STRATEGIES AND METHODS FOR AUTOMATIC SPACE-DEBRIS OPTICAL SURVEY OBSERVATIONS AND PROCESSING OF THE IMAGES

Nomen, J.[(1)]**, Sanchez-Ortiz, N.**[(2)]**, Guijarro-Lopez N.**[(2)]**, Pina-Caballero, F.**[(2)]

[(1)]*Observatorio Astronomico de Mallorca-La Sagra Sky Survey, 07144 Costitx, Mallorca, SPAIN.*
Email: jnomen@oam.es

[(2)]*Elecnor Deimos, S.L.U. Ronda de Poniente 19, 2º, Tres Cantos, 28760 Madrid, SPAIN.*
Email: noelia.sanchez@deimos-space.com

ABSTRACT

Observatorio Astronómico de Mallorca, conducting the La Sagra Sky Survey and DEIMOS Elecnor S.L.U. have been involved in a co-founded project devoted to testing the operational feasibility of enhanced optical survey-only strategies minimizing the tracking needs to create and maintain a catalogue of high altitude objects. It was also aimed to minimize the routinely human efforts during the nightly control of the telescopes and particularly to avoid manual steps when processing of the images for delivering the astrometric measurements of the detected objects. This paper is focused on this second topic, to show some of the strategies and the robotic capabilities of the La Sagra telescopes and the processing tools for automatically detecting and delivering accurate measurements. Traditionally, these steps require humans in the loop, carrying out repeated tasks, making all the process non-practical and expensive when the aim is not an experimental campaign but to produce a regular service.

1 DEVELOPED AREAS

The cumulated OAM-LSSS experience and the developed tools after surveying asteroids and Near Earth Objects during the last 15 years have been progressively applied to the space debris optical observations. Recently and together with DEIMOS Elecnor, the efforts have been focused on their adaptation and improvement on three main -related to the observations-fields: Scheduling observations, Control of the telescopes and Processing of the images. However, any development on these fields might consider and should be built in accordance to the previous design of the suitable survey observing strategy for detecting and cataloguing some defined orbital populations. The following sections describe some relevant issues concerning those areas from the practical observing point of view.

2 DESIGNING OBSERVING STRATEGIES

Designing the observing strategy is the first step, and is involved with all the scheduling-observing-processing chain. Each precise observing strategy requires not only the definition of the optical telescope features and its operation: kind and number of sequences, tracking speed, gaps and exposures, but particularly deep changes in all the processing of the images software. Strategies based on 3 or more track detections, or the angular speed gaps of the planned detectable space debris regimes, or the sidereal / earth / targeted telescope tracking chosen, among others, are requirements that imply to adapt or modify many of the processing software routines.

Fig. 1 shows some advantages and inconveniences according different strategies based on 3 or more tracks, and how the processing filters might be adjusted in order to avoid too many false detections / omissions.

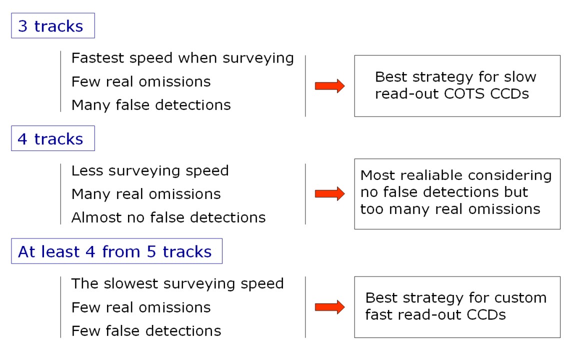

Figure 1. Strategies based on 3 or more tracks

Fig. 2 shows two survey strategies based on different tracking speeds: Earth fixed fences (top) and dynamic shrink-back sidereal fences (bottom). Shrink-back performs more sky coverage and much more detectable orbital regimes, but reaches less limiting magnitude compared with the Earth fixed fences. The processing of the images software needs to be adapted according each particular telescope tracking.

