ESC-TR-96-115

Project Report
STK-249
Volume I

Proceedings of the 1997 Space Control Conference

L.B. Spence
Editor

25–27 March 1997

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LEXINGTON, MASSACHUSETTS

Prepared with partial support of the Department of the Air Force
under Contract F19628-95-C-0002.

Data fusion experiments with metric and photometric observations.

Dick, J., Appleby, G., Sinclair, A., (Royal Greenwich Observatory, Cambridge, UK),
Liddell, P., Seidman, P., (Defence Research Agency, UK), &
Holland, D., (Ministry of Defence, UK).

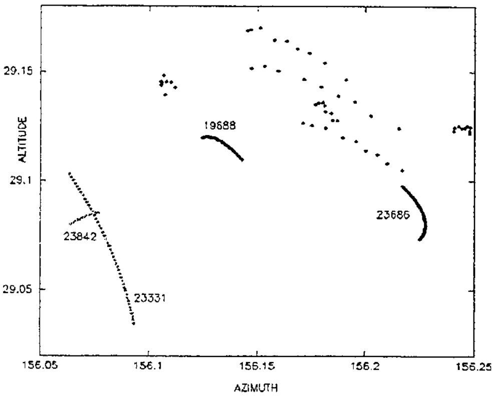
1. Introduction

The UK satellite observatory at Herstmonceux has two telescope systems. One telescope is equipped with a laser-ranger and with a co-mounted optical photometer; the other telescope is used for metric and photometric observations on GEO satellites. These three instruments are used to support in-house research work related to SOI and orbital dynamics.

Currently, part of the site's defence research programme is targeted at providing i) improved matching between ephemerides and observations, or "tagging", for GEO satellite clusters, and ii) a better understanding of satellite optical signatures. Here, we report on our work in these areas, and on our experiments in data fusion.

2. Cluster tagging

Figure 1
Observations and TLE predictions for the Astra cluster, 96-11-09

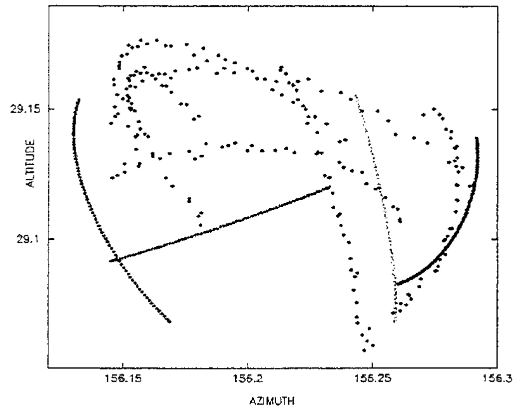


The Astra cluster is a group of six TV-relay satellites in GEO at 19° East, maintained within a box ~0.15° square on the sky. Because it is often difficult with radars to resolve the cluster (with consequent degradation of orbital information) it is useful to observe these satellites optically with consistent tagging. To improve tagging consistency, we have tried two methods: i) precision orbit determination and propagation using in-house code, and ii) linking the metric observations with photometric observations.

The Passive Imaging Metric Sensor (PIMS)[1] at Herstmonceux was used to obtain a series of metric observations of the cluster members on six nights during November 1996. Each night, tracks up to seven hours long were obtained. Figure 1 shows as individual points, the observed positions {*alt*, *az*} of the satellites during the night of November 9/10 compared with their tracks (full lines) predicted using two-line elements (TLEs); SDC numbers are shown next to the tracks. The positions and motions of the satellites are only poorly represented by the predictions, with differences of up to 0.2°; the predicted positions of two of the satellites, Astra 1B and 1C, are outside the bounds of the plot axes. The predictions offer little clue as to the correct identification of individual cluster members, because not only are the predicted tracks offset from the observations, but also the orientations and lengths of the tracks bear little resemblance to any of the observed tracks — this implies that, in particular, the orbital inclinations and eccentricities are poorly determined.

So, it follows that the predictions do not help in the difficult task of tagging of a given satellite from one night to the next, and it is impossible to tag correctly if several days elapse between sets of observations. To address this point, we carried out an experimental orbit determination process for each satellite, in a bootstrap manner, using in-house code[2]. The differential orbit-determination scheme requires initial values of the satellites' state vectors which we derived from the TLEs, noting that for this purpose correct — absolute — identification of each satellite is not required (or possible). Orbits were computed by numerical integration of the equations of motion, using a force model which includes the the gravity field of the Earth, Sun, Moon and planets, and solar radiation pressure.

