Space Debris Observations with ZimSMART

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ABSTRACT

The Zimmerwald observatory, located about 10km South of Berne (Switzerland), consists of several optical telescopes. One of them, the Zimmerwald SMall Aperture Robotic Telescope (ZimSMART) is best suited for surveying the sky searching for space debris. ZimSMART is used to develop an orbital elements catalogue, i.e. without any a priori information. Two different orbital regions are surveyed: the geostationary ring (GEO) and the Medium Earth Orbit region (MEO). The aim of the surveys of the geostationary ring is a coverage of as much as possible around the celestial equator we can observe from Zimmerwald. Surveys of the MEO region will give a first hint about the population of large-sized, uncatalogued space debris there.

In this paper we will present observation strategies of ZimSMART for building up such a catalogue. The observation strategy for the MEO region differs significantly from that of the GEO region, due to the unique properties of each region. We will discuss survey results which we could obtain, including the catalogue itself, the limiting magnitude of ZimSMART, the fraction of catalogued objects we can observe and their composition concerning different object types. The same analysis was performed for new objects, which were not found in any external catalogue. With the latter we build up our internal AIUB catalogue.

We took in consideration the period between June 9th, 2008 and May 9th, 2011 with 279 nights of observations in total. During this period we used three different set-ups of the telescope alternatively. We could identify 1335 objects of the USSTRATCOM catalogue. Furthermore we detected in total 1598 uncatalogued objects, but those are not all unique objects due to difficulties to connect short orbit arcs with long gaps in between.

INTRODUCTION

The observation facility of the AIUB is located in Zimmerwald, 10km South of Berne (Switzerland). It consists of the ZIMmerwald Laser and Astrometric Telescope (ZIMLAT, est. 1996) and the Zimmerwald SMall Aperture Robotic Telescope (ZimSMART, est. 2006), described below.

ZimSMART Set-ups

Although we perform routine observations, we keep the telescope in an experimental state. Therefore we used three different set-ups of the telescope. First of all we used the "Paramount ME MKS 4000" as mount from 2006 to 2009. It was exchanged by the "ASA DDM85" developed by Astrosysteme Austria and is currently used since 2010. We used two different telescope tubes, which were exchanged in 2009 and 2010. First, we used the "Takahashi ε-180ED" with a diameter of the primary mirror of 18cm and a focal length of 500mm. The resulting field of view is 4° 6' x 4° 6'. The second type is the "Astrosysteme Austria Astrograph ASA12N-OK3 f 3,6" with 30cm diameter of the primary mirror and a focal length of 1080mm. The field of view was 2° x 2°. In 2010 we switched to the first tube again. In the Fig. 1(a) to 1(c) one can see the different set-ups of the telescope.

a) 2006 - 2009 b) 2009 - 2010 c) since 2010

Fig. 1: Set-ups of ZimSMART

ZimSMART Operations

With a field of view (FOV) of 4° 6' x 4° 6' and 2° x 2°, respectively, the ZimSMART telescope is best suited for performing sky surveys in either set-up. The purpose of these surveys is the search for space debris in different orbital regions, on the one hand the geostationary ring (GEO), on the other hand the Medium Earth Orbit region (MEO). Scheduled observations of bright objects (so-called follow-up observations) are also possible, but we do not perform them on a regular basis.

OBSERVATION STRATEGIES

The observation of different orbital regions requires different observation strategies. With ZimSMART we observe that part of the geostationary ring (GEO), which is visible from Zimmerwald, and the Medium Earth Orbit region.

Geostationary Ring

Surveys of the geostationary ring are executed by scanning declination stripes with fixed right ascension. These observations are taken without a priori information of any catalogue objects. The object identification of the observed objects is done in a subsequent step.

Objects of the geostationary ring move with 15° per hour with respect to the celestial background. We defined one declination stripe at one fixed right ascension, which is followed by another one shifted 15° in Eastern direction (cf. Fig. 2). In case of a perfect geostationary object with 0° inclination and no eccentricity, which can be found in a field of the first stripe it will be found again in the second stripe one hour after detection in the first stripe. In reality one cannot expect to find an object at the same position on the frames of the second stripe.

