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SATellite IDENTIFICATION BY ANGLES-ONLY POSITION CORRELATION.(U)
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Project Report

Satellite Identification by Angles-Only Position Correlation

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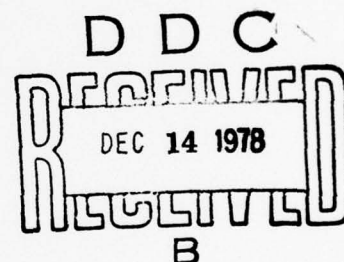
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LINCOLN LABORATORY

SATELLITE IDENTIFICATION BY
ANGLES-ONLY POSITION CORRELATION

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Group 94

PROJECT REPORT ETS-36

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ABSTRACT

The problem of determining the identities of satellites in the field of view of an electro-optical sensor must be adequately dealt with if satellite surveillance is to become a routine operation. At the ETS, the problem of developing a quick, accurate correlation technique is complicated by the circumstance that both the data base and the computer resources are limited. A technique known as Vector/Element Comparison (VEC) has been developed to solve the problem within these constraints. *(This report contains)* The fundamentals of this technique are presented here. Methods of improving the approach, bringing more and better information to bear, are also presented.

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I. SATELLITE IDENTIFICATION

There exist several satisfactory techniques for correlating the observables of a satellite to a catalog of satellite data in order to deduce the identity of that satellite. In general, these have been rejected for application at the ETS. A few of these methods are as follows:

A. Orbital Element Correlation

Orbital element correlation compares the orbital elements of the object being observed to each set in the catalog. This requires the expenditure of several minutes of time in measuring the position of the object in order to generate an element set from which to correlate. Many more observations must be collected so that this element set may then be refined by a differential correction process in order to achieve accurate results. A differential correction technique is not available at the ETS and would require many man-months to develop. Most important, however, is the fact that the time necessary to collect the initial data is considered to be excessive.

B. Instantaneous Position/Velocity Correlation

This method compares the instantaneous position and velocity of the observed satellite to that predicted for each object in the catalog. This approach requires much less time than "A". However, not all of the information necessary to determine the required position is directly observable from a passive electro-optical

site. Specifically, range cannot be measured directly. Only the direction cosines of the desired values are measured directly. In order to determine range with sufficient accuracy, again, several minutes of data would be required*.

C. Angles-Only Position Correlation

This method compares the observed right ascension, declination and time to that predicted for each object in the catalog. The object predicted closest to the observed position is the most likely association. Position correlation has been used regularly at the ETS for over two years. It requires only a single position measurement, it is fairly quick (15 - 20 seconds of shared time); and, it is usually correct (based on over two years of experience). However, it does not use all of the available information to solve the problem. For instance, the fact that it is known that an object is generally more likely to deviate along its orbit than across its orbit is not considered. Hence, at times when several objects are predicted to be relatively near each other and when one or more of them have non-negligible along-orbit errors, the identification can be incorrect. Efforts to correct this situation have thus far

* A method of range determination using angles and angular rates is being developed by Dr. L. G. Taff. The amount of data necessary to determine range using this technique should be greatly reduced from that required by the angles-only method. However, the method is still under development and is not directly available in the system.

been unsuccessful. The efforts did, however, point strongly to a need to resolve error predictions into in-plane and out-of-plane components.

D. Along/Across Orbit Error Correlation

This method is a parameterization of positional correlation, where the parameters can be applied directly to the orbit as opposed to observer's space. Under the hypothesis that each object in the catalog is the object being observed, the difference between the predicted and observed position is resolved into along-orbit and across-orbit components. The object with the most acceptable errors (within bounds) is selected as the most likely association. Again, only a single position measurement is necessary. Processing time is only slightly greater than method "C". The two parameters in the correlation can be independently treated, with across-orbit errors being counted more heavily against association than along-orbit errors. This method has been recently installed at the ETS. The algorithm is described in §III.

II. OBSERVABLES

Before discussing the algorithm in detail we should be familiar with the information which is available to the operator and to the computer in making an association decision. Additional information which will become available in the near future to improve the accuracy of the judgment is also indicated.

