

Scoring sensor observations to facilitate the exchange of space surveillance data

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Abstract

In this paper, a scoring metric for space surveillance sensor observations is introduced. A scoring metric allows for direct comparison of data quantity and data quality, and makes transparent the effort made by different sensor operators. The concept might be applied to various sensor types like tracking and surveillance radar, active optical laser tracking, or passive optical telescopes as well as combinations of different measurement types. For each measurement type, a polynomial least squares fit is performed on the measurement values contained in the track. The track score is the average sum over the polynomial coefficients uncertainties and scaled by reference measurement accuracy.

Based on the newly developed scoring metric, an accounting model and a rating model are introduced. Both models facilitate the exchange of observation data within a network of space surveillance sensors operators. In this paper, optical observations are taken as an example for analysis purposes, but both models can also be utilized for any other type of observations. The rating model has the capability to distinguish between network participants with major and minor data contribution to the network. The level of sanction on data reception is defined by the participants themselves enabling a high flexibility. The more elaborated accounting model translates the track score to credit points earned for data provision and spend for data reception. In this model, data reception is automatically limited for participants with low contribution to the network.

The introduced method for observation scoring is first applied for transparent data exchange within the Small Aperture Robotic Telescope Network (SMARTnet). Therefore a detailed mathematical description is presented for line of sight measurements from optical telescopes, as well as numerical simulations for different network setups.

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1. Introduction

The large population of space debris and their predicted future evolution present a growing hazard to the space infrastructure and the usability of Earth orbits. Sharing of space surveillance information is mandatory to better

understand and preserve the space environment. The quality and effectiveness of close approach warnings, re-entry predictions, and other data products is driven by the accuracy of orbit information. For the most accurate and precise orbit information, all sensor observations available have to be combined. All mentioned is well-known but in the real world sharing of space surveillance sensor observations still seems to be an exception rather than the rule.

A large part of space surveillance observations, mostly for Low Earth orbits, is gathered by ground-based radars which are costly to produce and operate. Furthermore,

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these sensors are mostly operated by military organizations. Usually, no sensor observations are shared to prevent disclosure of information on sensor performance or on the orbits of classified satellite missions. For high altitude orbits, optical telescopes with an aperture size below 1 m are well suited to detect objects. Additionally, these sensors are affordable to a vast number of research institutes, commercial companies, or even amateur astronomers. These space surveillance sensor operators usually generate relative small amounts of observation data on their own and are highly interested in data sharing. The International Satellite Laser Ranging Service (ILRS 2017) is a good example for open data-sharing policy in the field of satellite tracking. All participating laser stations upload their ranging measurements to two redundant data centres with further release to the public. Without any restrictions, a large community of scientist and spacecraft operators make use of the SLR measurements. A data policy in between the two extremes of completely blocked or free data exchange has to reflect and balance the efforts made to regularly observe the large number of near Earth objects.

If sensor operators share their data within a network, the data quantity and data quality will differ among participants. Participants contributing a larger number of observations with high measurement accuracy should be given some kind of advantage or additional benefit. Participants with minor contribution to the network should stay motivated to increase their efforts. As a measure of sanction, the possibility for data reception from other network participants can be limited. In this paper, a technical solution is introduced for the implementation of compensatory data policies.

2. Scoring sensor observations

To quantify the value of sensor observations, a scoring metric is introduced. In principle the value of each measurement is defined by the information gain and depends not only on the measurement type and accuracy, but also on the observation geometry and a priori orbit uncertainty. For example, to compute the Fisher-information for a set of tracklet measurements the modelled or expected observations have to be derived from a priori trajectory first. This approach requires additional input information of objects orbits and orbit uncertainties. This additional input data need to be consistently provided to all network participants to make observation scoring transparent. Sharing a common orbit database is difficult to implement in practice, more due to political than technical constraints. In case of classified objects, one participant may have precise orbit information with corresponding low information gain of new observations. Another entity considering the same object to be newly detected would score for the same observations much higher on the basis of large initial orbit determination errors. Another example is the surveys for new objects, essential for building up a space object catalogue.

Again, a common understanding among all participants which objects are already known is the prerequisite for consistent observation scoring.

On the technical site, all network participants would need to use the same methods or even software for orbit determination and propagation including orbit uncertainty. Next, an observation score depending on the orbit and orbit uncertainty varies in time depending on measurement update. This becomes a technical challenge if for example two sensors provide observations of the same object in non-chronological order.

To be independent from a coordinated catalogue of space objects and information on their orbits and orbit accuracy, the scoring metric should be based on the sensor measurements alone, like range, range rate or line of sight angles. The scoring metric should take into account different measurement accuracy, sampling rates, and number of observations. As a consequence, no differences are made between observations gathered in surveys for new objects, follow-up observations of known objects, or even missed object detections.

A time series of position measurements of the same object by monostatic, bi-static or multi-static sensor is called track or tracklet. The latter term is normally used for ground-based telescope observations. The position measurement type may be range, range rate or angles, or a combination thereof. It can be assumed that all measurements of a track belong to the same object. This may inhere from the way of sensor operation, e.g. in the case of close-loop radar tracking, or from raw data processing, e.g. in the case of object linkage on multiple consecutive optical image exposures.

The following method is proposed to score single sensor tracks. For each measurement type, a polynomial least squares fit is performed on the measurement values contained in the track:

$$P(t) = \sum_{i=0}^m a_i t^i = a_0 + a_1 t + a_2 t^2 + \dots + a_{m-1} t^{m-1} + a_m t^m \quad (1)$$

with P being the polynomial function of as a function of time t , and a_m being the polynomial coefficients. The polynomial degree m can be adjusted to the present dynamics and time span of a typical sensor track. The track score is generally independent from the estimated polynomial coefficients itself. Instead of these, the polynomial coefficients uncertainties σ_{a_i} as 1-sigma errors are required.

The track score is a scalar value without unit. It is an average sum over all measurement types with the number k and scaled by 1-sigma reference measurement accuracy $\sigma_{a_i,ref}$:

$$S = \frac{1}{k} \sum_{i=0}^{k-1} \frac{\sigma_{a_i,ref}}{\sigma_{a_i}} \quad (2)$$

The reference measurement accuracy has to be defined. In Section 4 there is an example for optical telescope observa-

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