Figure 2
Observations compared with predictions for four cluster members, 96-11-18



The computed orbits were then compared with PIMS observations from three nights (November 8, 9, 15), when efforts were made to identify the same satellites on the three nights, using plots similar to that shown in Figure 1. The residuals were used iteratively to improve the orbits by adjusting the state vectors, a coefficient of solar radiation, and an empirical along-track acceleration. In this way, observations of four satellites on the first night were identified with observations of the same satellites on the second and third nights, and eight-day orbits were fitted through the data.

The post-solution residual RMS values were about 6", close to the precision of the observations. We found that a single orbit could be fit successfully only to observations of the same satellite; the method identifies the same four satellites over the period November 8-15. We believe that the two sets of observations on each night that could not be fit by computed orbits indicate that those satellites had been maneuvered; all attempts to fit orbits to subsets of these data failed.

We tested the accuracy and predictive quality of the four successful orbits by extrapolation and comparison with the PIMS observations of November 18, 21 and 23. Two of the orbits, when extrapolated, compared well with two sets of observations taken on the night of November 18, clearly identifying the same satellites. The offset between predictions and observations on November 18 was about 1'. The other two orbits compared less well with the observations, but still well enough to identify the objects.

The results are shown in Figure 2, where the dots represent individual observations of all cluster members taken throughout the five-hour observing session. The full lines show the predicted positions of all four satellites using the extrapolated orbits. Further extrapolation of the orbits and comparison with the data of November 21 and 23 confirmed the quality of the two best orbits, which again uniquely identified the objects. However, attempts to include the data into the orbital fitting process failed, and we conclude that the two objects have been maneuvered at some time between November 18 and 21.

Figure 3
Colour of two Astra cluster members

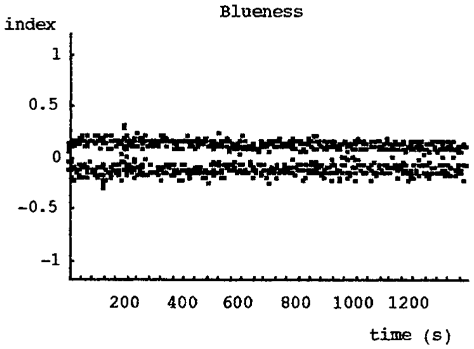
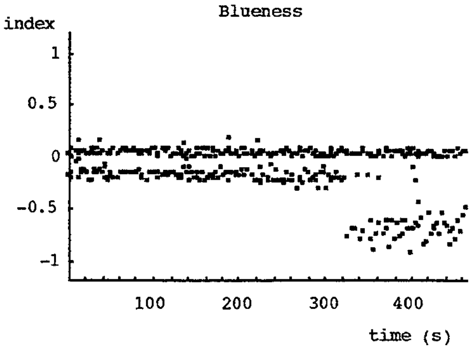


Figure 4
Colour of two Astra cluster members



To help further with the tagging process and, in particular, to try to maintain tagging consistency over extended periods of time, we have taken photometry of the cluster members with the FOX twin-channel CCD photometer system[3] to discover if useful colour differences exist between the cluster members. Simultaneous FOX observations of two satellites do show colour differences (Figure 3) but further long photometry observations on the whole cluster are required before the tagging value of colour and photometric signature can be assessed.

For example, if colour is a function, as expected, of satellite movement then sometimes quite quick changes in colour — and thus movement — can be observed(Figure 4). Whether such changes aid in, or distract from, the process of unique satellite identification remains to be determined.

Thus, optical metric observations from a single site, combined with precise orbit determination, can help to remove ambiguity in identification, and to monitor orbital maneuvers; SOI photometry's value remains unclear at this time.

