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AN APPLICATION OF A PNEUMATIC MUSCLES ACTUATOR FOR A DELTA PNEUMATIC MANIPULATOR

APLIKACE PNEUMATICKÝCH SVALŮ PRO PNEUMATICKÝ DELTA MANIPULÁTOR

Abstract

The main aim of this study was to use pneumatic muscle actuators in the construction of the delta manipulator with a closed kinematic chain. The paper presents a solid models of the manipulator and the kinematic diagram. Based on the kinematic diagram and using DH notation (Denavit-Hartenberg) manipulator kinematic models was determined. On the basis of developed solid model simulation studies were conducted and the shape and size of the workspace determined. On the basis of 3D models prototype of the manipulator was constructed. Experimental studies were performed to select the regulators settings P, PI, PID for one of the pair of BMDS (Bi-Muscular Driving System) muscle-type drives. Based on integral quality indicators the used types of regulators were compared and proposed final controller. Performed experimental studies confirm the possibility of muscle control in the BMDS (Bi-Muscular Driving System) type system drives and tuning controller settings using the Ziegler-Nichols method.

Abstrakt

Hlavním cílem této studie bylo použití pneumatických svalových aktuátorů při konstrukci delta manipulátoru s uzavřeným kinematickým řetězcem. Příspěvek prezentuje solidní modely manipulátoru a kinematické schéma. Na základě kinematického schématu a použití DH (Denavitova-Hartenberg) notace byl stanoven kinematický model manipulátoru. Konstrukce byla vytvořena na základě simulačního modelu a byl určen přesný tvar a velikost. Manipulátor byl zkonstruován na základě 3D modelu prototypu. Experimentální studie byla provedena pro volbu nastavení regulátorů P, PI, PID pro jeden z dvojice svalových BMDS pohonů. Výsledný regulátor byl navržen na základě porovnání integrálních ukazatelů kvality používaných typů regulátorů. Provedená experimentální studie potvrzuje, možnost ovládání svalů v systému BMDS (Bi-muskular Driving System) a doladění nastavení pomocí metody Ziegler-Nichols.

Keywords

parallel manipulator, pneumatic muscle, notation Denavit-Hartenberg, Bi-Muscular Driving System

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1 INTRODUCTION

Mechanisms of closed kinematic chains delta have been developed in the 80s of the last century by a team of prof. Reymond Clavel at the École Polytechnique Fédérale de Lausanne (EPFL, Switzerland). The design obtained patent protection US4976582 (A) and in the 90s was introduced on the market. Currently, most manufacturers of industrial robots offers a delta-type structures [1,2]. The most commonly used are in the process of sorting and packing and packaging small details. Device is characterized by three arms in its kinematic chain and each of the arm has an electric drive which acts as a hinge-type rotor (R). Moreover, in the arms of device are mounted the rods elements ended by spherical joints. Such structure of the delta type device we describe as a 3-RSS. To arms ended by spherical joints is mounted work platform, to which are commonly mounted the different types of effectors. The result of the work of delta device is to perform the most common type of moves such as pick and place with mean frequency. In the present device, a rotary drive was replaced with a pair of pneumatic muscles working alternately. Using the two-armed lever the linear movement of alternating shortening muscles is converted into a finite angle of rotation.

2 MATHEMATICAL MODEL OF MANIPULATOR

For considered manipulator kinematics equations requires a designation of parameters according to the notation of DH (Denavit-Hartenberg) for working platform and arms. Table 1 includes the kinematic parameters of the work platform, while the Table 2 contains the parameters for the manipulator arm [3–6].

