SIMULATION AND EVALUATION SYSTEM FOR SPACE SURVEILLANCE PHASED ARRAY RADAR

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ABSTRACT

With the abilities to change observing directions and take trivial affection from disadvantageous weather conditions, the phased array radar (PAR) has taken an important role in space surveillance. It would be advantageous to have a simulation system to test and evaluate the performance of its data processing procedures while the hardware being fabricated. The simulation and evaluation system for the space surveillance PAR would be studied with its architecture and implementation illustrated in this paper.

Key words：Phased Array Radar, Space Surveillance, Simulation and Evaluation， LEO Object

1. INTRODUCTION

The surveillance of low earth orbit (LEO) objects can be performed by photoelectric telescopes and radars. While telescopes could provide high precision measures, they take a long time to observe just only a few objects, and their functionality would easily be hampered by daylights or clouds. Thereby the validity of telescopes in space surveillance was limited. As a contrary to telescopes, phased array radars (PAR) could change their observing directions promptly and could only take trivial affection from different weather conditions. These features have made phased array radars preferable in fast cataloging of space objects and debris.

The performance of a space surveillance system is not only determined by the parameters of the hardware, but also affected by its data processing software, especially the data correlation and the orbit determination algorithms. Because it took quite a lot resource for the construction and running of a PAR for space surveillance, it would be advantageous to have a simulation system to test and evaluate the performance of its data processing procedures while the hardware being fabricated. The performance evaluation system would allow optimal parameters be calculated against given running configurations. In this paper, we will study a simulation and evaluation system for the space surveillance PAR with its architecture and implementation illustrated.

With the simulation system implemented with given algorithms for the PAR, we can evaluate the performance of these algorithms by running the simulation for a certain period and compare the catalog made by the post-processor against the actual values of the space objects. It has proved that the simulation and evaluation system could reduce the time and cost for the development of space surveillance PARs remarkably.

2. SYSTEM ARCHITECTURE

Before the simulation and evaluation system was developed, the operational routine of the PAR and its observing procedure should be modeled first. With this study, we have found that the performance of a PAR space surveillance system for given hardware was primarily determined by the scheduling algorithm for radar observations and the orbit determination algorithm. With these findings in mind, the whole simulation system can be segmented into three parts including a simulation data source, a radar observation creator and a post-processor. The architecture is shown

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in Fig. 1.

The simulation data source comprised a position calculator that calculated the motions of a predefined set of space objects for the duration of the simulation time, and then the scheduling algorithm will take hand. With the same algorithm that would be running in the operational circumstances, it chooses the space objects for the PAR to observe. For these objects, it also calculated all the times for their observations and their positions at those times, and the PAR will allocate its observing resource according to these data.

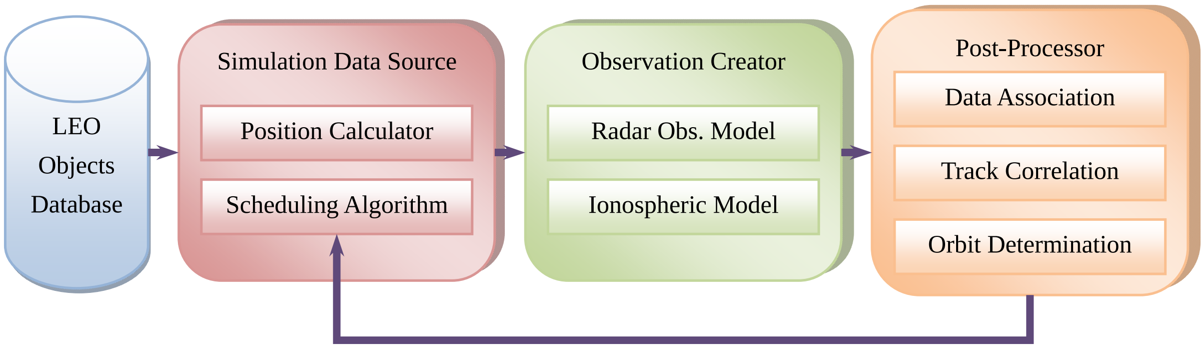

Figure 1 System Architecture

These position data will feed into the radar observation creator in order of their observation times. The creator used the radar observation model and the ionospheric model to compute the metric value for the phased array radar and determine whether the objects would actually be "seen" by the radar.

