Mutual Synchronization of Multiple Robot Manipulators with Unknown Dynamics

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Abstract In this paper, we investigate the mutual synchronization control problem of multiple robot manipulators in the case that the desired trajectory is only available to a portion of the team members, and the dynamics and the external disturbances of the manipulators are unknown. Treating the weighted average of the outputs of the neighbors as the reference trajectory, an adaptive neural network (NN) tracking control is designed for each manipulator. Based on the Lyapunov analysis, rigid mathematical proof is provided for the proposed algorithm for both state feedback and output feedback cases. It is shown that, under the proposed adaptive NN control, the tracking error of each manipulator converges to an adjustable neighborhood of the origin. Simulations are provided to demonstrate the effectiveness of the proposed approach.

Keywords Synchronized tracking control · Cooperative manipulators · Neural networks · Consensus · Multiple robots · Output feedback

1 Introduction

Robot manipulators have been widely used in production processes where manipulability, maneuverability, and flexibility are required [1–3]. With the increasing of the complexity of tasks and working environment, some tasks cannot be carried out by a single robot. It is beneficial to carry out the tasks through multiple robots cooperation for reasons such as increasing efficiency and providing redundancy in case of failure [4–9].

Various approaches have been proposed for the control of a single manipulator, including adaptive control [1, 2], neural network (NN) control [10], and fuzzy control [11], etc., in which most researches focused on addressing the problem of model uncertainties and unmeasured angular velocity. For electrically driven nonholonomic mobile manipulators, an adaptive robust output feedback control is proposed in [1]. The robust adaptive control is proposed for the uncertain force constraint nonholonomic manipulators in both holonomic mechanical systems and a large class of nonholonomic mechanical systems in the presence of uncertainties and disturbances in [12]. An adaptive fuzzy-neural-network control for robot manipulator position tracking considering output feedback is proposed in [10]. An adaptive motion control is designed for mobile underactuated manipulators with dynamics uncertainties taken into account in [13].
robust output feedback motion control of electrically driven nonholonomic mobile manipulators is proposed in [14]. The control of multiple robot manipulators can roughly fall into two categories, cooperative manipulate an object [15] and synchronized motion [4, 5, 16–18]. A fuzzy based decentralized adaptive hybrid intelligent control is proposed for the control of multiple strongly coupled manipulators handling a common object in [15]. Considering the relative motions of mobile manipulators, a robust adaptive control is designed in [17]. An adaptive robust coordinated control for multiple mobile manipulators interacting with rigid environments is proposed in [8].

In this paper, we consider the synchronization motion of multiple robot manipulators that use relative tracking errors to induce the mutual synchronization behavior, where synchronization tracking is defined as that all the trajectories of manipulators satisfy 
\[ x_1(t) = x_2(t) = \ldots = x_N(t) = x_d(t), \]  
where \( N \) denotes the number of sub-systems in the network, and \( x_d(t) \) denotes the desired trajectory of the manipulator. This is similar to the model reference consensus problem of multiple agents (e.g. [19, 20] and references therein), in which the agent dynamics are always defined as integrated system or linear system \( \dot{x} = Ax + Bu \) with \((A, B)\) a stabilized pair, and the proposed methods in these works are restricted to the control of agents with known dynamics; therefore, they cannot be used to synchronized control of the multiple manipulators directly. Under the leader-follower structure, NN adaptive control is proposed for the distributed synchronization of unknown networked Lagrangian systems [21], in which all the information of the manipulators are available for control design.

The main contribution of this work can be summarized as follows. Based on the condition that the extended formation graph has a spanning tree with the root manipulator can access the desired trajectory, we prove that the normalized Laplacian of this extended formation graph is positive definite. We use the weighted average of neighbors’ outputs as the reference output of the manipulator in the control design. To deal with the unknown dynamics and the unknown disturbances, the NN forward approximation is used to compensate for the unmodeled dynamics and disturbances. On the adaptive NN control designed, high gain observer is synthesized and augmented into the controlled system with the aim to estimate the unavailable signals which are required for control design. The mathematical proof of stability for both state feedback and output feedback cases are provided in the paper.

The remainder of the paper is organized as follows. In Section 2, some preliminaries and problem formulation are presented. We design the synchronized tracking control for each robot manipulator in Section 3 for both full state feedback and output feedback cases, where in the second design, we replace the velocity signals in the state feedback control law by the output of the observer. Simulation of four two-link robot manipulators are given in Section 4, followed by concluding remarks in Section 5.