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Angle tracking of a pneumatic muscle actuator mechanism under varying load conditions

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ABSTRACT

In this paper, an active disturbance rejection control approach is proposed for a pneumatic muscle actuator mechanism to achieve angle tracking precisely under varying load conditions. The varying load conditions are treated as external disturbances which are estimated by a linear extended state observer. An active disturbance rejection controller is presented to compensate negative impacts induced by the varying loads. Moreover, stabilization of the closed-loop system are performed for the pneumatic muscle actuator mechanism. Finally, experimental results show the effectiveness of the developed technique in this paper.

1. Introduction

Nowadays, motion simulation platforms are used in science and technology museum, theme park dynamic cinema, rehabilitation treatment and so on. The motion simulation platforms may include uniform speed, acceleration, turning or other functions. Many motion simulation platforms adopt hydraulic or electric motor servo systems. Due to the advantages of rapid response, low cost and high power-weight ratio, PMAs are widely used in motion simulators. As novel types of pneumatic actuators, PMAs are also used in many areas, such as healthcare, industry and entertainment robotics. A two-axis planar articulated robot driven by four PMAs has been introduced (Hildebrandt, Sawodny, Neumann, & Hartmann, 2005). PMAs have also been used in a specially designed hand rehabilitation device (Xing et al., 2010). A sliding mode controller has been designed for a linear driver with an antagonistic pair of PMAs in Aschemann and Schindele (2008). Three strategies for compensation on hysteresis in force characteristics of PMAs have been shown in Aschemann and Schindele (2012). An adaptive wearable ankle robot which is manufactured by PMAs has been presented in Jamwal, Xie, Hussain, and Parsons (2014). Note that varying loads always exist in control systems driven by PMAs (Tri, Tjahjowidodo, Ramon, & Van Brussel, 2011). It has drawn much attention of researchers for dealing with the varying loads in recent years. A linear parameter varying controller has been designed for wind turbines covering both partial load and full load conditions (Østergaard, Stoustrup, & Brath, 2009). In Iqbal and Bhatti (2011), a practical approach to deal with variant payloads has been proposed for a 2-DOF parallel manipulator. A friction observer has been employed for friction compensation control by considering load changes (Lee, Lee, Jeong, & Min, 2015). Thereby, lots of meaningful methods have been developed on estimating disturbances (Mohammadi, Tavakoli, Marquez, & Hashemzadeh, 2013; Yang, Li, Sun, & Guo, 2013). Actually, load changes can be considered as external disturbances for control systems (Chen, 2004), and disturbance observers have been introduced to design nonlinear controllers in Guo and Chen (2004), Sun, Li, Yang, and Guo (2014). Sliding mode observers have also been introduced for disturbance estimation via output and input information (Lu, 2009; Zhang, Shi, & Lin, 2016). Though many methods are developed to accomplish control task precisely by nonlinear observers, there is still much room for further investigation.

Since it was introduced by Han in 1990s, active disturbance rejection control has been successfully used in a lot of nonlinear systems (Huang, Li, & Xue, 2013b; Liang, Li, & Li, 2013; Xia, Shi, Liu, Rees, & Han, 2007). The active disturbance rejection control has been applied to achieve precise position control for magnetic rodless cylinders (Zhao, Yang, Xia, & Liu, 2015). In Castaneda, Luviano-Juarez, and Chairez (2015), the active disturbance rejection control has been adopted to solve a robot trajectory tracking problem. As an important part of the active disturbance rejection control, ESOs are widely used to estimate uncertain terms in nonlinear systems (Yang, You, Xia, & Li, 2014; Zhu, Xu, Liu, & Xia, 2013). In Guo and Zhou (2015), the ESO has been designed to estimate disturbances for an original multidimensional system. A generalized ESO has been proposed for nonintegral-chain systems subject to mismatched uncertainties (Li, Yang, Chen, & Chen, 2012). Moreover, linear ESOs have been

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proposed to deal with uncertain terms in nonlinear systems (Huang, Li, & Xue, 2013a; Zheng, Chen, & Gao, 2009). The linear ESO has been applied to estimate nonlinear variable cutting load for a variant dynamics in a fast tool servo-system (Dan & Chen, 2009). In Zheng, Dong, Lee, and Gao (2009), the linear ESO has been designed to estimate both internal and external disturbances actively for a micro-electro-mechanical system. Note that elastic forces of rubber, forces of friction, varying loads and other uncertain factors are included in total disturbances for a pneumatic muscle actuator mechanism. To deal with the total disturbances, some strategies on the active disturbance rejection control are adopted with the linear ESO for the motion simulator in this paper.

In this paper, a pneumatic motion simulate platform driven by PMAs is introduced. In order to control the mechanism motion as accurately as desired, particular attention is taken onto the active disturbance rejection control. Thereby, a linear ESO is designed to estimate nonlinear disturbances which include both internal and external disturbances in real time. Convergence analysis of the linear ESO and stability analysis of the closed-loop pneumatic system are performed, respectively. Finally, experimental results indicate that the proposed active disturbance rejection control approach has distinct advantage in dealing with varying loads for the mechanism with PMAs.