The post-processor is a duplication of the data processing procedures that will be applied in the concrete radar. It mainly fulfilled the data association, track correlation, and orbit determination jobs. It uses the outputs of the radar observation creator and achieves cataloging of the space objects. This catalog will then be pumped into the scheduler of the data source to decide which objects will be observed at their next pass.

3. IMPLEMENTATION

3.1. Simulation Data Source

The purpose of the data source is to provide accurate position information of the LEO objects to be observed. We used space objects elements from Celestrak [1], IDB Communications [2] and other sources as the inputs, and selected concerned objects fitting certain criteria (such as object classes and / or in certain parameter ranges).

The position calculator calculates when each concerned objects will pass through the radar's field of view. Then the data source will choose which objects would be observed according to the scheduling algorithm, and set the precise time points for their observation. Finally, the position calculator will active again to calculate the position and motion data of the objects at these observation time points. The course could be summarized as Fig. 2.

A PAR usually works in track-while-scan (TWS) mode, which is implemented in a time-divided mode with the flexibility of the pointing of radar wave beams [3]. There are various tracking modes when it is tracking multiple objects, and the timing of the observations would be very complicated. The main purpose of the simulation and evaluation system was to check the feasibility and performance of subsequent data processing procedures, the scanning and tracking might be simplified to the allocation of times of each observation.

In the operational environment, the LEO objects will be cataloged in a progressive mode, which means the elements of some objects have been known while the elements of some others are unknown. In our simulation, we divided the objects into these two groups at the beginning. For those known objects, the radar used tracking mode and waited for them at predicted positions. For those unknown objects, a scan screen with a small thickness was set up at a certain elevation. When space objects passed through the screen, they would be tracked if the tracking ability of the radar was not saturated; otherwise the objects would be discarded.

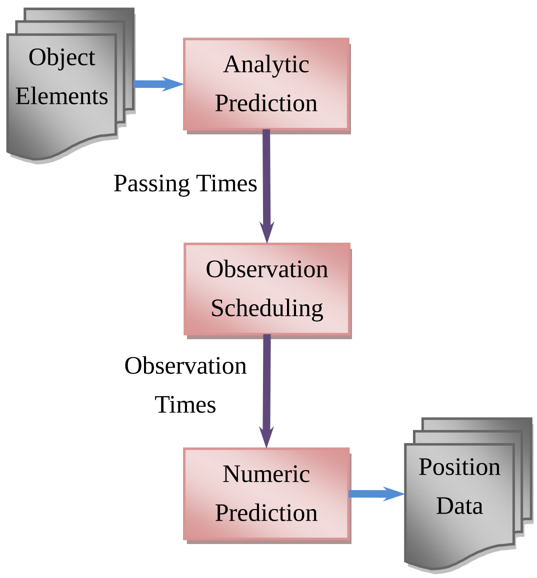

Figure 2 Processing of the Simulation Data Source

The scheduling algorithm would decide when and which objects would be observed. As it usually takes several minutes for a space object to pass through the observing field, it is not going to be a problem if the observation starts a few seconds earlier or later. However, the position predictions would decide whether the PAR could actually find and track the object, so the accuracy would take precedence.

With aforementioned concern, we implemented different prediction algorithms in the data source. As shown in Fig. 2, an analytic algorithm [4] was used for passing prediction, which was fast to provide the time periods during which the objects were in the radar's field of view (FOV); and a numeric algorithm [5] was used for position prediction, which could provide more accuracy but was more time consuming.

The result of the scheduling is shown in Fig. 3. The upper chart is the number of objects from selected set that passed through the radar's FOV in 120 minutes, and the lower chart shows how much of them were scheduled into observation. The horizontal red line is the upper limit of the tracking ability of the radar.