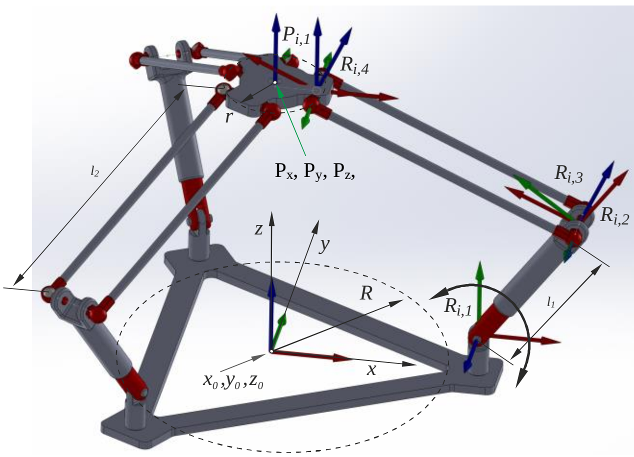


Fig. 1: Kinematic diagram of the delta type manipulator

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

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 – th (i=1,2,3)

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

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

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

Arm i – th (i=1,2,3)

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

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

3 CONSTRUCTION AND CONTROL OF MANIPULATOR

As previously mentioned, in order to build a manipulator a solid model of the main components in a Solid Works 3D software were designed. On the designed solid model was performed preliminary simulation studies specifying ranges of arm movements with a working platform and appropriate adjustments was made. The key of the solution was innovative pneumatic muscle actuator [7–9]. Was proposed the use of DMSP Festo muscles with a diameter of 10 mm and a length of 300mm, which size is shortened to 80% of the nominal length. In order to control the muscles were used piezoelectric proportional pneumatic pressure valves tecno plus Parker. Response time at full valve opening is to up to 7ms. In order to measure the angle of rotation of individual arms were used 12 bit converters MAB36A 12 2410 type of Mega Motive. On this basis, prototype manipulator was prepared and presented with solid model in Fig. 2. The control system has been implemented in a Speedgoat real-time system dedicated to the Matlab Simulink Target xPC environment.

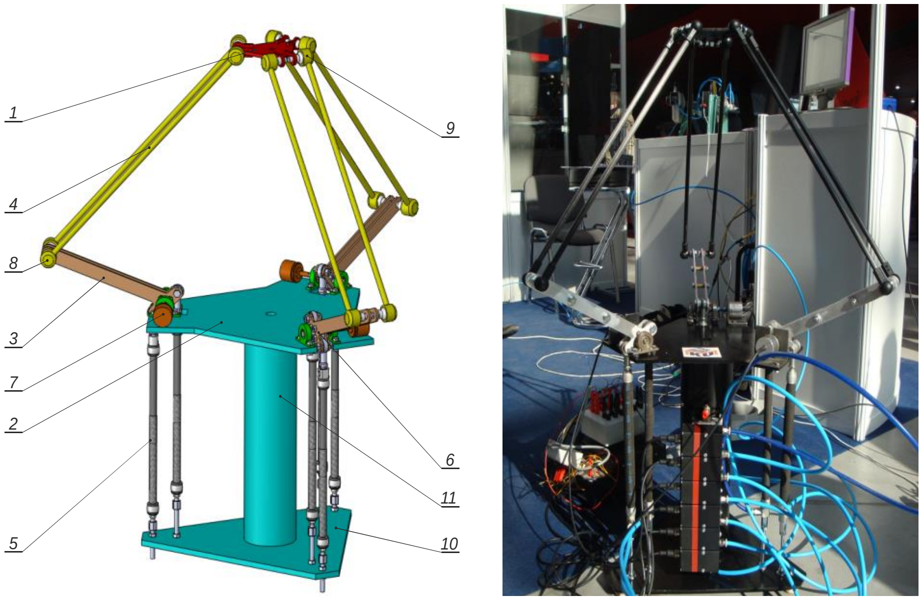


Fig. 2. View delta parallel manipulator: 1 – platform, 2 – base, 3 – arms drive, 4 – passive arms, 5 – actuators (pneumatic muscles), 6 – rotary joints, 7 – sensor rotary, 8,9 – spherical joints, 10,11 – base

Figure 3. is a diagram of the control system for one of the manipulator arms. By V1 and V2 were determined pressure proportional valves, A1 and A2 pneumatic muscle actuators, U1 and U2 voltage control signals ω1 valves and the voltage signal from the angular position of a pair of muscles.

