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Group controllability of discrete-time multi-agent systems

Bo Liu[a], Yue Han[a], Fangcui Jiang[b], Housheng Su[c,*], Jietao Zou[a]

[a]College of Science, North China University of Technology, Beijing 100144, PR China
[b]School of Mathematics and Statistics, Shandong University, Weihai 264209, PR China
[c]School of Automation, Image Processing and Intelligent Control Key Laboratory of Education, Ministry of China, Huazhong University of Science and Technology, Wuhan 430074, China

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Abstract

Controllability is a fundamental issue concerning control of multi-agent networks and a very important research topic in the modeling, analysis and coordination control of multi-agent systems. Group controllability problem is a further extension of the controllability problem of the general multi-agent systems, which mainly studies the cooperation and control of multi-agent systems with multiple sub-groups or multiple intelligence clusters. Comparing with the controllability of the general multi-agent systems, the group controllability is not only to consider the information interaction among the groups, but also to consider the information interaction between different groups, which makes the system reflect the effect of a whole and also the internal structure of the sub-groups. This paper addresses the group controllability problems of discrete-time multi-agent systems with time-delay, in which both switching topology and fixed topology are considered. This paper also proposes the general definition of the group controllability, as well as establishes group controllability criteria from the algebraic and graphical perspectives. Numerical examples and simulations are proposed to illustrate the theoretical results.

*Corresponding author.
E-mail address: houshengsu@gmail.com (H. Su).

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1. Introduction

In recent years, the multi-agent system has become a new branch of complex system in control field, which has attracted many researchers' interests and concerns in many areas such as engineering, ecology, biology, sociology, computing science, sensing and communication technologies [1–10].

The controllability of the control system is an important basic problem in modern control theory and plays a key role in many research fields. Controllability problem is one of the basic problems for distributed coordinated control of multi-agent systems. In engineering practice, in order to accomplish a specific task and achieve certain performance requirements, by controlling some of the agents, the rest of the group can move or achieve the desired goal of the group via designing the dynamic evolutionary algorithm or control law for each agent. As the evolution behavior of multi-agent system can be affected by many factors, such as the dynamic evolution of the agent itself, the communication topology among agents, the state evolution protocol and the external interference, as well as the structure, parameters, control input (leaders selection), feedback gain and the dimension of the multi-agent system, the controllability of multi-agent system becomes a very challenging task.

The controllability problem of multi-agent systems was first proposed by Tanner [11] in 2004, in which one-integrator dynamic model through nearest neighbor rules was presented, where one of the agents was regarded as a leader (external input), and necessary and sufficient conditions of the controllability were derived under a fixed time-invariant nearest-neighbor topology. In what follows, some related results on the controllability of multi-agent systems are investigated, such as continuous-time [12–14] and discrete-time [15,16]; first-order [12,17,18], second-order [19] and high-order [13]; undirected topology and directed topology [16]; switching topology and time delay in [17,20].

At present, the main methods for the controllability of multi-agent systems have concentrated on investigating graph-theoretic characterization [21,22] and algebraic criteria [17] of the systems. Much work has focused on the graphical conditions of controllability based on equitable or relaxed equitable partition in [22], external equitable partition in [23] and the references therein. Algebraic conditions characterized the relationship between controllability of topological structures described in [17,24–29] and so on. There is other progress in the controllability of paths [30], multi-chain topologies [31,32], tree graphs [33], symmetric structures [17,34–36], grid graphs [37], Cartesian product networks [38], threshold graphs [39], etc.

For multi-agent systems, the controllability refers to transferring the remaining intelligent agents of such system from any arbitrary initial state to any final state by controlling dynamics of a small amount of intelligent agents under exchanged information between each other. With the improvement of multi-agent systems' complexity, the whole system can be divided into some subgroups. How to investigate the controllability of the multi-agent system containing multiple subgroups, that is, how to make the intelligent agents of each subgroup in the multi-agent system be transferred from any arbitrary initial state to any final state by controlling dynamics of a small amount of intelligent agents? In a recent paper [40], the authors studied the group consensus in multi-agent systems with switching topologies and communication delays.

Motivated by the work in [40], we will investigate the controllability of the general multi-agent systems based on the group consensus. However, comparing with the controllability of the general multi-agent systems, the group controllability is not only to consider the information interaction among the groups, but also to consider the information interaction among different