OBSERVABILITY OF NON-COOPERATIVE SPACE OBJECT'S TRACKING AND CHARACTERIZATION

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Keywords: *space debris, astrodynamics, optical sensors*

1. Extended abstract

The knowledge of space objects, which are not operational and communicating any more relies solely on observations. Most observations are made ground based, mainly using radars or telescopes, or to a lesser amount space based using telescopes. Specialized observations of space debris objects, have been established and methods have been refined over the past 20 years. Recently extensive effort has been spent on the modeling and simulation of high-area-to-mass ratio objects and other objects, for which follow-up observations posed a significant difficulty because of non-negligible offsets between the predicted position and the actual observed one. These difficulties made clear that new models are needed, especially those including non-conservative perturbations, such as solar radiation pressure and enhanced drag modeling. Different BRDF models have been proposed in connection with a six degree of freedom shape dependent modeling. Although the models were inspired by the information form observations (or the significant lack of those), the loop back to the observations was almost never closed. The question remained open, how and to which extend do those new models influence the observation interpretation, and how do we discriminate between the different proposed models. The lack of closing the loop back to the observations has two different origins. For one, astronomic research is genuinely plagued with the old difficulty, that active experiments are not possible, but only observations. With the realization of the high amount of coupling between the different perturbations, standard observation methods that were used for e.g. simple orbit validation (smaller offset between prediction and new measurements) in a few random cases are not sufficient any more. The increased complexity poses different dimensions to the observation and data validation problem, which have been unknown to the field previously, such as the questions of different time scales and direct indirect observations. This makes clear that a new more rigorous approach to the model validation problem is needed in order to cope with the new difficulties. The investigation that is needed for the mediating step between observations and simulation/theory is tied to the concept of observability.

The problem of observability of space debris, can only be addressed by taking into account the higher dimensionality of the problem. The classical state of position and velocity of the center of mass needs to be expanded not only to attitude parameters (e.g. Euler angles, quaternions), but also shape and reflection parameters in the different wavelength bands. The dimensionality of the shape parameters is not easy to decide, it depends highly on the specific object. For a sphere, it can be reduced to two, the indicator for the shape and the radius, with more complex shapes, it can take on many more dimensions. Hence, the dimensionality can easily reach very large numbers. A middle way is to use simple predefined shapes, such as planes, cylinders, spheres and parabola

and their orientation and places relative to each other, to map together the shape of the object, depending on the shape, including possible antenna e.g. still high dimensionality is reached. The reflection parameters are coupled to the shape parameters, that for each defined (sub-)shape, at least one reflection parameters is needed in the simplest case, when defining a so-called albedo, or three defining a Lambertian reflection, specular reflection and absoprtion coefficient. More elaborate models are using bidirectional reflection distribution functions (BRDF), which normally has four dimensions. Additionally, one might have to include indication parameters for the amount of secondary reflections and emission.

But expansion of the state is unavoidable in order to correctly represent the space debris problem. However, the higher dimensionality of the input state, almost necessarily leads to an unobservability of single quantities in a control theoretic sense. In order to remedy this, a non-static consider-type approach for the extended state is used. Consider analysis has been introduced for Kalman filters to account for errors in both the dynamic and measurement models due to uncertain parameters. The consider Kalman filter analysis has been proven to be useful in cases of low observability and limited computational powers. With a certain type of measurement, not all dimensions of the state x are observable, although they all contribute to the measurement result. Whereas the classical consider approach, parts of the state is more or less kept fixed, the approach here is slightly different. Some parts of the state are indeed treated as classical consider parameters, e.g. such das the position and velocity in a characterization measurement. They do not need to be observable, but are assumed to be known to a certain confidence level. Depending on the sensor and measurement type the remaining parameters are grouped together in batches to represent one observable quantity . As an example shape, reflection and attitude in light curve measurements. This reduces the dimensionality of the state. As we are taking different sensors in different observation scenarios into account, the split in consider parameters and the grouping together of different state parameters into one is no fixed and static. But in different types of measurements, the batches will contain different variables, and different parameters are serving as batches. In the combination, a large portion of the state can be made directly locally observable in the superposition of different sensors and measurement types.

In this paper the simulations of space object trajectories and attitude motion are generated and the observability of different model parameters in astrometric optical observations and light curve measurements is shown.