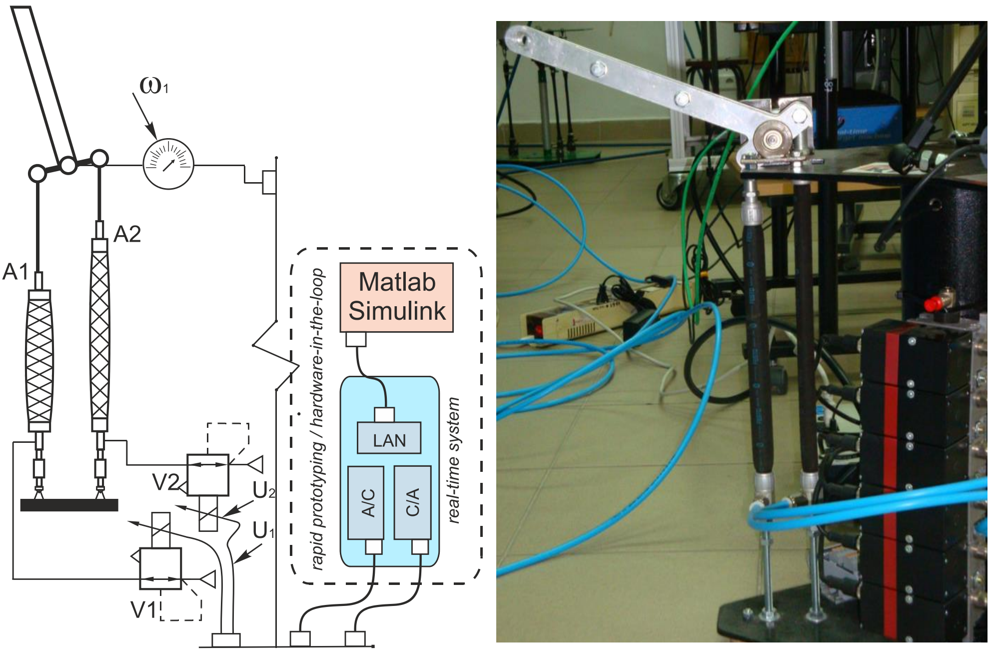


Fig. 3. Diagram of the control system of one pair of drive manipulator

4 THE EXPERIMENTAL RESEARCH OF MUSCLE CONTROL DRIVE

Control of pneumatic muscles pair requires alternating pressure value changes chosen so as to achieve the desired shortening and thus changing the angle rotation of the drive. Piezoelectric proportional pressure valves are controlled by voltage range of 0-10 V, which corresponds to a change in pressure in the range of 0 to 1 MPa [10,11]. Introduced the initial pulling force for a couple of muscles and for valves respectively initial voltage of 3V and 6V. With such settings, starting value were read from the rotation angle sensor and fed as an initial value. In order to control a pair of muscles were initially proposed P, PI, PID controllers. Amplification factors for the selected controller was adjusted using Ziegler-Nichols method [12]. One of the factors limiting the applicability of this method is the need for introduction an object in the oscillations up to the stability limit. Not for each object is safe or feasible, in the case of the proposed manipulator and because of the characteristics of the drive it was possible. Ziegler-Nichols method is a compromise between speed of response and overshoot. Its advantage is the ability to select optimal settings for controllers, without the need for painstaking research and calculations to develop a mathematical model of the object. According to the procedure followed for the selection of the controller settings set gain critical ratio k_{Pkry}=2.45 and oscillation time T_{osc}=0.11[s] (Fig. 4). Then from the relations of 1.1 to 1.4 was determined gain factors for the three regulators P, PI, PID.