Fig. 2 illustrates the observation strategy for a high inclined object: First, the object is found in the lowermost frame of the stripe (red dot). It is observed one hour later in the uppermost frame of the second stripe. Additionally, the position on the second stripe is shifted to right. This means that the distance in right ascension is indeed smaller than 15°, but alongtrack the object has moved about 15°.

The objects, which can be observed with this strategy, fall into three categories:

1. GEO (geostationary objects): semi-major axis larger than 30000km and numerical eccentricity smaller than 0.1 and area-to-mass-ratio smaller than $0.5m^2 \cdot kg^{-1}$

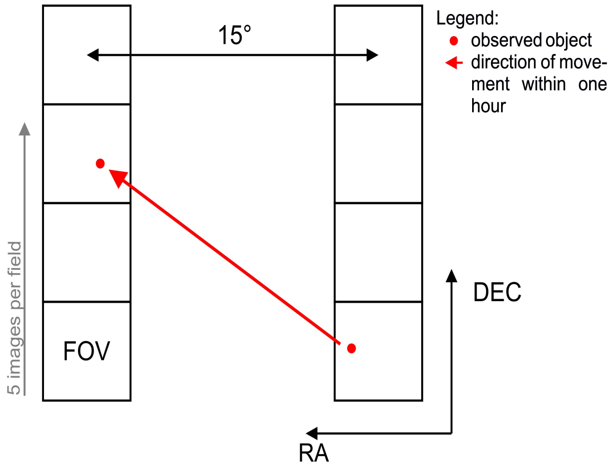

Fig. 2. Observation scenario for GEO surveys

2. eGEO (eccentric geostationary objects): semi-major axis larger than 30000km and numerical eccentricity equal or larger than 0.1 or area-to-mass-ratio equal or larger than $0.5 m^2 \cdot kg^{-1}$

3. GTO (geostationary transfer objects): semi-major axis smaller than 30000km and numerical eccentricity equal or larger than 0.1

When performing observations in this manner it is almost ensured that one observes an object twice a night to allow a first orbit determination, but there are three critical cases to focus on:

1. The object is one hour after crossing the first stripe not yet in the field of view of the second stripe or is currently moving out of one field. This corresponds to a semi-major axis larger than 42164km or an object with an eccentric orbit near its apogee.

2. The object is one hour after crossing the first stripe not any more in the field of view of the second stripe or again moving out. This corresponds to a semi-major axis smaller than 42164km or an object with an eccentric orbit near its perigee.

3. The object has moved out of the stripe in Northern or Southern direction. This corresponds to an object with an inclined orbit.

There are five images taken for each field within the stripes. If the same object is detected on at least three images a tracklet will be produced. It contains the observing epochs, positions in right ascension and declination and apparent magnitudes.

Medium Earth Orbit Region

According to simulations of explosion populations in MEO regions, see e.g. [1], space debris objects are approximately in the same orbital plane as the satellites they stem from. The orbital elements, which differ the most from the orbit of the parent object, are the inclination i and the right ascension of the ascending node (RAAN) Ω. It could be shown that more than 90% of the explosion population have an inclination within 2° around the inclination of the parent object and a RAAN within 7° around the RAAN of the parent object.

We decided to observe orbital planes of satellites of different Global Navigation Satellite Systems (GNSS), e.g. GPS, GLONASS or Galileo (represented by the test satellites GIOVE-A1 and GIOVE-B). Firstly, we chose one orbital plane and define so-called pseudo-objects. The orbital elements of these pseudo-objects are equal to the parent objects, except of the eccentric anomaly E. The value of E was varied between 0° and 360° to get a homogeneous coverage of the orbital plane. For the ZimSMART surveys the eccentric anomaly was varied in steps of 4° from 0° to 356°. Then Two Line Elements sets (TLE) of the pseudo-objects and the corresponding ephemerides were calculated. The computed coordinates and the velocities were used for the observations. This method is called ephemerides tracking. Each field which is visible during a night is planned and tried to observe. Our zero hypothesis is that the chosen GNSS object appears in one field, which is tested to ensure the survey strategy and detection algorithm works properly. Again, five images per field are taken and if the same objects is detected on at least three images a tracklet will be produced.