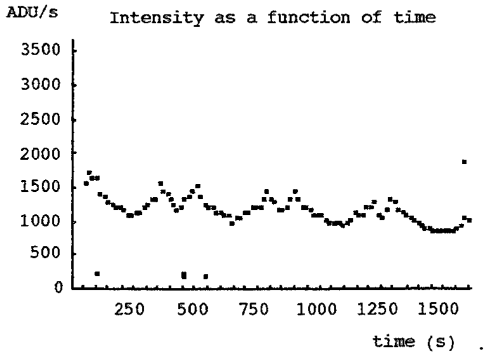
3. SOI signature interpretation

Photometry is a simple monitor of a satellite's health and an indicator of major surface features. Although optical imaging is a vastly more effective technique, no operational ground-based systems are capable of imaging deep-space targets. Radar doppler-imaging can see targets in deep-space but such work requires significant resources and is difficult against objects with minimal differential motion in range.

Over the last few years, we have used a series of photometers to gather optical signatures of satellites as a guide to their health and shape. The current generation of photometer is based around a twin-channel CCD system called FOX[3]; the passbands of the channels are chosen to help identify different surface materials. We have an on-going programme of surface spectral characterization by laboratory measurements and results from this programme assist in the choice of photometer passband.

The interpretation of SOI signatures is quite challenging because of the number of parameters that determine the signature at any instant. In particular, the specular index of a surface, the surface's albedo, and the configuration of that surface and its light sources in the observer's image plane all affect the signature dramatically; the multitude of surfaces on even an unsophisticated satellite means that an unambiguous solution to the problem is impossible. However, we can choose to make assumptions about the principal surfaces and let them aid our morphology; observations of the same satellite — or members of the same constellation — under different Sun–satellite–observer configurations also help us work towards an understanding of a satellite's signature.

Figure 5: Archetypical signature feature



For one constellation, a archetypical signature feature is shown in Figure 5. We observe this feature often, on many constellation members, and for long periods of time.

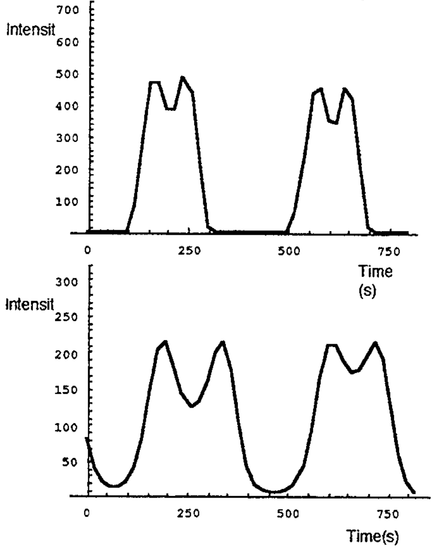
We find the repeating nature of the feature difficult to interpret because it could be caused by a number of diffuse surfaces on a tumbling structure or by a specular surface caught on the edge of its reflection.

For example, the following two computed signatures in Figure 6 are from models i) with two diffuse surfaces and ii) a single specular surface, but with different motion models: one is tumbling, the other is rocking.

To help resolve this ambiguity, we have used simultaneously-acquired laser-ranging data to estimate the relative motion of the laser-reflecting surface to the centre of gravity. In cases where the object is tumbling, there is a clear, cyclic variation in the range residual.

Our computer model requires only a few degrees of rock to reproduce the observed signature (Figure 5); analysis with FFT techniques on the range-residuals fails to show any variation above the noise floor of the observations, implying that any relative motion is small.

Figure 6: Spinning and rocking signatures



Although not proof-positive, fusing ranging and photometric observations and modelling has produced a consistent result.

Acknowledgements

The SLR is operated by the Royal Greenwich Observatory on behalf of the UK Natural Environment Research Council, the Department of Trade & Industry, and the Ministry of Defence. The FOX and PIMS systems are funded by the Ministry of Defence; their work programme is managed jointly by the Defence Research Agency and the Ministry of Defence.

[1] Dick, J.S.B., Sinclair, A.T., Liddell, P., Holland, D., "PIMS:Progress report on a deep space metric sensor project," Proceedings of the 1996 Space Surveillance Workshop, MIT Lincoln Laboratory

[2] Sinclair, A.T., Appleby, G.M., "SATAN — Programs for the determination and analysis of satellite orbits from satellite laser ranging data," SLR Technical Note 8, Royal Greenwich Observatory, 1986.

[3] Dick, J.S.B., Sinclair, A.T., Greenaway, A., Liddell, P., "Initial results from a new sensor system on the UK SOI facility at Herstmonceux," Proceedings of the 1995 Space Surveillance Workshop, MIT Lincoln Laboratory