博士学位论文摘要选登

数值积分和数据融合在单位矢量法中的应用

掌 静[†]

(中国科学院紫金山天文台 南京 210008)

单位矢量法是紫金山天文台提出并得到广泛应用的一种系列轨道确定算法. 该算法通过投影变换, 对不同类型的观测数据构成不同的条件方程, 从而便于不同类型数据的加权处理, 充分发挥了高精度数据在定轨中的作用, 显著提高了定轨精度.

改进的有摄单位矢量法 (PUVM2) 将单位矢量法从初轨计算推广到轨道改进, 将初轨计算和轨道改进有机结合起来, 减少了工作环节, 进一步提高了轨道测定精度和效率. 本文基于海上测控工程的应用, 对数值积分和数据融合在单位矢量法的基础上做了深入研究, 进一步夯实了算法的理论基础, 提高了定轨精度, 拓宽了应用领域.

由于观测技术的改进, 人卫测量数据的精度有了大幅度的提高, 如原有海上测控设备的测角数据通常为 $1'$ 左右, 即 10^{-4} 量级; 但测距数据达到了 m 级, 即 10^{-6} 量级; 测速也有 cm/s 级, 约 $10^{-5} \sim 10^{-6}$ 量级, 而且实际工作需求也迫切要求进一步提高定轨方法的计算精度, 一阶分析摄动模型已经无法完全满足需要. 本文在单位矢量法基础上, 引入数值积分方法计算摄动量, 提高了动力学模型的计算精度, 使之与观测数据的精度相适应; 又相应修改了单位矢量法的条件方程, 进一步提高定轨精度, 为单位矢量法的推广应用打下了坚实的基础.

随着观测手段的增加, 观测数据的类型也大大增加, 不仅有传统的地面测站获得的测角、测距、测速数据, 还有星载设备下传的卫星三维空间位置、速度数据 (如 GPS 数据、平台数据、惯阻数据等), 如何合理利用这些不同类型数据对定轨方法提出了新的要求. 本文引入了数据融合概念, 从理论上进一步阐明了原单位矢量法的收敛机制, 简化了近似状态转移矩阵计算方法, 改进了对不同精度、不同类型、不同量纲数据的加权处理策略, 从而进一步提高了单位矢量法的通用性和数值稳定性.

大量的仿真和实测计算结果表明, 本文所做的改进方法是有效的:

(1) 在引入数值积分摄动计算后, 单位矢量法的定轨精度得到了显著提高, 完全能够适应目前实用的高精度观测数据的要求. 在精度不低于采用相同力学模型的经典微分轨道改进数值方法的前提下, 计算速度显著加快;

(2) 引入数据融合后, 单位矢量法对不同精度、不同类型、不同量纲数据的权重分配更加合理, 各种精度的观测数据都得到了充分而有效的使用, 算法的数值稳定性也得到显著提高.

[†]2011-01-08 获得博士学位, 导师: 紫金山天文台李广宇研究员、陆本魁研究员; zhangjing@pmo.ac.cn

Application of Numerical Integration and Data Fusion in Unit Vector Method

ZHANG Jing
(*Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008*)

The Unit Vector Method (UVM) is a series of orbit determination methods which are designed by Purple Mountain Observatory (PMO) and have been applied extensively. It gets the conditional equations for different kinds of data by projecting the basic equation to different unit vectors, and it suits for weighted process for different kinds of data. The high-precision data can play a major role in orbit determination, and accuracy of orbit determination is improved obviously.

The improved UVM (PUVM2) promoted the UVM from initial orbit determination to orbit improvement, and unified the initial orbit determination and orbit improvement dynamically. The precision and efficiency are improved further.

In this thesis, further research work has been done based on the UVM:

Firstly, for the improvement of methods and techniques for observation, the types and decision of the observational data are improved substantially, it is also asked to improve the decision of orbit determination. The analytical perturbation can not meet the requirement. So, the numerical integration for calculating the perturbation has been introduced into the UVM. The accuracy of dynamical model suits for the accuracy of the real data, and the condition equations of UVM are modified accordingly. The accuracy of orbit determination is improved further.

Secondly, data fusion method has been introduced into the UVM. The convergence mechanism and the defect of weighted strategy have been made clear in original UVM. The problem has been solved in this method, the calculation of approximate state transition matrix is simplified and the weighted strategy has been improved for the data with different dimension and different precision.

Results of orbit determination of simulation and real data show that the work of this thesis is effective:

(1) After the numerical integration has been introduced into the UVM, the accuracy of orbit determination is improved obviously, and it suits for the high-accuracy data of available observation apparatus. Compare with the classical differential improvement with the numerical integration, its calculation speed is also improved obviously.

(2) After data fusion method has been introduced into the UVM, weighted distribution accords rationally with the accuracy of different kinds of data, all data are fully used and the new method is also good at numerical stability and rational weighted distribution.