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Robust Finite-Time Consensus Tracking Algorithmfor Multirobot Systems

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Abstract—This paper studies the finite-time consensus track- ing control for multirobot systems. We prove that finite-time con- sensus tracking of multiagent systems can be achieved on the terminal sliding-mode surface. Also, we show that the proposed error function can be modified to achieve relative state devia- tion between agents. These results are then applied to the finite- time consensus tracking control of multirobot systems with in- put disturbances. Simulation results are presented to validate theanalysis.

Index Terms—Finite-time consensus, multiagent systems, mul-tirobot systems, terminal sliding-mode (TSM) control.

INTRODUCTION

IN RECENT years, there has been an increasing research in-terest in the consensus control design of multiagent systems. Consensus algorithms have applications in rendezvous controlof multinonholonomic agents [1]–[3], formation control [4]–[6], and flocking attitude alignment [7]. In leader–follower mul- tiagent system, the leader is usually independent of their follow- ers, but have influence on the followers' behaviors. Hence, bycontrolling only the leader, the control objective of the networkscan be realized easily. Such a strategy not only simplifies thedesign and implementation, but also saves the control energy and cost [8], [9].

The objective of this paper is to address the following is- sues 1) Under what conditions, a nonsmooth control algorithmcan be developed to guarantee the leader–follower multiagent system to reach consensus in a finite time. 2) How to de-sign this finite-time control algorithm systematically. Our in- terest in these two issues is motivated by the preliminary re- search work in [10] on finite-time consensus design for first- order systems, and the work in [11] on finite-time consen-sus for second-order systems with undirected communication topology.

In practice, the network topology might be directed and the time-varying control input of the active leader might not be available to all the followers (e.g., multiple missiles tracking a fighter aircraft). Therefore, it is important to investigate how todesign consensus control algorithm applicable to the case, where only a portion of the followers have directed communication with the leader under the condition that the control input of the leader is unknown to any follower.

Based on the previous works on terminal sliding-mode (TSM) control [12]–[15], we present in this paper a practical robust finite-time consensus tracking (RFTCT) algorithm for multia- gent systems. In particular, we show that for leader–follower multiagent systems dominated by second-order systems, it is possible to achieve global finite-time consensus on the TSM surface by switching control law. This conclusion is proved based on the Lyapunov theory for finite-time stability and TSM control design methodology. Our proposed RFTCT algorithm is robust to system uncertainties and input disturbances. There- fore, the proposed scheme does not require the information of the time-varying control input of the active leader. Since not all followers have directed communication with the leader, ourresults assume that the agents in the network only need to com- municate with their neighbors and not the entire community.In contrast to consensus tracking of the leader's state, we showthat the proposed error function could be modified to achieve finite-time relative state deviation between agents. The desired deviation between agents could be specified in real time and hence different formations can be formed. The proposed con- trol scheme is then applied to the finite-time consensus trackingcontrol of multirobot systems with m degrees of freedom with input disturbances.

The remainder of this paper is organized as follows. Section II reviews some basic concepts in graph theory, the Lya- punov theory for finite-time stability, and the basic principle of TSM control. An error function for consensus control is pro- posed in Section III, where the design of RFTCT algorithm to guarantee finite-time consensus tracking of multiagent sys- tems is discussed in detail. The proposed scheme is then ap- plied to the consensus tracking control for multirobot systems with m-DOF in Section IV. Section V gives numerical exam- ples to illustrate our results. Concluding remarks are given in Section VI.

Background and Preliminaries

In this section, we introduce some basic concepts in algebraic graph theory for multiagent networks and review some termi- nologies related to the notion of finite-time stability and the corresponding Lyapunov stability theory first. Then, we briefly study the basic principle of TSM control, focusing just on the second-order nonlinear system that we shall need.

A. Concepts in Graph Theory and Multiagent Systems

Consider a multiagent system consisting of one leader and n followers. To solve the coordination problems and model the information exchange between agents, graph theory is in- troduced here. Let $\mathbb{G} = \{\mathbb{V}, \mathbb{E}\}$ be a directed graph, where $\mathbb{V} = \{0, 1, 2, \ldots, n\}$ is the set of nodes, node i represents the ith agent, $\mathbb{E}$ is the set of edges, and an edge in $\mathbb{G}$ is denoted by an ordered pair (i, j). $(i, j) \in \mathbb{E}$ if and only if the ith agent can send information to the jth agent directly, but not necessarily vice versa. In contrast to a directed graph, the pairs of nodes in an undirected graph are unordered, where the edge (i, j) de- notes that agent i and j can obtain information from each other. Therefore, an undirected graph can be viewed as a special case of a directed graph. A directed tree is a directed graph, where every node has exactly one parent except for the root, and the root has a directed path to every other node. A directed spanning tree of $\mathbb{G}$ is a directed tree that contains all nodes of $\mathbb{G}$ [16].

$A = (a_{ij}) \in \mathbb{R}^{n+1 \times n+1}$ is called the weighted adjacency matrix of $\mathbb{G}$ with nonnegative elements, where $a_{ii} = 0$ and $a_{ij} \geq 0$ with $a_{ij} > 0$ if there is an edge between the ith

B. Lyapunov Theory for Finite-time Stability

Here, we recall some Lyapunov theorem for finite-time stabil- ity of nonlinear systems, which was discussed previously in [20] and [21]. The classical Lyapunov stability theory is only appli- cable to a differential equation whose solution from any initial condition is unique [22]. A well-known sufficient condition for the existence of a unique solution of a nonlinear differential equation $\dot{x} = f(x)$ is that the function $f(x)$ is locally Lipschitz continuous. The solution of such nonlinear differential equation can have at most asymptotic convergence rate.

Since finite-time stability guarantees that every system state reaches the system origin in a finite time, finite-time stability has a much stronger requirement than asymptotic stability. The following theorem presents sufficient conditions for finite-time stability.

VI. Conclusion

This paper has presented an RFTCT control scheme for leader–follower multiagent systems with applications to multi-robot systems. A new error function is proposed for the system to ensure consensus. By using this error function, the consen- sus control problem is transformed to the conventional control problem. It is proven that finite-time consensus can be reached on the TSM surface. Simulation results have validated the anal-ysis. The proposed RFTCT algorithm can be easily applied to practical control of multirobot systems.

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