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IAA-CSIC CAPABILITIES FOR SPACE SURVEILLANCE AND TRACKING

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RESUMEN

Space Surveillance and Tracking (SST), como parte las actividades del programa *Space Situational Awareness (SSA)*, tiene la tarea de detectar y predecir el movimiento de basura espacial en órbita alrededor de la tierra. Los datos generados por SST podrán ser usados para proteger de forma activa la infraestructura espacial, como saltélites de observacion de la tierra o sistemas de navegación, ante el riesgo de posibles colisiones con cualquier nube de basura espacial. En este artículo presentamos las capacidades del Instituto de Astrofísica de Andalucía (IAA-CSIC) para participar en SST, describiendo las características y el estado actual de los sensores que el IAA-CSIC tiene disponigles para dicho programa.

ABSTRACT

Space Surveillance and Tracking (SST), as a part of the Space Situational Awareness (SSA) programme activities, has the task to detect and predict the movement of space debris in orbit around the Earth. The data generated through an SST system can be used to actively protect space-based infrastructure, such as Earth observation satellites or navigation systems, from colliding with the ever-increasing cloud of man-made space debris. This paper shows the current Instituto de Astrofísica de Andalucía (IAA-CSIC) capabilities for SST, describing the features and current status of the sensors that are available in the IAA-CSIC for this program.

Key Words: methods: observational — space vehicles

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Editors: M. D. Caballero-García, S. B. Pandey, D. Hiriart & A. J. Castro-Tirado

1. INTRODUCTION

The Instituto de Astrofísica de Andalucía (IAA[2]) belongs to the Consejo Superior de Investigaciones Científicas (CSIC) in Granada (Andalucía, Spain). The activities of the IAA-CSIC are related to research in the field of astrophysics and the development of instruments for ground-based telescopes and space vehicles.

The Institute operates the telescopes installed in the Sierra Nevada Observatory (OSN[3]) and jointly with Max Planck Institute for Astronomy (MPIA), the Calar Alto observatory (CAHA[4]).

2. THE OBSERVATORY OF SIERRA NEVADA

The OSN is an astronomical facility located at the Loma de Dílar, at the Sierra Nevada (Granada, Spain). It is located 2935 m above sea level, at 37° 03′ 46.41″ North, 03° 23′ 09.75″ West. Since 1981, it is operated and maintained by the IAA-CSIC.

Site testing studies (Aceituno J. et al 2002) are carried out periodically since 2002 with a Differential Image Motion Monitor (DIMM) installed in a telescope. Last results obtained[5] in 2012 yielded a median V-band seeing of 0.61″, with a mean of 0.69″. In that run, the fraction of nights with a seeing below 0.7″, between 0.7″ and 1.09″ and between 1.10″ and 1.69″ was of 60.3%, 34.5% and 5.2%, respectively.

2.1. *Telescopes and sensors*

The observatory is equipped with two main telescopes, the 1.5 m (T150) and the 0.90 m (T90). Under final contruction is the BOOTES-IR (Castro-Tirado et al. 2005), a robotic altazimuth telescope with a 60 cm mirror (T60) that can slew rapidly while carrying heavy instrumentation at the Nasmyth focus. Its operation and routine observations are expected to begin within the next few months. Additionally, there are a small 35 cm (T35) telescope and a seeing telescope located at dedicated buildings next to the observatory.

OSN is fully equipped with a wide equipment set, including a residence, a weather station with redundant sensors, a liquid nitrogen generation system, an emergency power generator support for possible electric grid failures, a snow groomer vehicle and a radio link for communications with the IAA headquarters.

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[2]`http://www.iaa.csic.es/`

[3]`http://www.osn.iaa.es/`

[4]`http://www.caha.es/`

[5]`http://www.osn.iaa.es/sites/default/files/docs/tel/datos_caracterizacion_2012.pdf`

2.2. *T150*

The T150 has a Nasmyth-Cassegrain f/8 optical configuration with an aperture of 150 cm. The scale of the focal plane is 17.19″/mm. The operation of the T150 is based on a telescope control system (TCS) developed and maintained by IAA. Additionally, a set of ASCOM (AStronomy Common Object Model) drivers exists, which allow the control of the telescope using `TheSky` and `MaxIm/DL`, a set of commercial control tools for `Windows` with a nice and user friendly interface.