The telescope mount at the ETS is uncalibrated. That is, there exists no model for dynamic or static errors or for atmospheric refraction. When the real-time system is to be used the registers of the relative encoders are reset to the values of the position of the known star boresighted by the operator. The position is in a coordinate frame referenced to the mean equinox and ecliptic of the current year. The coordinate frame of the orbital element set is referenced to the mean equinox and ecliptic at the time of epoch. This difference is about $50 \text{ } \overline{\text{sec}}$ per year at the celestial equator, but much greater at high declinations. This difference contributes errors to the boresight versus prediction comparison.

In sum, the measurement of the position of boresight as taken from the relative encoders is inaccurate. It is planned that VEC will use calibrated positional data from either the Single Star Calibration (SSC) or the Precision Local Calibration (PLC) in order to produce more accurate post-observation correlations. Use of the uncalibrated boresight data has historically demonstrated sufficient veracity to warrant the

expenditure of the time necessary to collect the calibrated data.

During the observation of a known satellite the telescope is generally driven by the ephemeris of the intended target. Since the ETS servo system is not closed-loop, it is not currently possible to measure the rate of the object at boresight.

Hence, computer rate comparison is not possible. A program modification will soon allow the operator to track the object at boresight very accurately. Once this is done the very powerful rate comparison can be used in the association process. For the moment, a crude comparison can be accomplished by the operator "eye-balling" the object to see if it tracks the nominal ephemeris. The quality of track is one aid for the operator in determining the identity of an object.

Correlation of optical signatures is still in its infancy. Still, for frequently observed objects or frequently observed object types, the operator may have a sufficiently good memory data-base to allow him to make a judgment based on object brightness and spin characteristics.

III. THE ALGORITHM

The comparison involves resolving a "residual vector", the difference between a satellite's predicted position and the observed position, into in-plane and out-of-plane components. The satellite with the most acceptable differences in both of these dimensions is chosen to be the most likely association.

Let

t = time of interest. All quantities are specified at t .

$\vec{s}$ = the instantaneous vector from the geocenter to the site

$\vec{R}$ = instantaneous predicted geocentric position vector to satellite

$\vec{\dot{R}}$ = instantaneous total velocity vector

$\vec{w}$ = instantaneous unit orbital normal vector

(α, δ) = observed position

ρ = predicted slant range for the satellite being tested

Then

$\vec{\rho} = (\alpha, \delta, \rho)$, converted to Cartesian coordinates

$\vec{R}' = \vec{s} + \vec{\rho}$

$\vec{P} = \vec{R}' - \vec{R}$, the residual vector

$\vec{P} \cdot \vec{w} = |\vec{R}| \sin \beta$, the out-of-plane component

$\vec{V} = \vec{P} - |\vec{R}| \sin \beta \vec{w}$, the in-plane component

$$\Delta t = \frac{\vec{V} \cdot \vec{\dot{R}}}{|\vec{R}|^2}$$

Any satellite predicted* to be within +15 minutes in time

*The prediction includes any known time bias.

and ± 3 degrees across orbit of the observed position is listed on a CRT display for the operator's information. The information presented includes the catalog satellite number, national origin, total (central) angular difference, along-orbit error, across-orbit error, last known along-orbit error, date last tracked, right ascension rate, declination rate and angular uncertainty*. A right arrow (>) is printed along with the above information for any object for which the angular uncertainty is at least half the angular distance (see Figure 1). This is intended to be informative to the identification process, but not definitive. The predicted look points are written to a printer file in order to provide a permanent record and aid in post-mission analysis.

A version of the program which produces a graphic representation of the relative satellite location is available. Because of the size of the graphics routines, this version is not routinely used. It produces an x - y graph whose axes are scaled in delta right ascension and delta declination. Rectangles represent the nominal 0.5° and 1° fields of view. The overall size of the display is 10×10 degrees centered about boresight. An alphanumeric code is placed at the position of each satellite. A legend on the left margin associates a satellite number with each symbol.

* Angular uncertainty is an empirically derived quantity involving the semi-major axis of the orbit and the age of the element set.