Some of the survey strategies designed by OAM-LSSS and DEIMOS Elecnor [1], [2], have been tested on the 3 survey telescopes that OAM operates at La Sagra. These strategies usually work with all 3 telescopes pointing at

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different longitude regions, sweeping consecutively declination fences from East to West as the night runs, trying to reach the best phase angle. Fig. 3.

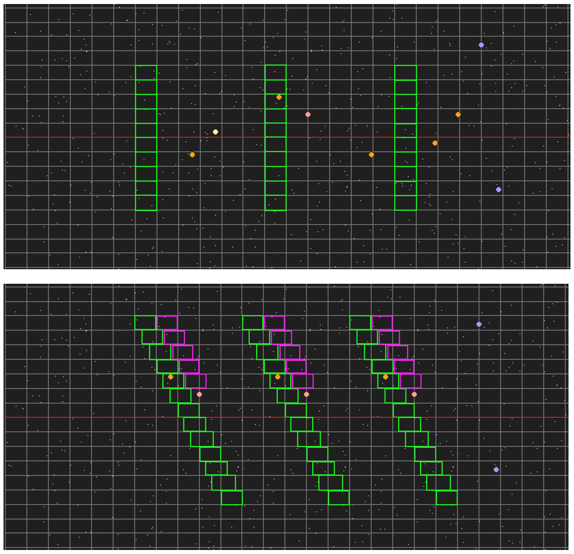

Figure 2. Two survey strategies by 3 OAM telescopes

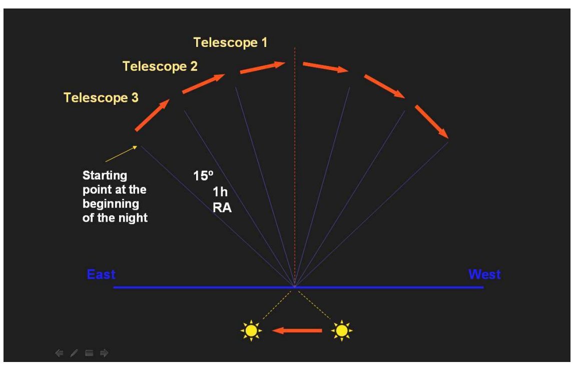

Figure 3. East-West coverage along the night

3 SCHEDULING OBSERVATIONS

Meteorological and seeing constraints make difficult to automatically schedule observations under a regular survey service. This is the only step on which a last human decision is convenient, particularly when assessing if it is worth to start to observe under not optimal or uncertain sky conditions and when there are partially cloudy nights. Any attempt trying to schedule automatically observations based on a weekly forecast or even after some current quality meteorological parameters as maximum wind speed, % humidity, seeing FWHM or % of clear skies, is affected sometimes by fast variations. Only taking advantage of every available gap among the clouds and conditions or during a first or second part of a night may provide the most performing system with more data and better distribution along the year. On the contrary, some nights flagged at the beginning as not suitable could be very useful some hours later.

The OAM-LSSS scheduler tool is a manual graphical editor, in which telescope's tasks are programmed the same afternoon-evening or even during the same night by the operator, after assessing the sky quality and the immediate expected forecast, and considering other back-up alternatives for those not optimal for survey sky conditions as shifting for timing calibrations, requested observations or priority targeted follow-up.

Fig.4 shows part of the OAM-LSSS graphical scheduler editor: a Mercator projection of the sky is plotting some examples of vertical fences and mosaics. It is centered on the local sidereal time at mid night.

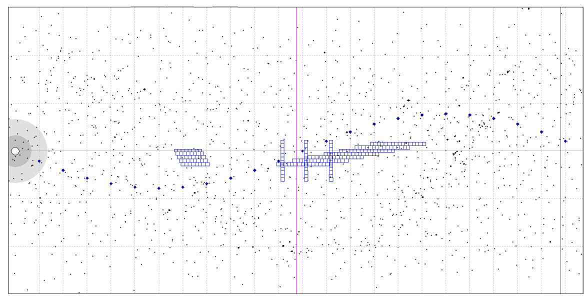

Figure 4. OAM-LSSS graphical editor scheduler

4 CONTROL OF THE TELESCOPES

This is a fully robotic procedure, which also includes other operational ways as manual, automatic, local and remote control. The telescopes follow the nightly tasks written through ASCII files created by the scheduler and uploaded locally or remotely to each telescope computer. Most of the time the telescopes are slewing and taking images, however also they are carrying out other more "intelligent" actions as re-focusing, re-synchronizing coordinates, auto-guiding, taking auto-masterflats, cancelling operations if bad sky conditions, etc.

