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Impulsive practical tracking synchronization of networked uncertain Lagrangian systems without and with time-delays

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HIGHLIGHTS

- Impulsive control is used to study synchronization of networked Lagrangian systems.
- Each agent instantaneously interacts with its neighbors only at discrete moments.
- Agents in the network are allowed to be nonidentical, even uncertain dynamics.
- Both cases without and with communication time-delays are fully addressed.

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ABSTRACT

This paper presents a procedure for studying tracking synchronization of networked Lagrangian systems via impulsive control, where each agent is allowed to be nonidentical, even uncertain dynamics. Some algebraic criteria for tracking synchronization without and with time-delays are established respectively. It turns out that these criteria can provide a novel impulsive control strategy to synchronize globally networked Lagrangian systems to a given time-varying target trajectory with a desired tracking error bound (called as practical tracking synchronization). A distinctive feature of the developed control strategy is fully to take into account the effects of impulsive constraints, and thereby to yield impulsive synchronization motion of networked Lagrangian systems, provided that each agent instantaneously interacts with its neighbors only at some discrete moments. As a direct application of the theoretical results, practical tracking synchronization of nonidentical 3-DOF mobile robots without and with time-delays is discussed in detail. Simulation results illustrate and visualize the effectiveness and feasibility of the proposed control technique.

1. Introduction

Over the past decades, synchronization and control problems of networked multi-agent systems have attracted a great deal of attention from various fields of science and engineering. Remarkable contributions have been devoted to consensus or synchronization seeking in networked multi-agent systems modeled by single and double-integrator dynamics [1–8].

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Clearly, such multi-agent systems with single and double-integrator dynamics cannot formulate a large quantity of real physical and mechanical objects in practice. On the other hand, a class of physical and mechanical systems including autonomous vehicles, robotic manipulators, and walking robots are formulated Lagrangian dynamics [9,10]. Therefore, synchronization and control of networked Lagrangian systems have emerged as a new challenging research area due to their inherent nonlinearity, especially when there exist parametric uncertainties. The synchronization objective in this problem is to reach some kind of agreement between some variables of interest of the systems, and an important issue is the design of interconnection control laws to synchronize nonidentical, nonlinear dynamical systems described by Lagrangian equations. As a result, more and more authors recently devoted to propose different kinds of synchronization control laws for networked Lagrangian systems from various perspectives. For example, PD-type control law with robustness property is introduced to address the coordinating problem of Lagrangian systems [11,12]. Some distributed leaderless consensus algorithms for networked Lagrangian systems are proposed under an undirected graph [13]. Contraction analysis method was used to study the synchronization problem of Lagrangian systems [14], while a strategy based on virtual systems is given to deal with the same problem [15]. Synchronization of networked Lagrangian systems with a single leader is investigated under a passivity-based framework [16–18]. In addition, distributed adaptive controlled synchronization scheme is designed for Lagrangian network with parametric uncertainties [19–24].

Despite the interesting results on networked Lagrangian systems cited above, most of the existing works are concentrated on the continuous-time coupled Lagrangian network [11–24]. In recent years, dynamics and control of hybrid dynamical systems with discontinuities or abrupt change behaviors have become a rather significant topic, and have also been intensively investigated due to its broad applications in many areas including multibody system collisions, robots with flexible manipulators, airplane propellers, switched electrical circuit, and biological neural networks [25,26]. Generally speaking, hybrid dynamical systems can be described mathematically as the dynamical systems with combined behaviors of continuous and discrete-time variables, which arise from a variety of factors involving impact, switching, friction and sliding, from the physical point of view [27]. All these impact factors may allow for the sudden appearances of constraints or sudden changes in system motion, and thereby we often refer to this phenomenon as impulsive motion [28–30]. Impulsive motion of networked multibody systems arises when the interactional subsystems or agents are physically subject to either direct or indirect impulsive forces or impulsive constraints, or when subjected to both simultaneously [30]. These impulsive forces or impulsive constraints produce impulsive effects. That is, the generalized coordinates or velocities of the agents in the networks may change abruptly. Thus, impulsive control strategy based upon impulsive force or impulsive constraint is actually a discontinuous control scheme [28], which has been successfully used to stabilize a large class of physical and mechanical systems [2,3,31–34]. Accordingly, such impulsive controlled network can be regarded as the instantaneous-time coupled network. Indeed, by the impulsive control, the agents in the networks instantaneously interact with its neighbors only at some discrete moments, which drastically reduces the amount of information transmitted from one agent to others. In addition, sampled-data control systems in the form of impulsive model have recently attracted considerable interests on both theoretical and practical fronts in the background of networked control systems for simplicity of implement procedure, effectiveness of control performance and robustness of suffering disturbance in many practical applications, especially in the technological appeal of digital implementations [35,36]. In a recent paper [37], Wu et al. proposed a distributed impulsive control law for the synchronization motion of networked identical Lagrangian systems.

Although many literature are available on synchronization problem of networked multi-agent systems with identical agent dynamics, it is desirable to synchronize nonidentical networked Lagrange systems in some practical applications, where all agents may have different dynamics, and even dynamics uncertainties occur because of a wide variety of environmental factors including the various kinds of physical constraints, the imprecision of parameter measurements, and external abrupt disturbance and so on. As a consequence, these uncertainties will inevitably degrade performances with unpredictable responses. On the other hand, it is well known that communication delays are usually viewed as one of the key factors which may affect the performance of multi-agent systems adversely, or even cause the systems instable [36,38]. Communication delays often arise as a consequence of data transmission and/or packet drop due to the restriction of the network communication channels. To the best of our knowledge, so far little attention has been paid to the synchronization problem of networked nonidentical Lagrangian systems with uncertain dynamics via impulsive control, which may be subject to communication delays. Therefore, as an interesting and challenging topic, this motivates our present research.

With the aforementioned background, in this paper we consider practical tracking synchronization in networked systems modeled by Lagrangian dynamics without and with time-delays via impulsive control, where each agent is allowed to be nonidentical, even uncertain dynamics. By developing the preliminary feedback control, in cooperation with the effects of impulsive constraints or impulsive forces, we present a novel impulsive control law for practical tracking synchronization of Lagrangian network. Some general algebraic criteria are established to regulate globally all agents to a given time-varying target trajectory with a desired tracking error bound. Subsequently, the results are illustrated by a typical system of multiple 3-DOF mobile robots equipped with robotic manipulators on a cart in detail, and simulation results are finally given to show the effectiveness of the proposed theoretical results.

This paper is organized as follows. In Section 2, we introduce the considered model of Lagrangian network, and design the impulsive control law. In Section 3, some algebraic synchronization criteria are given to make the uncertain Lagrangian network achieve practical tracking synchronization. In Section 4, examples and simulations are given to illustrate the effectiveness of the proposed control strategy. Finally, Section 5 presents a brief conclusion to this paper.