69th International Astronautical Congress, Bremen, Germany. 1-5 October 2018.

IAC-18-A6.9.7

Using Conjunction Analysis Methods for Manoeuvre Detection – Application to Optical Observations

Johannes Herzog[a*], **Hauke Fiedler**[b], **Thomas Schildknecht**[c], **Andreas Hinze**[d]

[a] *German Aerospace Center, Münchener Straße 20, 82234 Weßling, Germany, Johannes.Herzog@dlr.de*
[b] *German Aerospace Center, Münchener Straße 20, 82234 Weßling, Germany, Hauke.Fiedler@dlr.de*
[c] *Astronomical Institute, University of Bern, Sidlerstrasse 5, 3000 Bern, Switzerland, Schildknecht@aiub.unibe.ch*
[d] *German Aerospace Center, Münchener Straße 20, 82234 Weßling, Germany, Andreas.Hinze@dlr.de*
[*] *Corresponding author*

Abstract

Detecting manoeuvres of satellites in a database is an issue to keep those objects in the database instead of having multiple instances. Those multiple instances may occur because manoeuvres lead to difficulties in the object identification and orbit determination process. Efficient manoeuvre detection helps reducing the number of duplicate objects by connecting orbits after a manoeuvre to those before.

This work is based on an earlier study where methods traditionally used for collision probability estimation were used to identify manoeuvres. It was possible to calculate a "collision probability" of two osculating element sets, representing two pseudo-objects, and therefore to decide whether a manoeuvre took place. Furthermore, by scanning the interval between both osculating epochs, e.g. calculating one collision probability for each time step, it was possible to estimate the manoeuvre epoch, too.

In the transistion to optical observations, the distribution of observations of the satellites of interest to determine orbits of sufficient quality is an open issue. One has to find a compromise between dense observation distribution and not focussing solely on that topic. Otherwise, the telescop may be blocked just for that one project, without being intended to. In this study, we compare the former observation strategy to the upcoming one.

The satellites are identical to those of the previous study, being Meteosat−8, −9, −10, and −11 operated by EUMETSAT. The optical observations are planned for the telescope network SMARTnet™. Due to the geostationary orbits of the satellites, the only affected telescopes of the network are in Sutherland (South Africa) and Zimmerwald (Switzerland), respectively.

1. Introduction

In the sense of maintaining a database of objects, identifying manpeuvres is an issue. Otherwise, it might be possible that multiple instances of the same objects are stored. These multiple instances are the result of deviations between the orbital elements before and after the manoeuvre, respectively. These deviations may lead to problems in the identification process and observations after the manoeuvre are not filtered to the correct object, but instead stored as a new detection.

To minimise - or ideally to avoid - those wrong "new" detections, criteria have to be found to conclude that two orbital element sets belong to the same object and the reason for the deviation is a manoeuvre.

In a precursor study (see [4] for details), operator data in form of state vector together with SRP coefficient and satellite mass were taken from the satellites Meteosat−8, −9, −10, and −11. These satellites are operated by EUMETSAT and orbital elements are published on a weekly basis ([2]).

Although orbit determination software may be equipped with a module to estimate manoeuvres, the results of the manoeuvre detection analysis may be used to adjust the estimation parameters.

1.1 Manoeuvres as a special Kind of Collision

At the manoeuvre epoch, a satellite changes its orbit. The elements for both orbits are given. We can now define one pseudo-object on each orbit, propagate the positions to the same epochs, and calculate an "encounter" probability. At the manoeuvre epoch, the "encounter" probability should reach a maxmimum, which will nevertheless not be equal to 1 as orbits carry uncertainties. To achieve information as reliable as possible, the time interval between both osculating epochs is scanned and for each epoch a probability is calculated.

Because the pseudo-objects have similar orbital periods, there will be resonant behaviour, e. g. the "encounter" probability will reach a maximum once or twice an orbital period, depending on manoeuvre type. Therefore another decision criteria was introduced where the values of the highest and the second highest maximum are compared; the ratio is called peak contrast.

The method is described in detail in [4], the contributing formulae based on [1].