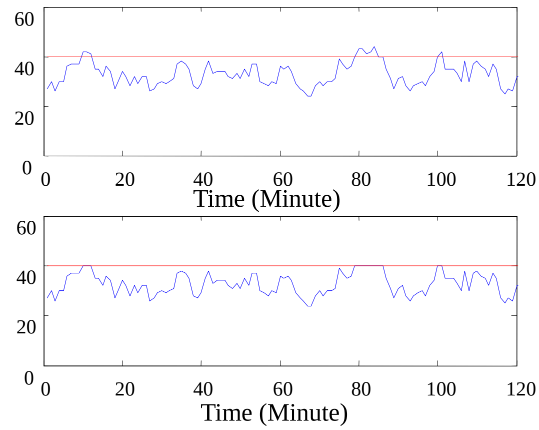

Figure 3 Result of Scheduling

3.2. Observation Creator

The function of the observation creator is to transform the position and motivation data provided by the simulation data source into radar metric data. It will use the radar parameters, the atmospheric transit parameters, and the radar observation model to make certain adjustments [6][7].

When radar beams pass through the atmosphere and the ionosphere, they will distort because the incident angles are not vertical. We implemented a first-order single-frequency ionospheric range-delay model to simulate the operational situation [8][9]. With the radar operational frequency and its geographic location given, the observation creator transforms the radar position data into metric data. The radar observation model will be used again to incorporate the observation noise into account. It used the average radar cross sections (RCS) of each objects to calculate the received signal and judge whether the object was actually "seen" by the radar.

After these transformations, the observation creator has simulated the signals the radar might receive in operational mode.

3.3. Post Processor

The post processor is where the processing algorithms that would be used in operational system to be tested. Algorithms that had shown fine performance here would be cloned into the information processing system for the PAR. This processing procedure could be divided into three parts, as shown in Fig. 4.

For the metric data provided by the observation creator, we should determine which points were from the same space object. Since most data came from tracked objects, the step would simply be to check whether the data consistently satisfied one orbit equation within given error tolerance. If the number of data exceeding the error tolerance was small, these points would be rejected as wild points. If the number was too high, we might take the tracking as a failed one as no subsequent processing was needed.

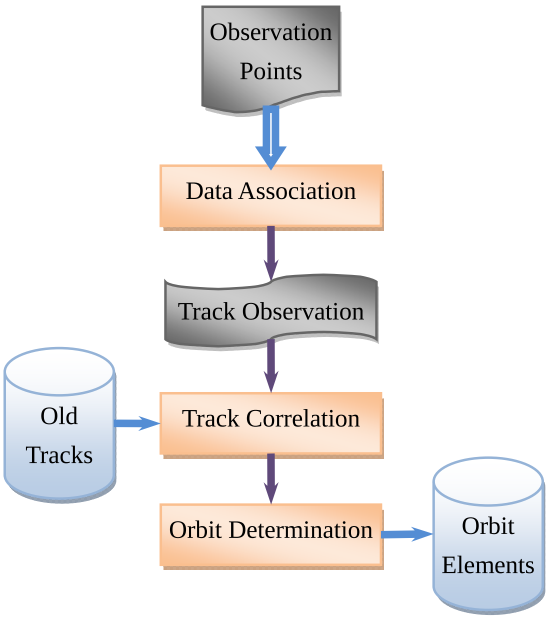

Figure 4 Processing of the Post Processor

The associated data are then taken as the observation of tracks of different space objects. The second step is to find which tracks were from the same space object. The track correlation took current track data to compare with older tracks observed by the radar. Tracks that fixed in a single orbit with least error and satisfied the time interval condition are seen as from the same object.

The final step is the orbit determination procedure. After a new track was correlated with a space object, it took several most recent tracks of the object to update its orbital elements.

4. CONCLUSION

In this paper, we have illustrated the simulation and evaluation system for the space surveillance phased array radar. The architecture has been shown with the implementation of each part described in detail. With different algorithms implemented in the simulation and evaluation system, we could analyze the data processing procedures before the hardware be made. This has significantly saved the efforts and cost in the building of the space surveillance PAR system.

5. REFERENCES

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