Fig. 5 clarifies some expressions: "robotic" is a commonly in fashion word for wrongly describing sometimes a telescope that is simply operated remotely through internet. The telescopes at OAM-LSSS can be operated in all these ways.

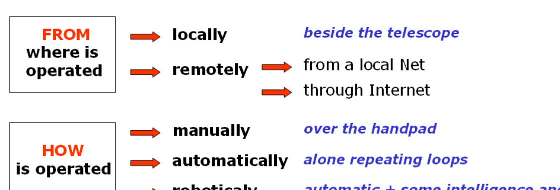

Figure 5. Telescope operations

5 PROCESSING OF THE IMAGES

This is a crucial step on the chain. It is not too complicated to take thousands of images each night on the sky by the robotic telescopes but not so simple to detect and extract the many moving objects from the raw images every night and produce accurate astrometric measurements in close to real time and with no humans in the loop. Following fig.6 shows all the procedures carried out by the OAM-LSSS automatic processing software.

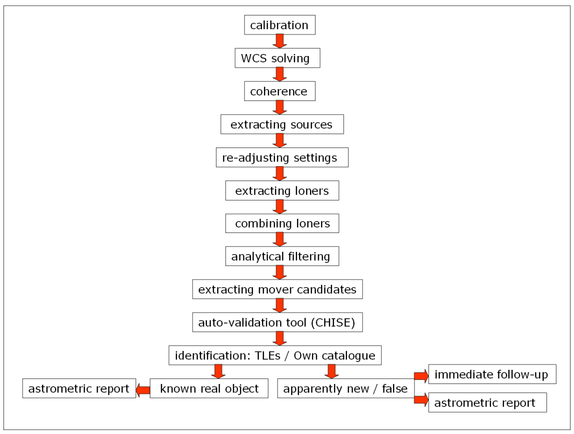

Figure 6. OAM processing software main steps

After calibrating the images by bias, masterdarks, and masterflats, and usually removing background gradients, they are solved by UCAC3 star catalogue and edited their FITS headers with World Coordinate System standards. Images of the same field might show coherence, thus similar background, similar number of stars, among others, before trying to compare among them. At that point, starts all the process for extracting sources, loners and movers by combining them under several filters.

Filters and adjustments are required in order to select from the moving candidates only the most probable real ones. The maximum magnitude gap, the minimum and maximum motion distance, the linear RMS fitting among close loners, the equidistance, the constant speed and few others. Next figure 7 shows a graphical example of some of them under 4 tracks strategies.

Other filters developed by OAM-LSSS as the Expected Trail Matching Tool by medianing the sources and their thresholding binarization are of a great help when the detections are faint and trailed. See Fig. 8. This tool works by medianing the signal of the 3 or more detections of the same moving candidate, and compares the resulting binarized trail with the expected synthetic one (length and angle) generated on the basis of the exposure times and the gaps among the images.