The remainder of this paper is organized as follows: Section 2 introduces the experimental equipments and the mathematical model of PMA mechanism system. In Section 3, active disturbance rejection controller is designed, convergence analysis of the linear ESO and stability analysis of the closed-loop system are performed. Experimental results are shown in Section 4 and conclusion is given in Section 5.

2. Pneumatic servo position system

2.1. Introduction of experimental platform

Based on the character of pneumatic actuators and PMAs, a 3-DOF pneumatic motion experimental platform has been established as shown in Fig. 1. The pneumatic motion experimental platform includes two parts: a pneumatic control system and a computer control system. As shown in Fig. 1(a), the computer control system is comprised of an industrial control computer (Advantech, 610 H) including a counting card (Advantech, PCL-833) and a D/A card (Advantech, PCL-726). The pneumatic control system is comprised of an aircompressor, a control cabinet and a motion platform. The motion platform consists of two mechanisms of PMAs (Festo, DMSP40) driven by four pressure proportional valves (SMC, ITV3050) and an air cylinder (SMC, CE2G100-400) driven by a proportional directional control valve (Festo, MPYE-5-3/8-010-B). The two mechanisms are able to achieve

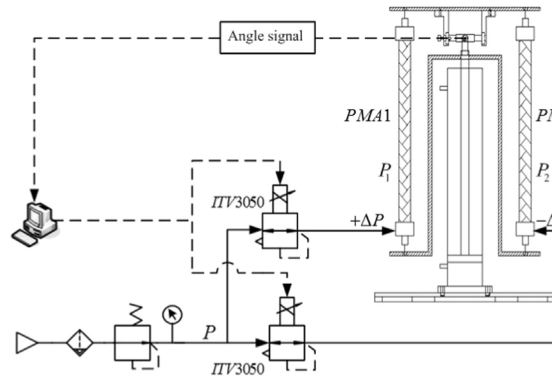


Fig. 2. Control system structure of the mechanism.

rotation movement around X-axis and Y-axis by two antagonistic PMAs, respectively. The up-and-down motions of Z-axis is realized by the air cylinder. The deflection angles of two mechanisms of PMAs and height of air cylinder are measured by angle sensors (E6B2-CWZ3E) and displacement sensor (included in the air cylinder), respectively, as shown in Fig. 1(b). The maximum and minimum deflection angles of the two mechanisms of PMAs are $\pm 15°$.

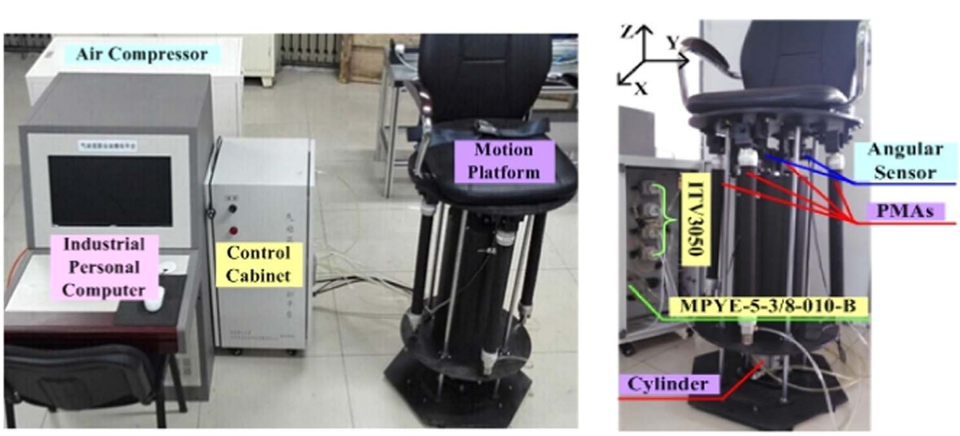
2.2. System model

In this paper, a trajectory tracking problem is studied for two PMA mechanisms. Note that only one pair of PMAs is to consider for the reason of that the two pair of PMAs are parallel to each other. The control system structure of one mechanism considered is shown in Fig. 2, and the working principle of PMA mechanism is shown in the following. In Fig. 2, the same supply pressure P_0 is given to PMA1 and PMA2. The charging or discharging of PMA1 and PMA2 are controlled by a computer for the opening of the two pressure proportional valves, respectively. The upper platform deflects by the two opposite-pull PMAs. The signals of deflection angles are transmitted to computer through an angle sensor. Note that input voltages of the two PMAs are designed as

$$\begin{cases} u_1 = u_0 + k_u u \\ u_2 = u_0 - k_u u \end{cases}$$

where u_0, u and k_u are the initial preload control voltage, input control and voltage distribution coefficient, respectively. Internal pressures of the two PMAs are shown as

$$\begin{cases} P_1 = P_0 + \Delta P = k_0(u_0 + k_u u) \\ P_2 = P_0 - \Delta P = k_0(u_0 - k_u u) \end{cases} \tag{1}$$



(a) (b)

Fig. 1. Pneumatic motion experimental platform.