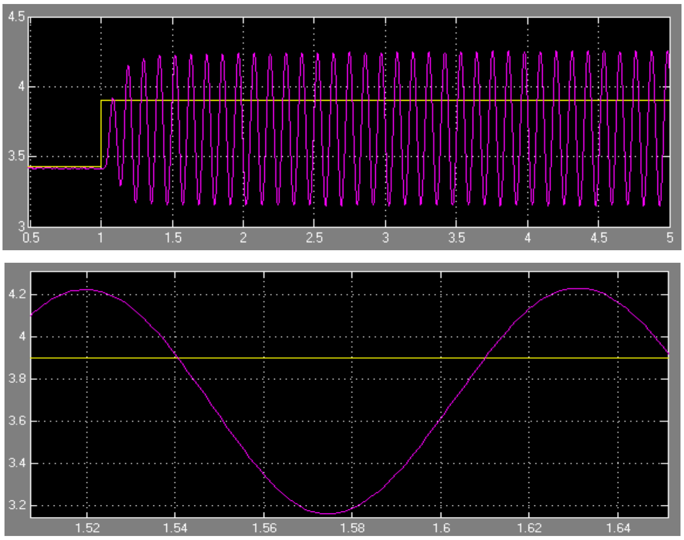


Fig. 4. Tuning with Ziegler-Nichols method k_{Pkry}, T_{osc}

P type controller

$$k_P = 0.5 \cdot k_{Pkry} \tag{1.1}$$

PI type controller

$$k_P = 0.45 \cdot k_{Pkry}$$
$$k_I = \frac{1}{0.85 \cdot T_{OSC}} \tag{1.2}$$

PID type controller

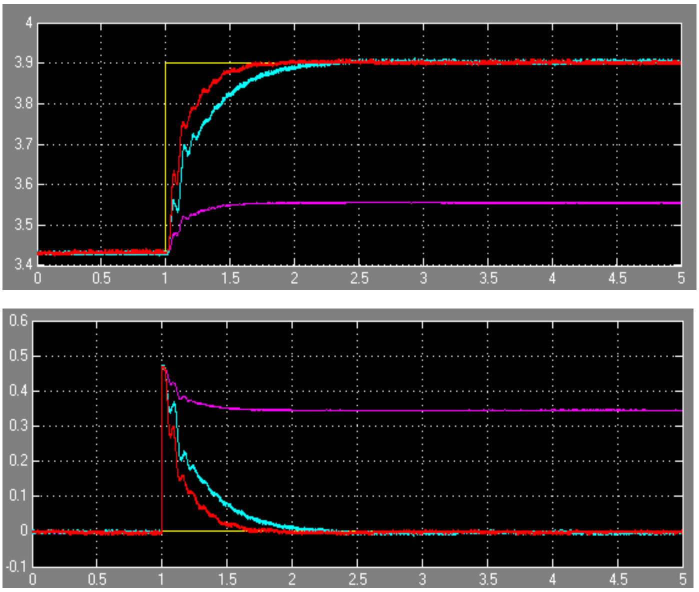
$$k_P = 0.6 \cdot k_{Pkry}$$
$$k_I = \frac{1}{0.5 \cdot T_{OSC}} \tag{1.3}$$
$$k_D = 0.12 \cdot T_{OSC}$$

Table1. shows the value of the gain factors for P, PI, PID type controllers.

Tab. 1

controller type	gain factor		
	k_P	k_I	k_D
P	1.225	-	-
PI	1.103	10.953	-
PID	1.47	18.182	0.014

The experimental studies of the positioning of one of the driving arm manipulator were performed as a response for discrete step signal (Fig. 5). The charts show step signal yellow, response of the PID controller red, the PI controller response aquamarine and purple as response of P regulator.



response

error

Fig. 5. Porównanie sygnałów odpowiedzi regulatorów P, PI oraz PID oraz uchybu regulacji.

For the purposes of assessing the quality of regulation, on the basis of response static deviation $\delta = 0.01\,[\mathrm{V}]$ was established. Based on the received responses it can be concluded that a P-controller did not meet expectations and does not reach the set value. Regulators PI and PID provide satisfactory answers. Thus, PI and PID controllers maintain a response signal error at the border of the measurement noise [13,14]. The control system regulation process was conducted without any noticeable overshoot. This was probably due to the use in the delta manipulator parallel pairs of pneumatic muscles BMDS system. For a detailed comparison of the quality of regulation between PI and PID controller integral indicators of the quality of regulation was determined. Integral control quality indicators:

• IAE (integral of the error value module **Fig. 6.**)