For observations of MEO, the following critical situations occur: objects with slightly different orbital elements will also move out of the field, but maybe found later on in a neighbouring field. Differences in inclination are more critical than for GEO survey observations, because we do not define any fields in crosstrack direction.

When each of the 90 pseudo-objects are observed multiply, the orbital plane is changed. Following our hypothesis that space debris stay in the vicinity of the orbital plane of the parent object, we select one GNSS object as the reference for each single orbital plane. The number of orbital planes varies for the different GNSS systems: GPS has six and GLONASS has three and Galileo (represented by the test satellites GIOVE-A1 and GIOVE-B) has currently two orbital planes.

OBJECT IDENTIFICATION PROCESS

After taking observations and extracting tracklets, one has to identify the observed objects. We perform the process in three steps: first, we correlate each tracklet of the night with the USSTRATCOM TLE catalogue and an internal AIUB catalogue via positions and velocities. For each observation epoch there are positions and velocities computed for each object in the catalogue. The objects, which fit most probable, are listed. The complete procedures are described in detail in [2].

In the second step, the leftover tracklets are tested pairwise to check if some of them belong to the same object. If the case, they are stored as combined tracklets. Tracklets, for which no other fitting tracklet could be found, remain single. This procedure reduces the amount of computations in the following step.

In the last step of the object identification process we compare the orbital elements of objects in our internal catalogue with those of the new combined and single tracklets. This method is very effective for newly detected objects with observations of only one night. The correlation via positions and velocities fail in some of these cases. Therefore we take the determined orbital elements of the objects, perform an orbit determination of the new tracklets and compare the resulting elements. The method is described in detail in [3].

The identifications via positions and velocities as well as those via orbital elements have to be confirmed by an orbit determination. Only if the orbit determination was successful we associate the new tracklet with the object.

RESULTS

Between June 9th, 2008 and May 9th, 2011 there were 279 with observations. These stem mostly from GEO surveys, because MEO survey test observations began only in September 2010. Since April 2011, MEO surveys are performed regularly.

Limiting Magnitude Of The ZimSMART Telescopes

The second set-up of ZimSMART was expected to be more sensitive to observe fainter objects than the first and third set-ups. We analysed the apparent magnitudes of the GEO surveys. Fig. 3 shows the magnitude distribution of both telescopes: the second set-up was approximately one magnitude more sensitive than the other ones. In general the distribution of the second set-up is broader, but the maximum of both distributions lies between 11th and 12th magnitude, which is due to the fact that the same population of GEO objects were observed. The broadening is the result of the higher sensitivity of the second set-up of ZimSMART.