1.2 Application to Observations

Although operator data was used in the aforementioned study, the origin of the orbital elements may be arbitrary. Consequently, future analyses shall be performed with observations obtained by the telescope network SMARTnet^{TM}(see [3] for details on the network).

First of all, a suitable observation schedule has to be established in the sense of gathering enough observations for a good quality orbit and leaving enough time for other observations, respectively. It is the intention to fit such special projects into the regular observation schedule, i. e. survey and regular fullow-up observations.

Using an established observation scheduler inside the telescope managing software, objects for follow-up observations are selected internally, which makes it unforeseeable when an object will be observed. Objects may be observed as often as possible throughout the night, but the time interval between to series may be arbitrary. This behaviour is shown in Fig. 1 for the satellite Meteosat−8 between mid of April and beginning of September, 2018. On the x-axis, there is the date of observation where the night began. Epochs (shown on the y-axis) past midnight are also assiciated to that date, hence observations of one night are plotted in a single column. There is no pattern visible, which may indicate a regular distribution tracklets.

Already with this scheduler, the user has some control over the image acquisition, but not as much as with using the optisied scheduling procedure, which is described in the following section.

2. Resulting Orbits

EUMETSAT publishes orbits and schedules manoeuvres once a week (see again [2]). Although, the measurement periods leading to the corresponding orbital elements are not stated, we took optical measurements with an arc length of one week, starting on Mondays. The fact that observations are sparser distributed in some weeks than in others is already visible in Fig. 1. Table 1 confirms this impression where the observation arcs are summarised. When only one series of observation were taken in the period, no arc length is given as it equals the length of the tracklet, which is in the order of minutes.

In the selected 11 periods, there were only six with more than one tracklet, of which three had arc lengths of more than half a week. Compared to the Fig. 1, these results seem representative.

Table 1: Number of tracklets and corresponding arc length in weekly periods

Period in 2018	# of Tracklets	Arc Length (d)
25/6 to 1/7	1	
2/7 to 8/7	26	4.427
9/7 to 15/7	0	
16/7 to 22/7	6	3.316
23/7 to 29/7	0	
30/7 to 5/8	0	
6/8 to 12/8	35	5.436
13/8 to 19/8	16	5.142
20/8 to 26/8	5	1.004
27/8 to 2/9	1	
3/9 to 9/9	3	0.820

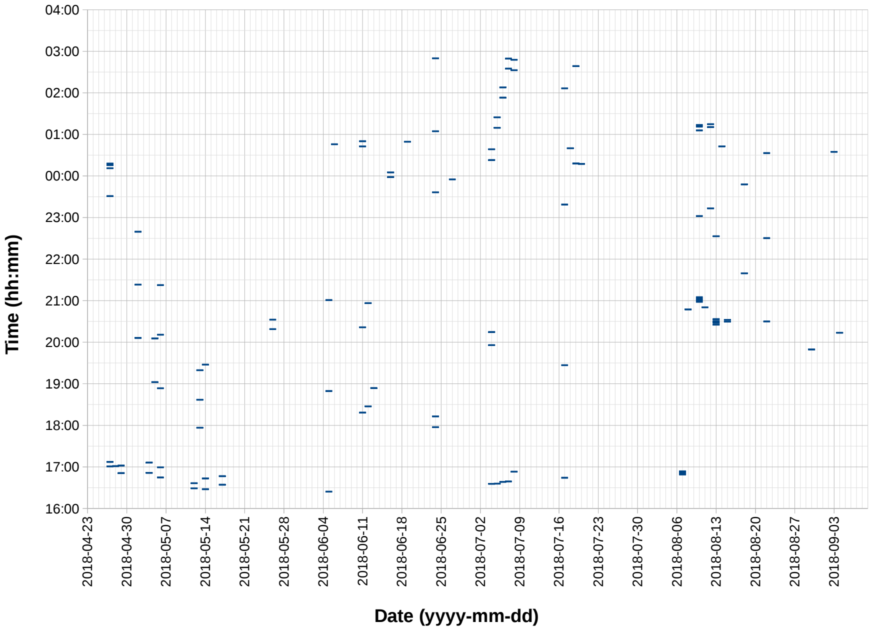

Figure 1: Distribution of observations of the satellite Meteosat−8 (2002-049B)

3. Optimised Scheduling

Based on the first results presented above, the observation strategy had to be re-organised.