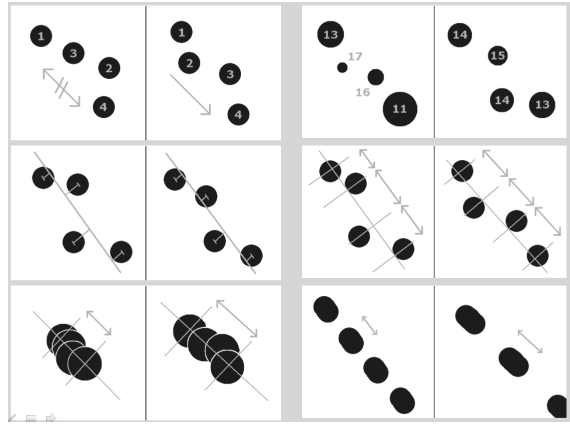

Figure 7.Graphical draft of some filters

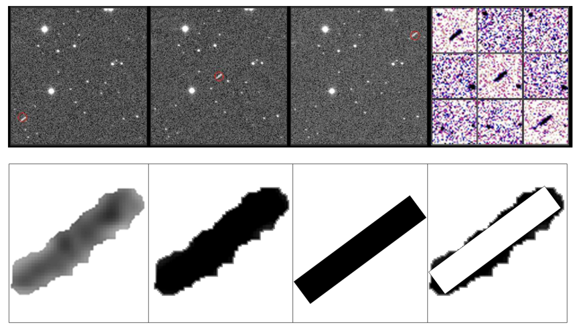

Figure 8. Expected Trail Matching Tool

Night to night and even during the same nights, images are commonly affected by quality variations due to turbulence, stars crowding, background gradients because of the increasing moon glow, sometimes crossing clouds, artifacts, planes or simply reaching less magnitude by poor transparency: Never images look the same, and the processing of the images software requires automatic self-adjusting parameters, in order to filter and being able to extract most of the real moving candidates over the lowest signal to noise ratio according to the current sky conditions, on the contrary thousands of false detections requiring visual validation could make the procedure completely usefulness.

5.1 False Detections versus Real Omissions

Sometimes the auto-detecting routine when processing the images includes some false detections on aligned low SNR stars, or around CCD hot pixels, cosmic rays, or asteroids, or inside “chained trails” or even mixing all these circumstances. Observing in real world these situations happen very often. There is no clear boundaries on the faintest signal to noise detections to 100% assess they belong to a false or real object, even not by visual inspection. Therefore the processing software, which automatically goes auto-detecting and measuring under some defined threshold, always produces false detections and real omissions. Depending on the "detection aggressiveness threshold" adjusted by means of some filters, will go collecting less false detections but implicitly getting more real omissions (not detecting the faintest real objects) or just the contrary, when trying to detect and thus not miss the faintest real objects, with more sensitive adjustments, getting more false detections.

False detections never would be correlated with other tracklets, therefore, they do not represent any risk when computing orbital solutions. Anyway is desirable that the sensor/processing software generates the least possible number of false detections. In the OAM-LSSS system, there is around 1% of false detections when the auto-detections are produced on follow-up targeted observations and never higher than 3% when detections come from survey observations, although after the development of new "intelligent" tools for auto-validate the detections.

5.2 The Auto-Validation tool (CHISE)

The nightly experience demonstrates that the experienced human Eye-Brain combination is the best tool for decide when a very faint signal to noise ratio moving candidate found on a sequence of CCD images is real or false. This visual procedure is usually taken on Near Earth Objects confirmations, however not many NEO candidates are discovered during a given night, on the contrary, thousands of detections of space debris moving candidates are generated by the processing software each observing night and there is no practical way to visually validate all them.

"CHISE", a new software tool has been developed by OAM-LSSS, improved and tuned by comparing same batches of long sequences of very faint SNR detections by experienced OAM-LSSS observers through visual inspection, flagging them as real or false and by the software tool, thus progressively adjusting the tool and making it more "intelligent" when under particular circumstances, as close involvements, blurred shapes, etc, all observers, were in agreement over the nature of one mover candidate but the software was producing the opposite output.

The next fig. 9 shows screenshots of two clear detections extracted from the OAM-LSSS processing pipeline, with a high signal to noise ratio. Both are real. The 3x3 boxes are small parts of the bigger windows on the left, and they compare the same region centered on where the object is found against the other two where is not yet there or moved already away. The real detections should be always centered on upper left – center – bottom right squares but might be away from the other 6 square centers.