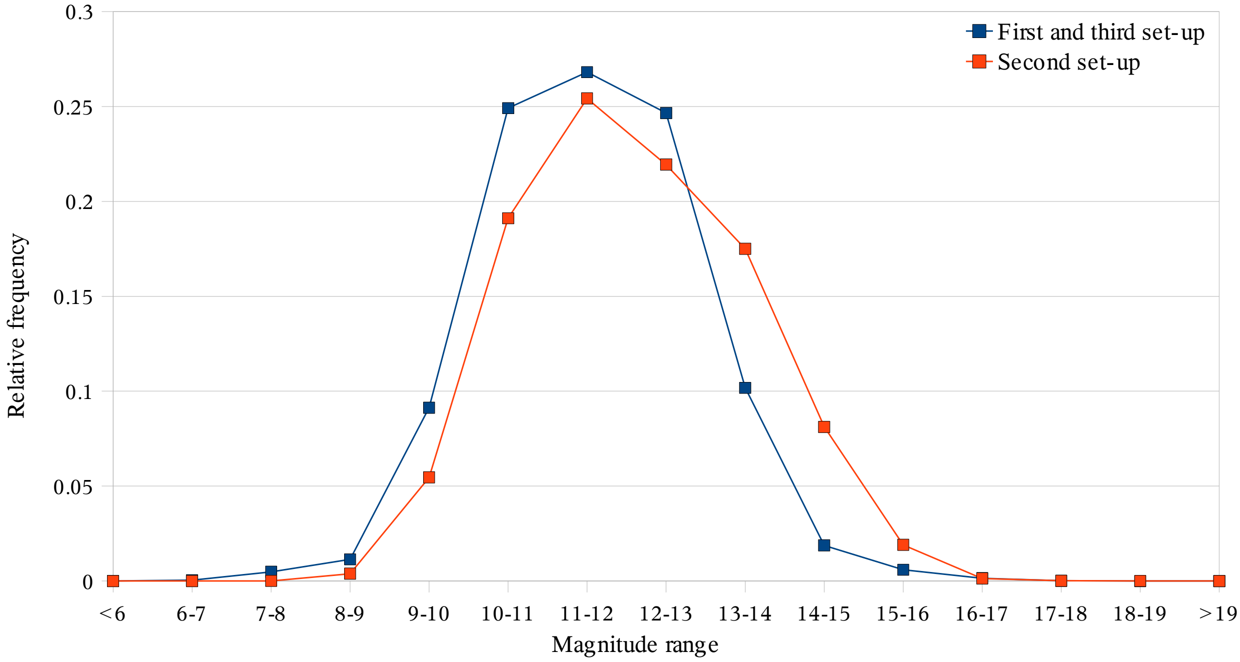

Fig. 3. Magnitude distribution of ZimSMART

Survey Analysis

In total 63743 tracklets could be extracted from the observations of that period. After the identification process via positions and velocities there remained 10612 uncorrelated tracklets, which equates to approx. 17.2%. After the complete identification process via positions, velocities and orbital elements the amount of uncorrelated tracklets could be reduced to 5494 tracklets (≈8.9%).

We could identify 2973 objects, which consist of 1335 objects of the USSTRATCOM catalogue and 1638 of the internal AIUB catalogue. The latter are most probable not all unique objects. A firm association is impossible when the gaps between the observations are too long to fit a suitable elliptical orbit.

Geostationary Ring

The internal AIUB catalogue consists of objects which are visible from the Zimmerwald observatory. These objects consist of the following object types (Fig. 4): 1098 geostationary objects (GEOs), 256 eccentric geostationary objects (eGEOs), 237 geostationary transfer objects (GTOs).

Medium Earth Orbit Region

We detected seven objects of the Medium Earth Orbit region (MEOs), which could not be correlated to USSTRATCOM objects, because of uncertain TLEs. Some time after the detection the TLEs were updated. New observations were correlated to the USSTRATCOM object again.

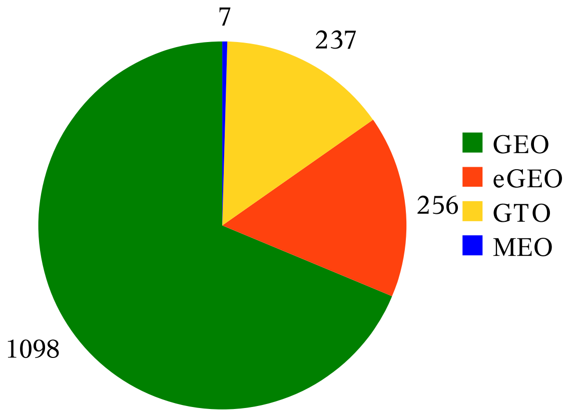

Fig. 4. Object distribution of the internal AIUB catalogue observed with the ZimSMART telescopes

CONCLUSION AND OUTLOOK

In this paper, we wanted to analyse on one hand the limiting magnitudes of the two telescope set-ups and on the other the possibility of building up a catalogue of space debris objects in the GEO and MEO region. We used different survey strategies for GEO and MEO objects, respectively.

The limiting magnitude of the first and third set-up of ZimSMART was estimated to be around 14^{th} magnitude, the one of the third set-up to be approximately 15^{th} magnitude.

In total we could extract 63743 tracklets, from which 91.1% could be correlated to already catalogued objects or combined to new objects.

We observed 1335 objects of the USSTRATCOM catalogue and detected 7 objects in the MEO region. Those are probably already in the USSTRATCOM catalogue, but due to too uncertain TLEs they could not be identified. We also could observe 1638 objects of the internal AIUB catalogue, but those are most like not unique. Due to large gaps between observations orbit determinations fail.

The orbital planes of the MEO surveys will be exchanged systematically when enough images of each frame was taken.

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