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Distributed event-triggered cooperative attitude control of multiple groups of rigid bodies on manifold $SO(3)$

Q1 Shengxuan Weng [a,*], Dong Yue [a], Xiangpeng Xie [a], YuSheng Xue [b]

[a] Institute of Advanced Technology, Nanjing University of Posts and Telecommunications, Nanjing 210023, China
[b] State Grid Electric Power Research Institute, Nanjing 211006, China

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A B S T R A C T

In this note, the distributed event-triggered cooperative attitude control of multiple groups of rigid bodies evolved on nonlinear manifold $SO(3)$ is investigated. The distributed event-triggered mechanism is introduced into the controller design to reduce the communication pressure. It is verified that, the orientations of rigid bodies in each group converge to a common value with zero angular velocities, and these common values in all groups achieve an anti-consensus configuration under the proposed intra- and inter-group cooperative control law. Simulation results show the effectiveness of the proposed method.

1. Introduction

Since the pioneering works of Reynolds [22] and Vicsek et al. [29], the problem of cooperative control of multi-agent system has been intensively studied, which has shown many significant applications in unmanned aircraft formation flying, flocking mechanisms, search and rescue missions, forest fire detection, distributed sensor networks, etc. The study of collective behavior of multi-agent system focuses on the construction of the distributed controller whose execution only depends on the local information received from the neighbors. Related research topics in this area include consensus [10–13,21], formation control [2,6,28], flocking [7,14,20,26,33,36], etc.

Traditionally, the considered agent in multi-agent system is always identified as a particle without concerning its attitude variations. However, in many applications such as satellite motion and deep-ocean monitoring, the attitude variations must be taken into consideration. Such a kind of system is usually regarded as the multiple rigid bodies system, though it can also be called a kind of multi-agent system. In recent several years, there have been some great achievements in the study of cooperative control of multiple rigid bodies by regarding them as multi-agents. A distributed control algorithm was proposed for attitude synchronization of multiple rigid bodies modeled by Eular–Lagrangian systems in [15]. In [39], a decentralized attitude tracking controller was designed for a class of multiple rigid bodies based on adaptive control and neural networks. Li and Kumar [16] considered the attitude tracking problem of multiple rigid bodies in the presence of external disturbances and actuator faults, where the effect of communication delays was also considered in [1]. The attitude synchronization problem in multiple rigid bodies system with directed and switching communication topology was addressed in [27]. The finite time attitude synchronization control with uncertainties including parametric uncertainties, external disturbances and

Q2 * Corresponding author. Tel.: +8615077872582.
E-mail addresses: shxweng@gmail.com, shxweng@163.com (S. Weng), medongy@vip.163.com (D. Yue).

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actuator failures was investigated in [32]. Mehrabian and Khorasani [17] dealt with the attitude synchronization control for multiple heterogeneous rigid bodies.

It should be mentioned that, the conventional control approaches in the existing literatures are to drive the attitudes of all rigid bodies in system to one common value. However, in some real applications such as search and rescue missions, the system with multiple rigid bodies often faces the cooperative task where more than one agreements of attitudes are needed to be achieved. To the best of our knowledge, there has not been suitable control strategy given for this topic up to now. In this paper, we will focus on the cooperative control for multiple attitude agreements problem. Different from the existing traditional synchronization control method, the designed control strategy could drive the attitudes of rigid bodies in system to more than one consistent values.

Meanwhile, only continuous cooperative control laws are designed for multiple rigid bodies in the existing literature, which means that each rigid body should transmit its own state information to its neighbors continuously in order to guarantee the performance of the closed-loop systems based on the proposed control. Obviously, it does not make sense from the viewpoint of networked control system [30,34]. Furthermore, although the implementation of the continuous cooperative control approach can be carried out based on the sampled-data control method with small enough sampling period in practical system, it may aggravate the communication pressure when the number of agents increase, and this is not suitable for the case with limited network bandwidth. Recently, the event-triggered method was developed to reduce the traffic in networked control system in [9,30,34,35,37], and then was introduced in the distributed controller design of multi-agent systems. Under the event-triggered strategy, each agent only need to transmit the triggered data to its neighbors at some discrete triggered times when a defined measurement error exceeds a given threshold. Therefore, the event-triggered method can be expected an efficient effect on reducing the communication pressure. The event-triggered control was taken into account in multi-agent system with integrator dynamics in [5] firstly, and [8] considered the case with general linear dynamics. The event-based consensus algorithm under switching communication network topology was developed in [18]. Cao et al. [3] constructed an event-based consensus control for double-integrator multi-agent system via synchronous periodic event detection, where the edge event-driven techniques was proposed. The distributed event-triggered control strategy under quantised measurement was discussed in [38]. However, the event-triggered scheme for cooperative attitude control of multiple rigid bodies system is still lacking up to now. Although we have considered the problem in [31], the control purpose was the attitude synchronization instead of the multiple attitude agreements. Moreover, the attitude kinematics and dynamics for rigid body in [31] was constructed based on modified Rodrigues parameters, which is geometrically singular and is limited to local attitude maneuvers [4].

Motivated by the above discussion, this paper proposes the multiple attitude agreements control protocol for multiple rigid bodies system. Meanwhile, the event-triggered mechanism is introduced in the cooperative attitude controller design, which could reduce the communication pressure. To summarize, distinct from the existing literatures studying the cooperative attitude control for multiple rigid bodies, the major improvements of the proposed control in this paper can be outlined as follows.

(1) Different from the conventional attitude synchronization, the multiple attitude agreements control purpose is considered. A multi-group control architecture is designed, where one rigid body in each group is considered as the leader and the other rigid bodies are considered as followers. The designed intra-group cooperative controllers drive the attitude of followers in each group to that of the leader located in this group, and the constructed inter-group cooperative controllers drive all the attitudes of leaders to an anti-consensus configuration. The two kinds of distributed cooperative control algorithms accomplish the multiple attitude agreements task.

(2) To the best of the authors' knowledge, there is not much work studying the distributed event-triggered attitude control of multiple rigid bodies. In this paper, the event-triggered mechanism is introduced in the distributed attitude controller design to reduce the communication pressure in each group, where there usually exist a mass of rigid bodies and a very complex communication topology in engineering applications. Moreover, the event-triggered controller is designed for the attitude control model constructed on the nonlinear manifold $SO(3)$, which is the unique model to represent attitude both globally and uniquely.

The rest of this paper is organized as follows. Section 2 gives preliminaries and the problem formulation. Our main results are given in Section 3. In Section 4, numerical simulations are provided. Finally the paper is concluded in Section 5.

2. Problem formulation and preliminaries

2.1. Notations

In this note, the orientation of a rigid body in a three-dimensional Euclid space is represented by the element in the special orthogonal group $SO(3)=\{A\in R^{3\times3}|A^TA=AA^T=I, det(A)=1\}$. The Lie algebra of $SO(3)$ is denoted as $so(3)$, which is the space of antisymmetric 3×3 matrices. The norm of $B\in R^{3\times3}$ is denoted by the Frobenius norm as $||B||^2=tr(B^TB)$, and the scalar product of B and C in $R^{3\times3}$ is defined by $B\cdot C=tr(B^TC)$. Define the operator $s(\cdot)$: $R^{3\times3}\to R^9$ as $s(B)=(b_{11},b_{12},b_{13},b_{21},b_{22},b_{23},b_{31},b_{32},b_{33})^T$ for $B=(b_{ij})\in R^{3\times3}$. Obviously, $tr(B^TC)=s^T(B)s(C)$ for any B, $C\in R^{3\times3}$.