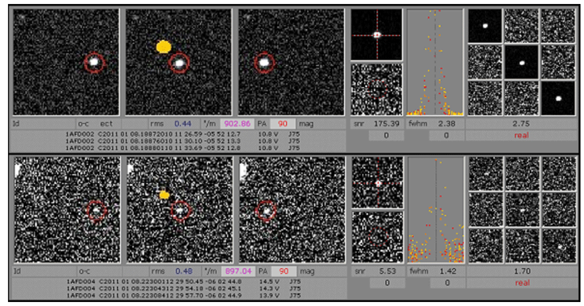

Figure 9. High SNR detections

The following fig. 10 shows very faint detections on the signal to noise border of other 6 examples. OAM-LSSS experienced observers flagged the first upper 4 as real, and later they were confirmed as real too through the TLE catalogue, the last two were false. "CHISE" was tuned until reaching quite similar results than observers, however no sharp boundaries exist on that, so there is always the risk to introduce false detections or the contrary, to get real omissions, particularly after only 3 detections per candidate or what is 3 rounds on the same sky area.

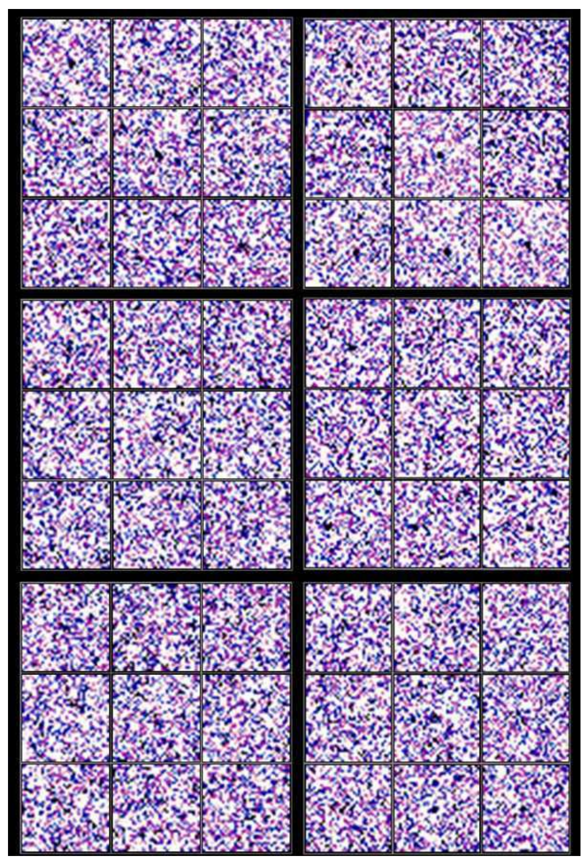

Figure 10. Very faint SNR detections

5.3 Delivered data outputs

Along a regular surveillance service, on where might be expected that the astrometric measurements should be produced by fully automatic means through robotic telescopes and automatic moving detection tools delivering as a final product and within a short delay after the observations a long batch of measurements, the astrometric format might consider and weight the degree of uncertainty of each measurement itself, due to the intrinsically variable behavior of the seeing conditions and the randomized electronic CCD noise, among others, even accepting that an small percent of the measurements could belong to a false detections. Otherwise the limited information contained in each tracklet makes often not possible to automatically rightly identify the corresponding known objects, particularly on satellite clusters, not even able to link several tracklets to a same object at the moment of the observation.

The OAM-LSSS processing software produces its own astrometric format "HUN". One single ASCII line per observation. This format has been created and improved after the nightly use, trying to include all the required and useful data and avoiding useless bytes, columns, and repeated headers, but including together with the measurements, information about the quality and the confidence of the measurements themselves. Moreover the software delivers other outputs shown in fig. 11. Only the weekly/daily schedule file is produced by manual means, all others are automatically generated, requiring only human supervision. Some delivered data shown in colors is shared by the different outputs.