The T150 is equipped with a direct imaging CCD on the east Nasmyth focus and a spectrograph (*Albireo*) on the west Nasmyth focus. Currently, the spectrograph is being refurbished and will have a Gaia RVS (Gaia Radial Velocity Spectrometer) grating to work as a follow-up instrument for observations made with the GAIA mission (Perryman et al. 2001).

The CCD is a 2k x 2k Marconi CCD42-40 scientific grade, back illuminated, with a 13.5 μm pixel and a scale of 0.23″/pixel. The FOV of the detector is 7.92′ *x* 7.92′ . The camera is provided with a filter wheel of six positions, and several sets of filters are available: Johnson, Stromgren, Gun, Molecular, Hα and Cometary.

2.3. *T90*

The T90 has also a Nasmyth-Cassegrain f/8 optical configuration with an aperture of 90 cm. The scale of the focal plane is 28.65″/mm. For the operation of the T90 the same TCS developed for the T150 is used. And equally, a set of ASCOM drivers exists, which allows the control of the telescope using TheSky and MaxIm/DL software tools for Windows.

The T90 is equipped with a direct imaging CCD on the the west Nasmyth focus. The east focus is equipped with a Strömgren photometer for simultaneous observations of the bands *uvby*, and bands *n* and *w* of the Crawford *Hb* photometric system.

The CCD is also a 2k x 2k Marconi CCD42-40 scientific grade, back illuminated, with a 13.5 μm pixel and a scale of 0.38″/pixel. The FOV of the detector is 13.2′ *x* 13.2′. The same set of filters of the T150 CCD are available for this CCD.

3. CALIBRATION CAMPAIGNS

In order to know the performances and feasibility of the OSN main telescopes (T150 and T90) as potencial sensors for the ESA's (European Space Agency) SST segment activities of the SSA program, we carried out two calibration campaigns. These campaigns were also intended to ensure the quality of the observations and the compliance of all integrated systems regarding observation data format, reference and time frames and observable computations. The outcome of the analysis will be the basis for the proposal on required enhancement of sensors to ESA.

TABLE 1

OBSERVATIONS @ T90 (2nd campaign)

Object	#Measures[a]
Navstar56	101
Navstar62	88
Navstar69	99
Navstar71	98

[a]Number of measures in a 15min run

The campaigns were focused in the tracking mode of the SST program, mainly because initially the tracking mode is much less ambitious than the surveillance mode. During these campaigns, we observed a set of objects in Geostationary Earth Orbit (GEO), one of the most valuable regions for telecomunications, Earth observation and space science. In a first campaign during six shared nights on May 2015, we observed some communication satellites: EUTELSAT 36B/9A, Hotbird 13C and the GPS satellite Navstar 66 with the T150 and the T90 telescopes. In this campaign of preliminary system tests, we focused on the training for the observation procedure for this kind of objects. Once we had learnt the observation procedure and had the requirements for a typical SST tracking request, we proceeded with the second campaign for one night in September 2015 with the T90 telescope; in particular the following GPS satellites were observed: Navstar 62, 69, 71, 56. In Table 1 we provide a detailed list of the observations.

3.1. *Observing requirements*

The calibration process for the second campaign consisted in only 1 hour of observations, scheduling it for the first part of the night when the four Navstar satellites were observable. Those four GPS satellites had to be observed for 15 minutes each. If one of them would have failed for its full interval, the sensor should have escaped at the scheduled time and move to the following one to try to follow each one inside the precise ephemeris.

In summary, the observation requirements for the SST tracking observations were the next ones:

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- 4 objects observed in the assigned time interval (15min)
- Minimum 25 observations per object
- Minimum 100 observations of the four objects
- Repositioning time between object less than one minute
- Random error in the observations below ±0.010 seconds (systematic bias can be compensated though)
- Delivery time after last observation below 12 hours
- Astrometric accuracy of observations below 1 arcsec for 95% of the observations (2 sigma)
- Photometric accuracy: 1 mag

3.2. *Observational procedure*

With the telescope in sidereal tracking, the observation procedure carried out was focused on the collection of at least 25 images (as quickly as possible due to the high speed of the objects) in order to get accurately the astrometric position of the tracked object. The procedure was as follows:

