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A Novel Method of Clock Synchronization in Distributed Systems† ⋆

LI Gun△ NIU Meng-jie CHAI Yang-shun
CHEN Xin REN Yan-qiu

School of Aeronautics and Astronautics, University of Electronic Science and Technology of China, Chengdu 611731

Abstract Time synchronization plays an important role in the spacecraft formation flight and constellation autonomous navigation, etc. For the application of clock synchronization in a network system, it is not always true that all the observed nodes in the network are interconnected, therefore, it is difficult to achieve the high-precision time synchronization of a network system in the condition that a certain node can only obtain the measurement information of clock from a single neighboring node, but cannot obtain it from other nodes. Aiming at this problem, a novel method of high-precision time synchronization in a network system is proposed. In this paper, each clock is regarded as a node in the network system, and based on the definition of different topological structures of a distributed system, the three control algorithms of time synchronization under the following three cases are designed: without a master clock (reference clock), with a master clock (reference clock), and with a fixed communication delay in the network system. And the validity of the designed clock synchronization protocol is proved by both stability analysis and numerical simulation.

Key words astrometry: time—methods: data analysis

1. INTRODUCTION

The time synchronization technique is widely used for the spacecraft formation flight and constellation autonomous navigation, etc.[1−5]. In the application of satellite navigation technique, the capability of constellation autonomous navigation plays an increasingly important role, in which the techniques of autonomous time synchronization and information

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△ ligun@uestc.edu.cn

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exchange in a constellation network are indispensable[6−9]. In the control of spacecraft formation flight, the mutual time synchronization is needed for the relative or absolute positioning between spacecrafts and their communications, and an unified time reference is also needed in the whole process of spacecraft formation flight. In addition, the international high-precision time comparison between various time laboratories is the most typical example of the application of distributed time synchronization[2−3]. Therefore, the applications of various types of time synchronization may be summarized as the problem of time synchronization in a distributed system of different topological structure. Previous researches focused their attention on that each node in a system may obtain the global clock information of the system, or on the time synchronization among fixed nodes, however, for a complicated network system with many nodes, if each node can only know the information of one or two of its neighboring nodes (with the prerequisite that each node is connected with one of its neighbor nodes), the problem how to realize the time synchronization of a network system in this condition is rarely studied sofar. Bolognani et al.[10] studied the time synchronization technique of multi-agent network systems using the theory of randomized linear system. In their paper it was assumed that multiple clocks have their own clock errors and clock rates different from each other, the communications among clocks are implemented through an asymmetrical broadcast protocol, and the control of clock synchronization is realized by designing the control protocol and adjusting the clock parameters, so that the clock synchronization in a network is achieved. In the light of References [10-12], the time synchronization method is studied in this paper for the following three cases in a multi-agent network system: without a reference clock, with a reference clock, and with the time delay disturbance in a clock system. A system without a reference clock implies that there is no master clock in the multi-agent network system, and that all nodes are of equivalent status. The clock synchronization technique with a reference clock means that there is/are a or several master clock/clocks, and in such a system the control of time synchronization is to implement finally the full synchronization of other secondary clocks with the reference clocks, namely to implement the absolute clock synchronization. If the clock differences of all the secondary clocks relative to the reference clock keep fixed, the relative clock synchronization may be realized.

2. CLOCK MODEL

With a distributed system composed of n clocks considered, for an arbitrary clock among them, which is noted as the i-th clock, its clock model may be approximately denoted as

$$T_i(t) = a_{i0} + a_{i1}t + a_{i2}t^2\,, \qquad (i = 1, 2, 3, \cdots, n) \tag{1}$$

in which, $T_i(t)$ expresses the indication of the i-th clock at the time t; a_{i0}, a_{i1} and a_{i2}, the clock error, clock rate and clock drift of the i-th clock, respectively. Such a model is known as the 2nd-order model. Sometimes, the distributed system composed of n clocks