Delivered file	Delivered data	Generation	Period
WEEKLY / DAILY SCHEDULE	Expected forecast 1week/1day before Expected strategy Expected availability of the sensor(s) Programmed particular requested observations	manual	1week/1day before
ASTROMETRIC BATCHES (own HUN format)	MANDATORY COLUMNS Temporary designation / Year / Month / Date and fraction / RA coordinate /Dec Coordinate / Apparent magnitude / Sensor topocentric code OPTIONAL COLUMNS Telescope ident. / Free byte / SNR / Limiting magnitude / FWHM / Mover Speed / Mover angle of motion / Knowledge Status / Probable identification	automatic + supervision	< 24h after observations
METEO FILES	Year / Month / Date and fraction / Temperature / Humidity / Wind speed / Sky status	automatic	< 24h after observations
COVERAGE FILES	SKY COVERAGE Sensor topocentric code / Year / Month / Date and fraction /Center RA / Center DEC / RA FOVº / DEC FOVº / Limiting magnitude INCIDENCES Sensor topocentric code / Key code failure	automatic	< 24h after observations
CALIBRATED CCD IMAGES	WCS solved FITS images with filled headers	automatic	on request

Figure 11. OAM-LSSS delivered outputs

Statistics and plots can be derived by combining the data outputs. The following two charts shown in fig.12 compare the evolution of the seeing quality of the night (FWHM) and the wind speed, which were responsible of the bad quality images at the beginning of the first part of that night (above). The same chart under a more stable night (below)

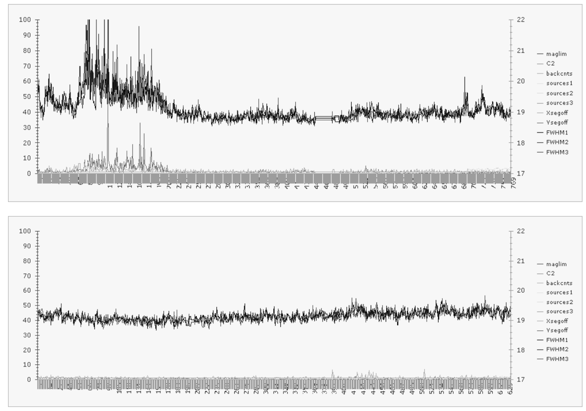

Figure 12. FWHM evolution

Other combined data outputs allow to edit the following plots shown in fig. 13. The western sky surveyed region of one LSSS telescope is plotted on top but was canceled after some crossing clouds (empty not processed and not plotting the corresponding FOV squares), and due to the increasing moon glow (close to full and seen on the eastern sky plot). The second plot shows a complete surveyed night of one telescope under good sky conditions and new moon.

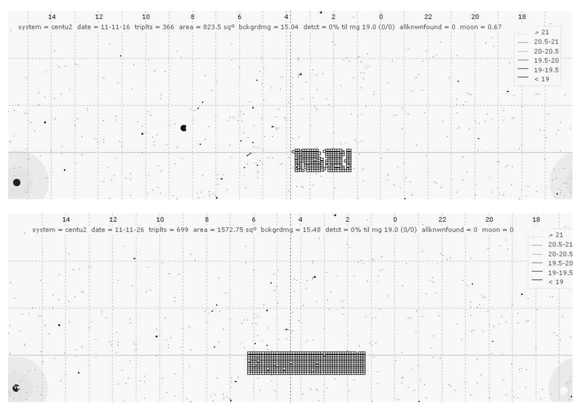

Figure 13. Sky Coverage Charts

6 ACKNOWLEDGMENTS

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7 ABBREVIATIONS AND ACRONYMS

CCD - Charge-Coupled Device
CDTI - Centro para el Desarrollo Tecnologico Industrial
FITS - Flexible Image Transport System
FOV- Field of View
FWHM - Full With Half Maximum
LSSS - La Sagra Sky Survey
NEO - Near Earth Object
OAM - Observatorio Astronomico de Mallorca
RMS – Root Mean Square
SNR - Signal to Noise Ratio
TLE - Two-Line Elements

8 REFERENCES

1. E. Olmedo, J. Nomen, N. Sánchez-Ortiz, M- Belló-Mora, '*Cataloguing capability of objects in GEO ring*', Proceedings of the 60^{th} International Astronautical Congress, Daejeon, Republic of Korea. Paper IAC-09-A6.5.3, 12-16 October 2009

2. E. Olmedo, N. Guijarro, N. Sanchez-Ortiz, J. Nomen, H. Krag, '*Survey only optical strategies for cataloguing GEO and MEO objects in the future*'. Advances in Space Research 48 (2011) 535-556