1. Get the updated TLEs (Two-line element) from `CelesTrak`[6]
2. Add the TLEs to `TheSky` catalog
3. Point the telescope to i-object
4. take around 6-8 measures (0.1 s exp time + 1 s for readout)
5. re-center the telescope to the *i-object*
6. Repeat 4) and 5) until number of measures > 25
7. Go to next object

3.3. *Data processing*

As a first approach, all the data was processed interactively using the `Astometrica` software tool (Herbert Raab, 2002). The data processing consisted in doing the bias subtraction and flat-fielding of the images. Then the astrometric calibration of each image was done, identifying and selecting interactively the moving object being tracked. Because this processing procedure should not be the normal run for a SST telescope, a dedicated data processing pipeline had to be implemented. As a result, we produced a text file in a HUN format (suggested by DEIMOS Space) with columns providing some fields like: object identifier, date and UTC, right ascention, declination, apparent magnitude and filter, observatory and telescope code, flag indicating problems in the observation (if any), Signal to Noise Ratio (SNR) against background, limiting magnitude of the image and Full Width Half Maximum (FWHM) average of the sampled stars in the image in arcsec.

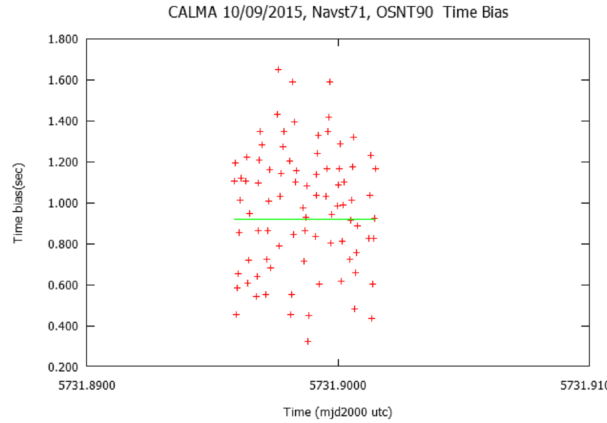

Fig. 1. Estimated time bias for Navs71.

4. DATA ANALYSIS

Once we obtained the processed data in HUN format, we proceeded to send them to DEIMOS, the company that collaborated with us for the calibration campaigns and carried out the data analysis of the observations.

4.1. *Analysis of Navstar71 Observations*

Observations of this satellite were selected for the first evaluation. This is the satellite showing better observation geometry. The astrometry data provided by the sensor was entered into DEIMOS CALMA tool. We noticed that no correction for annual aberration was applied since a non null cross-track error was found. This correction is normally considered when observing objects orbiting the Earth. Once this correction was applied, we proceeded with the analysis. A clear bias in time was observed (with an average around 0.9 seconds). From the analysis of the next satellite, the bias is considered to be between 0.9 and 1 second, as shown in Figure 1.

Once this bias in time was applied, the observations showed a better distribution in the radial direction, as shown in Figure 3. However, large errors were observed in position (up to 3000 m) and its error showed a very large dispersion.

This was derived from the large dispersion in the time error as observed in Figure 4 . It can be observed that the dispersion in the time error shows a large variability (0.6 seconds) which should be avoided. These errors in the time tagging produce

[6] `https://celestrak.com/NORAD/elements/gps-ops.txt`

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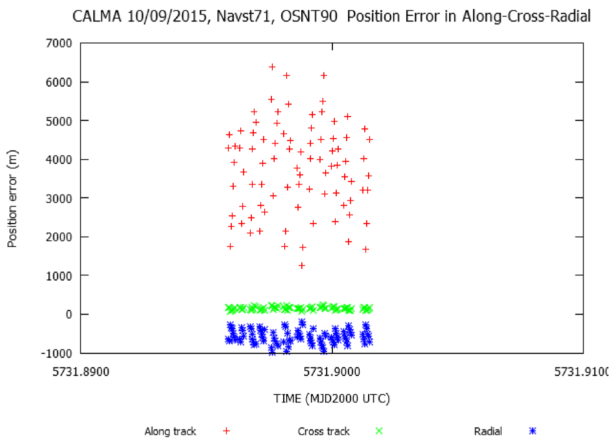

Fig. 2. Estimated position errors.

