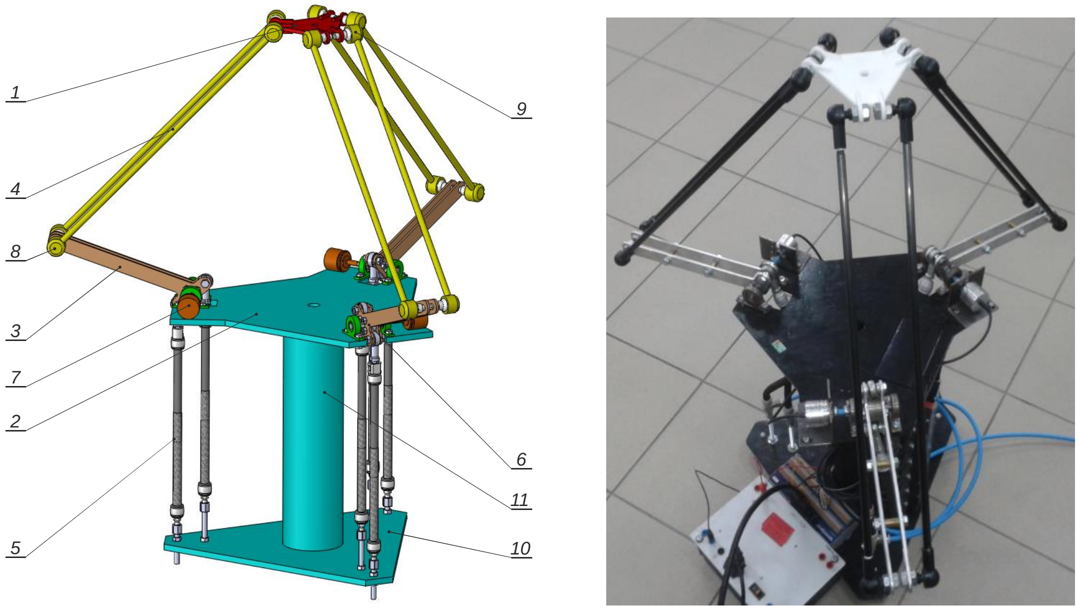

Fig. 3: Solid model of parallel delta type manipulator: 1 - working platform, 2 – upper platform, 3 - active arms, 4 – passive arms, 5 – muscles drive, 6 – revolution joints, 7 - angular position sensors, 8,9 – ball joints, 10 – base, 11 – support column.

2.2. The construction of delta type manipulator

In most delta type robots, rotary drive motors are mounted on the fixed base. Because the delta robot drives perform only limited moves with a certain angular range the drives were replaced by pneumatic muscles. In order to obtain angular movements of the joint muscles were paired to work alternately (antagonistic). Calling the rotational movement is a result of interaction of the two muscles on lever which is change progressive movement to the rotational. In order to obtain the movement one of the muscle is shrinking while the opposite relaxes and vice versa just as it is in human hand movements for the biceps and triceps muscles. Actuators of the robot arm transmit movement to the work platform via passive arms made of rods and ball joints connecting them (Krzysztofik & Koruba, 2012). The use of a ball joint kinematic chain causes the passive arms carry rods transmits only the tensile and compressive loading preferable from the viewpoint of strength of materials. This kinematic structure has a small mass resulting in significant dynamic robot (Laski et al., 2010). The main drive robot arms are made of aluminum. Passive arms are made of carbon fiber and the work platform is made of polyamide by SLS rapid prototyping technology. Used ball joints are also made of plastic with a small weight. Fig. 3 shows the solid model and the prototype of robot (Laski et al., 2009). To control the muscles pneumatic six ultra high-speed proportional pressure valves controlled by piezoelectric actuator were used (Takosoglu, Dindorf & Laski, 2009). Since the pneumatic muscles are nonlinear objects, control of each muscles is realized by PID controllers (Takosoglu et al., 2010). PID tuning was carried out using the method of Ziegler-Nichols (Cedro, 2013). A single muscle is controlled using a Hoerbiger proportional pressure valve, which is activated by voltage between 0-10V (tecno plus model). The control system and kinematic models have been implemented in Matlab / Simulink environment. The system designed constitutes an integrated environment for designing mechatronic systems, motion control, power electronics and signal conversion. xPC Target with the Education Real-Time Target Machine is a ready-to-use platform with embedded A/D and D/A cards. It is possible to control, tune and alter the parameters of the designed compensation-measurement system directly from Simulink in real time while the system is operating. All available functions of pneumatic valve terminal operate in real time (Blasiak et al., 2013). In the literature, there is no delta type pneumatic muslce robot solution. At this stage of construction it is difficult to compare the efficiency of the manipulator with the other structures of this type but with a different drive.

3. Conclusions

The paper presents the parallel delta type manipulator with the pneumatic muscle actuators. Structure with a description of the geometrical shape of the workspace is showed. Experimental studies have confirmed the assumption that the manipulator is characterized by high dynamics, soft start and stop, Robots of this construction can be used in medical rehabilitation processes of lower limb injuries and also in packaging processes, palletizing installation. In a further stage of construction the authors will performs experimental studies of positioning accuracy under different load mass of manipulator for classical and intelligent controllers.

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