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Direct inverse control of cable-driven parallel system based on type-2 fuzzy systems

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A B S T R A C T

This paper investigates the control problem for a cable-driven parallel system by using type-2 fuzzy logic systems (FLSs). The considered cable-driven parallel system is divided into six subsystems, and corresponding to each subsystem, a direct inverse controller is developed, which is expressed by an interval type-2 fuzzy nonlinear autoregressive exogenous (NARX) model. To determine the parameters of the inverse controller, the monotonic property of the fuzzy NARX model is proved. According to this property and based on the input–output training data, the heuristics and prior knowledge, the antecedent parameters of the inverse controller are determined. Furthermore, the consequent parameters are computed offline via a constrained least squares algorithm. By applying the proposed type-2 fuzzy direct inverse control scheme to the cable-driven parallel system, experiment results show that the proposed control method can not only level the top surface of a payload, but also balance the tensions of the four cables, and finally can ensure the safety of the payload.

1. Introduction

In some industrial areas, a cable-driven parallel system is a kind of important device which can automatically adjust the level of a payload. On one hand, some eccentric payloads whose centers of gravity are different from their centers of geometry are transported or assembled, the transportation or assembly of the payloads would cause lateral forces which usually lead to the payloads' distortion, damage, or even complete destruction. On the other hand, some big precious machines, such as aircrafts and ship hulls, are so heavy, valuable or fragile that they cannot endure point-to-surface or line-to-line touch with the assembly platform or the ground. For the sake of safety, it is necessary to level these payloads. In addition, during the process of level-adjustment, a cable or a connecting rod will break if it bears too much tension. In order to avoid the cases, the tensions of the connections should be balanced. For this kind of control problem, there exist several techniques and schemes including link parallel platform [7], cable-driven parallel platform [8,19,20,22,32], combinations of link structures and cable structures [2], and weight compensation mechanisms [26]. The link parallel platforms inevitably increase the system weight, and it is difficult to meet the precision requirements. Both cable-driven parallel platforms and combinations of link structures and cable structures require large space to fix the cables, and modeling and controlling the two kinds of systems are difficult. Weight compensation mechanisms can only accomplish one-dimensional regulation. Although cable-driven parallel systems have the aforementioned weaknesses, the kind of systems has received a lot of attention since

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it has various attractive features such as larger workspace, reduced manufacturing and maintenance costs, ease of assembly and disassembly, superior modularity, and reconfigurability [3]. Over the past two decades, the related research activities are mainly focused on stiffness modeling and stability analysis [3,8], dynamic modeling [20], and system control [32]. In addition, the above mentioned schemes seldom consider the equilibrium problem of the cable or link tensions. A cable-driven parallel system in Fig. 1 is a complex nonlinear system which is difficult to establish a precise three-dimensional mathematical model. Moreover, there exist high levels of uncertainties in the cable-driven parallel system, which mainly include inevitable measurement errors of sensors, operation errors of an actuator, uncertainties in the adjustment process such as the sway and change of a payload. Based on the above observation, some previous model-based control approaches [20,32] hardly handle the control problem of the cable-driven parallel system, which motivates us to investigate the problem by using the type-2 fuzzy logic systems (FLSs).

The concept of type-2 fuzzy sets is an extension of the concept of a type-1 fuzzy set [30]. In the recent years, type-2 FLSs have been drawn more and more attention. The theory and application researches of type-2 fuzzy logic have demonstrated that type-2 fuzzy logic systems can allow us to cope with the different sources of uncertainties, and weaken noisy disturbance, which cannot be appropriately handled by type-1 fuzzy systems [14,18]. Many fuzzy identification and control schemes have been developed for uncertain nonlinear systems, and found extensive applications based on type-2 FLSs, for example, [1,4–6,9–13,16,17,29] and reference therein. The authors in [4] investigated an optimization type-2 fuzzy controller for an autonomous mobile robot and compared with type-1 fuzzy controller. Yu and Chen developed an interval type-2 fuzzy adaptive tracking control scheme for a permanent magnet direct current motor system with sector dead-zones and external disturbances.

In the real situation, we frequently have only a small amount of information and a limited range of types of information. In order to use as much of the available information as possible, it is necessary to blend different kinds of information to obtain models [23–25]. Because of the insufficient training data, errors in the data and experiments of limited duration, data-driven identification methods alone sometimes yield unrealistic models. Although it is difficult to derive the accurate dynamic model for complicated nonlinear plants, the locality principles of the plants, which are named as prior knowledge such as physics or chemistry laws, can be obtained. If we have information such as heuristics described by linguistic rules, the rule-based approaches such as fuzzy logic methods can be used. In this paper, we combine the heuristics, prior knowledge and data information with direct inverse control scheme to control the cable-driven parallel system.

This paper considers the problem of the type-2 fuzzy direct inverse control for the cable-driven parallel system. The scheme not only can level the top surface of a payload, but also can balance the tensions of the four cables. Based on the heuristics and prior knowledge, the control system is divided into six subsystems. For each subsystem, there exists a fuzzy inverse controller which is an interval type-2 fuzzy NARX model. To obtain the inverse controllers, the monotonic property of the interval type-2 fuzzy NARX model is first proved. According to this property, their antecedent parameters can be determined. And then, the consequent parameters of the inverse controllers are computed offline via a constrained least squares algorithm. The main contributions of this paper can be summarized as follows: (1) A novel type-2 fuzzy direct inverse control scheme is developed to realize the inclination and tension control of the cable-driven parallel system; (2) the heuristics and prior knowledge of the system are integrated into data-driven control method; (3) the comprehensive control scheme involved inverse control and multi-source knowledge needs no mathematical model. Experiment results on the cable-driven parallel system are given to show that the proposed type-2 fuzzy direct inverse control scheme can realize the control objectives and achieve a good control performance.

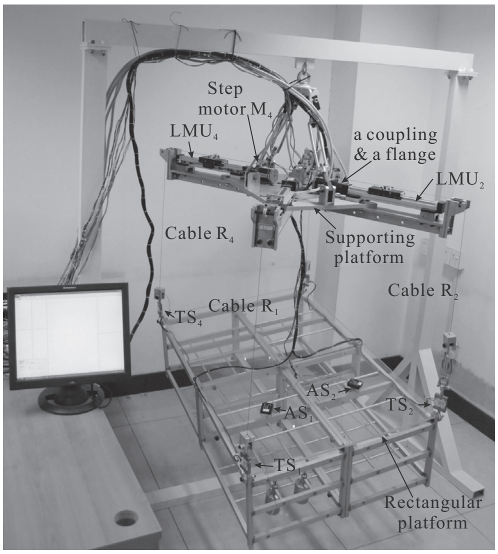

Fig. 1. Cable-driven parallel system.