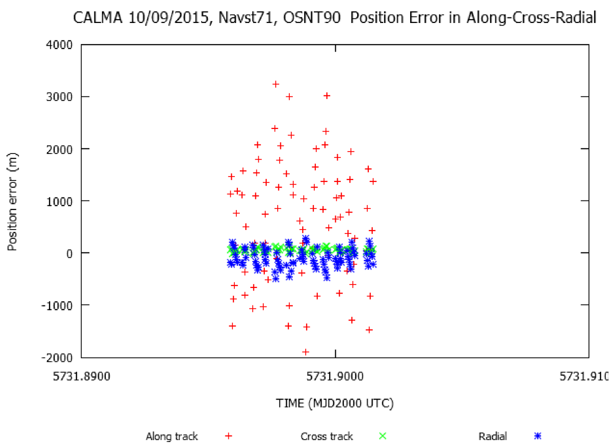

Fig. 3. Estimated position errors after time bias correction.

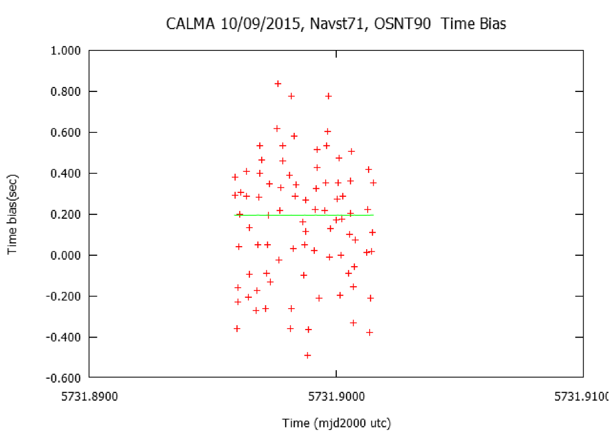

Fig. 4. Time dispertion after bias correction.

about 12 arcseconds error in declination and about 35″ in right ascension. These errors correspond to about 3 km in position. The errors are assumed to be associated to time tagging problems, discarding other issues, as the cross-track component is very

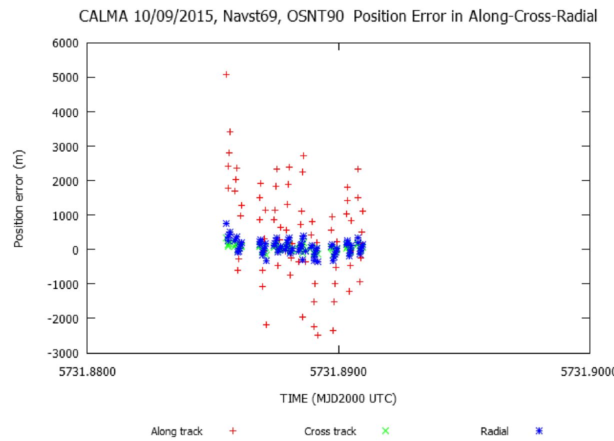

Fig. 5. Estimated position errors after time bias correction.

stable and constrained (100 m). This fact indicates that astrometry accuracy can be very accurate if time errors are corrected.

It must be noted that the measurements are provided with times down to 0.1 second. It is also recommended to improve the format of the time information down to 0.001 second (0.1 second corresponds to around 375 m in position of the satellite). In addition to the expected good astrometry (if we discard the time tag problems), another positive aspect observed in the data files was the number of observations. All of them contained a large number of observations (70-80) within the 15 minutes observation period.

4.2. *Analysis of Navstar69 Observations*

Similar to the former case, aberration correction was needed, and a time bias was found (1 second). It was needed to clarify whether this was a bias or not, since it was not exactly the same as the one observed in the former satellite (although similar). Once this bias was applied, similar results were obtained, although a larger dispersion was found, as shown in Figure 5.

5. CONCLUSIONS

We report the capabilities of the telescopes at OSN (T150 and T90) for the SST program. Once calibration campaigns were analysed by DEIMOS, we concluded that it is recommended to correct the time tagging process to improve the final accuracy. Typical accuracy for this kind of observations is expected to be about 1-2″ with time random errors < 0.010 seconds. Also, it is needed to identify the value of the time bias, by minimizing its error range.

It has been shown to be different in the two analysed cases. Further analysis will be done with additional data for both ensuring the consistency and the review of the results after the application of the processing update.

We can conclude that the telescopes at OSN are in a good position to partipate in the SST program. The next steps will be to focus in the development of a custom observation tool for space debris and a data reduction pipeline for automatic processing of the obtained data.

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