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Genetic Algorithm for Initial Orbit Determination with Too Short Arc

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Abstract A huge quantity of too-short-arc (TSA) observational data have been obtained in sky surveys of space objects. However, reasonable results for the TSAs can hardly be obtained with the classical methods of initial orbit determination (IOD). In this paper, the IOD is reduced to a two-stage hierarchical optimization problem containing three variables for each stage. Using the genetic algorithm, a new method of the IOD for TSAs is established, through the selections of the optimized variables and the corresponding genetic operators for specific problems. Numerical experiments based on the real measurements show that the method can provide valid initial values for the follow-up work.

Key words space vehicles, celestial mechanics, methods: numerical

1. INTRODUCTION

The short arc determination, known also as initial orbit determination, or more briefly orbit determination, is to determine an orbit under the meaning of two bodies without any a priori information and on the basis of a few observational data of only one station and only one cycle. The orbit determination of angular measurement data is one of the classical problems in celestial mechanics, the study on the orbit calculation method of real observational data has been continued for more than two hundred years, and along with the appearances of

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new objects and new observational measures, the new necessaries and difficulties emerge unceasingly [1].

The classical method of orbit determination was set up by Gauss and Laplace in terms of asteroid orbit determination, and was considerably developed since the launch of artificial satellites, on which Escobal shed light thoroughly [2]. Taff made the classification and comparison on the various methods [3]. And the researchers of our country have also done a lot of investigations, which are focused on the improvements of Laplace method, in combination with our own observational data [4-10].

The problem of initial orbit determination has not yet been satisfactorily settled, which is fundamentally caused by the intrinsic ill-condition of the equation to be solved, so, the problem of short arc orbit determination is ill-posed. With such a difficulty confronted, only to collect an arc as long as possible can a relatively good result be obtained. As for the optical observations, a rather good result will not be acquired until an arc as long as $5 \sim 6$ minutes is collected [11]. In practice, the continuous data collection of an arc longer than 3 minutes is required at least.

Along with the ceaseless increase of the quantity of space objects, a new observational mode aiming at the spatial domain has recently appeared in the observations of space objects. By means of sustained observations on the spatial domain, the position information of all the objects which pass through this spatial domain is recorded. This observational mode has changed the previous situation that one set of equipment can only track a single object, so that all the objects which pass simultaneously through the spatial domain can be monitored. Under this observational mode, the observation efficiency is raised, and the observation quantity is substantially increased, however, this has brought about a new problem. Even if a wide-field telescope is applied, but the collected arc length for a low-orbit space object is very limited. For example, the arcs collected by the telescopes of ultra-wide field of view in the Network of Space Object and Debris Observation of Chinese Academy of Sciences are mostly not longer than 30 seconds, and in a quite part only 10 seconds or so. Recently, many large-scale sky survey projects in the world have taken the space objects as their observing targets, and collected a huge quantity of data, the problem of orbit determination with a too short arc has become the crux of effective utilization of data [12].

Classical methods can hardly apply to initial orbit determination of a too short arc, the main problem is that the calculation is not convergent or the obtained solution is unrealistic (the orbital semi-major axis shorter than the Earth's equatorial radius). An arc short like this is known as "too short arc" (TSA) to distinguish it from the short arc in traditional meaning [13−14]. The specific length of TSA has not been exactly defined. In Reference [11], an arc shorter than 2 minutes is considered as TSA, while in Reference [14] that shorter than 1 minute is taken. In general, a TSA is considered as the arc whose realistic solution can hardly be obtained with the classical method, while its real length may be determined according to the specific object.