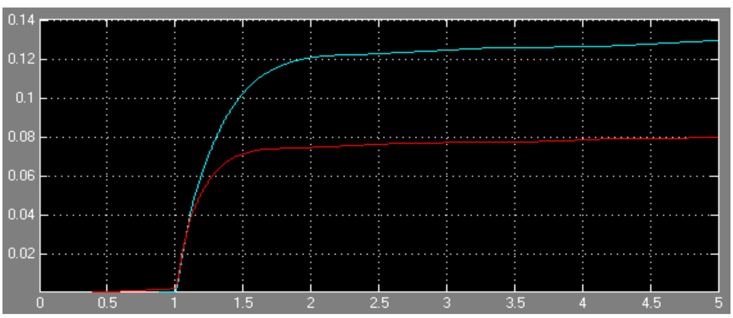


Fig. 6. IAE (Integral Absolute Error) PI and PID

Fig 6 shows integral regulation criterion IAE of the PI controller and PID. The result obtained for the proportional-integral-derivative controller (0.08) was 38% less than the result achieved by the proportional-derivative controller (0.13). This meant that the PID controller is better characterized by the oscillation damping properties.

ISE (integral of squared regulation error Fig 7.)

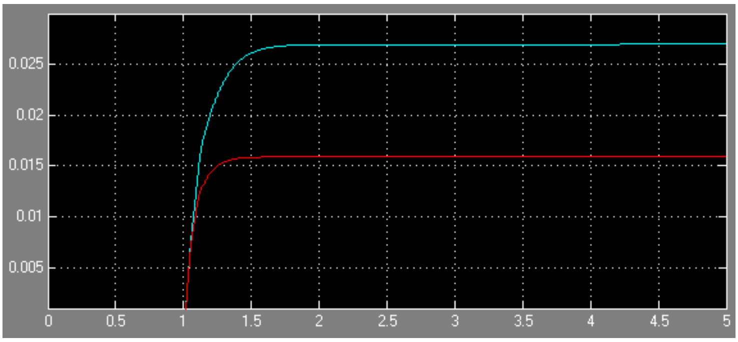


Fig. 7. ISE (Integral Square Error)

Fig. 7. shows integral regulation criterion ISE of the PI controller and PID. The result obtained for the proportional-integral-derivative controller (0,016) was 41% less than the result achieved by the proportional-derivative controller (0.027).

ITAE (integral of the product of time and error regulation Fig. 8.)

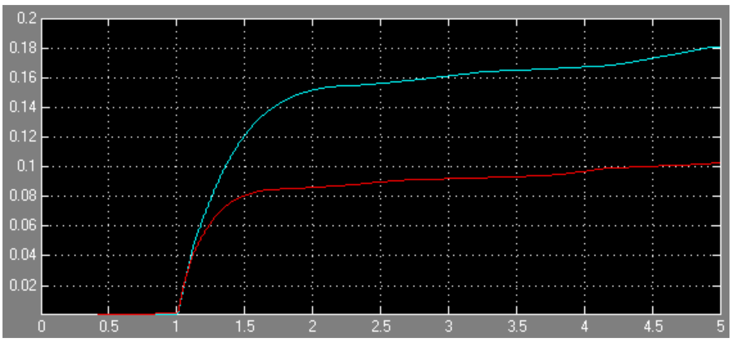


Fig. 8. ITAE (Integral Time Absolute Error)

Fig. 8 shows the integral regulation criterion ITAE PI and PID controller. The result obtained by the proportional-integral-derivative controller (0.1) was 44% less than the result achieved by the proportional-derivative controller (0.18).

5 CONCLUSIONS

Used pneumatic muscle actuators in parallel delta manipulator enabled the construction of device with unique utility features. On the basis of the results of experimental studies it can be concluded that the PID controller was the most appropriate. For tuning controller settings was used engineering Ziegler-Nichols method. Used BMDS type drive system (Bi-Muscular Driving System) allows us to conclude that the obtained structure have unique handling characteristics. Pneumatic muscles allow working platform to start and stop gently. Drives allow for high overload of structure without the need for extra security while maintaining low energy intensity. Currently being carried out further research to determine the repeatability and precision, and the implementation of intelligent control algorithms.

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