3.1 Operation Mode

The scheduler is based on a genetic algorithm to optimise on the one hand the information content of a measurement and on the other hand the detectability of the target object. Furthermore, additional observation requirements may be specified for assigned objects. The first specification is the number of measurements. Observations for these objects are scheduled uniformly distributed over the whole night. The second specification is the frequency of the observations. Finally, if both specifications are set, the observations will be scheduled with the given frequency around the optimal observation time of the target object. Depending on the number of assigned objects not all requirements may be fulfiled but a minimal required time between observations of one target object ensures unique measurements. The entire optimisation procedure is described in [5].

3.2 Meteosat−8 as Example

The boundary conditions for the example satellite Meteosat−8 were: as many as observation series should be performed and time interval between series has to be 30 min. The resulting schedule created with the optimised scheduling method is shown in Fig. 2 for nights of September 10th, 2018 and onwards. For clearity reasons, the scheduled epochs are shown only for the satellite Meteosat−8 (2002-049B). Each square represents an epoch where observations are scheduled. The large gap around 21:00 UTC represents passages through the Earth's shadow, the smaller gap around 00:00 UTC is a close distance to the Moon. No observations were scheduled at those epochs but as close as possible when conditions allowed them again.

In practise, not all observations at these scheduled epochs will be successful, as weather conditions may change thoughout the night. Furthermore, the observation time may be reduced by hardware and software issues, respectively.

The high density of observations serve the purpose of avoiding resonant behaviour in the orbit

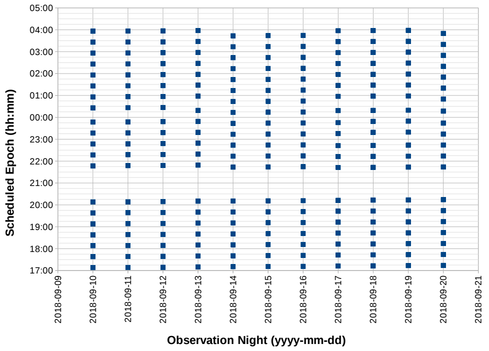

Figure 2: Distribution of scheduled observations of the satellite Meteosat−8 (2002-049B)

determination phase. When a little number of observations is taken and repeatedly around the same time every night, the true anomalies are about the same and the orbit might not be represented correctly. Those critical conditions are only valid for geostationary satellites. Nevertheless, for each orbital region there are conditions, where resonant behaviour may occur.

3.3 Restrictions in the Observation Phase

Having a database of objects, this schedule cannot be performed with all objects trying to detect each and every manoeuvre. The corresponding set up of observation conditions have to be worked out in the observation phase.

To date, due to other important projects, no observations could be taken for this study.

4. Conclusions

This study presented preparatory analyses for observations in the scope of manoeuvre detection based on optical observations. Due to sparse observations based on a former used observation scheduler and resulting orbits of insufficient quality, a new scheduler using optimisation criteria was implemented. Observations will be scheduled according to results of the new scheduler. Start of the observation campaign is assumed to be late 2018.

References

[1] Salvatore Alfano. Relating Position Uncertainty to Maximum Conjunction Probability. *The Journal of the Astronautical Sciences*, 53(2):193 – 205, 2005.

[2] Orbital data. Webpage. Retrieved May 22, 2018.

[3] Hauke Fiedler et al. SMARTnet™ – Status and Statistics. In *Proceedings of the* 68th *International Astronautical Congress*, 2017.

[4] Johannes Herzog et al. Using Conjunction Analysis Methods for Manoeuvre Detection. In *Proceedings of the Seventh European Conference on Space Debris*, 2017.

[5] Andreas Hinze et al. A Sensor Tasking Tool to build-up and maintain a Catalogue of Geosynchronous Space Objects. In *Proceedings of the* 42nd *COSPAR Scientific Assembly*, 2018.