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Chinese Astronomy and Astrophysics 42 (2018) 303–312

CHINESE
ASTRONOMY
AND ASTROPHYSICS

Probabilistic Data Association Method for Space Object Tracking† ⋆

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Abstract In the optical observation of space objects, multiple measurements often occur in the tracking gate, which brings about the uncertainty of tracking measurement and the reduction of tracking accuracy, causes the instability along the tracking path, and eventually leads to the interruption of tracking and the loss of the target. A new approach, combining the Kalman filter and probabilistic data association, is proposed in this paper for the adaptive tracking of space objects. In this method, the gate of association is predicted by the Kalman filter, while the equivalent measurement obtained from the probabilistic data association is adopted as an effective feed. The experiments show that this technique can effectively improve the tracking accuracy as well as the robustness for the automatic tracking of space objects.

Key words astrometry, space vehicles, telescopes, methods: statistical

1. INTRODUCTION

The optical observation system is indispensable in the network of space target monitoring. One of the most important approaches of monitoring the space targets is to detect their state variations by optical telescopes. With the great increase of the number of space targets and the improvement in the automation of observational instruments, it has become the mainstream to monitor space targets in a fully automatic tracking mode. The automatic tracking of space targets covers the whole process of track starting, maintaining and ending.

† Supported by Innovation Foundation of Defense Science and Technology of Chinese Academy of Sciences (CXJJ-15S129)

Received 2016–11–17; revised version 2016–12–13

⋆ A translation of *Acta Astron. Sin.* Vol.58, No.3, pp. 26.1–26.8, 2017

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doi:10.1016/j.chinastron.2018.04.009

Due to the complexity of the target's motion and the guidance error, the closed-loop tracking is generally adopted. Predict the track according to the historical information and update the track according to the real-time information, by such continuous cycles of prediction and updating, the telescope is guided to perform automatically the tracking of space targets.

In the optical observation of space targets, the images of numerous background stars densely spread on the detector surface, and their brightness and profiles are similar to the signals of space targets. Thus, the probability is very high that multiple measurement signals occur in the same tracking gate. In addition, with the quick development of aerospace technology, more and more satellites are flying in formations. Due to the prediction error, it is very difficult to accurately determine whether the tracking target is the required one.

For faint space targets, taking into account the detection efficiency, a low signal-to-noise ratio (SNR) threshold is generally chosen, resulting in some false alarms. Meanwhile, mixed with interferences and false alarms, the targets are generally difficult to distinguish, so that the automatic tracking in practice does not work ideally. The uncertainty of the correspondence between the observed data and the target is the most difficult problem in the target tracking. This difficulty exists throughout all stages of the automatic tracking, and it is the key to improve the efficiency of automatic tracking. Many studies have been devoted to this problem, but so far there is no universal algorithm existed for the data association.

The Nearest Neighbour (NN) algorithm was proposed[1] to solve this problem, in which the measurements with the minimal statistical distance from the predicted position in the entire measurements within the tracking gate are applied to updating the trajectory. In this method, a selection criterion is given for the multiple measurements. When the guidance is relatively accurate and the tracking is relatively stable, this method can efficiently maintain the effective tracking. However, in practice it is quite often that the measurement with the smallest statistical distance is not a true measurement of the target, resulting in a failure of tracking. To solve the general problem of target tracking, the concept of Probabilistic Data Association[2] (PDA) was proposed. Other than the NN algorithm which takes only one measurement into account, the PDA method considers all the measurements in the gate, and performs data association after weighting according to the posterior probability information, so that the stability of target tracking under the environment with many false alarms and interferences is improved. Based on the PDA algorithm, it was proposed that the joint probability data association algorithm[3] should be used in the multi-target tracking, in order to overcome the difficulty of signals' attributions when multiple targets are considered simultaneously. Later, some other data association algorithms were raised[4-7] for specific data sources and reasons. These algorithms have been widely applied to the target tracking practice in many fields, and obtained good results[8-10].

In the optical tracking of the space targets and debris, it remains to be the standard operation to open a window in the observed image according to the predicted position, and the window centre is regarded as the centroid of the space target. Despite its simpleness, this