VECTOR / ELEMENT COMPARISON										1.8
OBJECTS PREDICTED WITHIN 15 MIN. X 3 DEG.										
SAT#	NATION	DIST DEG	&TIME MIN.	BETA DEG	LAST TRACK	LAST &TIME	RA RATE	DEC RATE	UNCER- TAINTY	
83564	UNKN	2.4	-8.2	-1.2	207.4	0.0	15.1	1.2	0.0	
83557	USA	2.8	10.2	-0.1	0.0	0.0	16.4	0.5	0.0	
83502	NATO	2.1	0.8	-2.1	0.0	0.0	15.1	1.0	0.1	
> 7648	USA	0.0	0.0	0.0	84.0	0.0	15.1	0.1	0.0	
6437	CANA	0.3	1.3	-0.1	305.6	0.0	15.0	0.0	0.0	
3771	USA	18.1	10.6	-1.1	0.0	0.0	168.2	66.5	8.6	

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 VEC COMPLETE.

ETS-36(1)

Fig. 1. The information presented by VEC at the operator's console.

IV. ASSOCIATION

Note that, to this point, no mention has been made of the actual association criteria. The reason for this is that the criteria are now being fine-tuned to produce the best results. The obvious choice of association criteria is minimum absolute error. As is the case with many obvious choices, this one is not necessarily the best. In effect, it relegates the method to a special case (i.e., parametric transformation) of method (C). We noted that method (C) can err.

It is an unfortunate fact that the orbital elements do not perfectly represent the position of satellites. If they did so, the present problem would vanish. Since there are errors, we need to determine how large they can be and which errors are more likely to occur. Becoming familiar with these errors, which are really the performance statistics of the orbital elements, is necessary in order to fine-tune the selection algorithm. Because of the observables at the ETS, the errors are divided into two classes: along-orbit errors and across-orbit errors.

We know that, except for cases of gross orbital maneuvers, along-orbit errors are typically much less than 10 minutes of time in absolute value; and across-orbit errors are typically less than two degrees in absolute value. These estimates

include errors caused by orbital adjustments such as station-keeping maneuvers, and by relatively old orbital elements (up to, say, 40 days given initially "good" elements). From this information we must formulate the best association criteria.

The present selection is that satellite whose predicted absolute time error is least among those whose across-orbit error is 2 degrees or less. One can think of several other choices for the best association which are at least as likely as the above. Several of these have been tested with disappointing results. In testing the current choice in a simulated real-time environment on two separate occasions, satellites were found "closer" in time to boresight than the nominal target (off less than one second in time!) and within the necessary 2 degree across-orbit error. In both cases, the extraneous satellite was moving at a vastly different rate than the intended target. It was obvious to all but the most casual observer that they were not the intended targets. But here the great advantage to be garnered when target rates become available is clearly seen. By comparison with the rates of the intended target such objects may be easily eliminated.

What can be done for the moment to reduce the probability of a false association? It seems likely that once some

initial testing is done and a reasonable idea of the magnitudes of the parameters of interest is obtained, the size of the across-orbit error which is acceptable can be reduced to one degree, or perhaps less. This should reduce false association greatly.

V. FUTURE

After all useful data has been made available to VEC and the algorithm and selection process have been refined, the run time of the program must be reduced. As noted above, the previous version of the program ran in 15 - 20 seconds of shared real-time and the version documented here runs slightly longer (18 - 22 seconds in preliminary tests) for comparable catalog sizes. In order to satisfy the needs of the planned rapid search capability the run-time should be about half that. There are two areas where execution time can be decreased. These are the areas of non-critical data production and of gross satellite rejection.

Much of the data produced by the program is not critical to the association process. It is produced for the operator's information and for the historical log. These data can be eliminated (or postponed in production until a conflict in identification arises), reducing the run time by a few seconds. The amount of time saved is a fixed number times the variable number of objects in the vicinity.

The greatest expenditure of time by the program is in determining whether a given satellite might be in the area. This time can be greatly reduced by preprocessing. One gross check is now made by the program. This involves a quick determination of whether a given satellite can reach the

observed declination. For observations at high declinations, the number of ephemeris computations, and hence the run time, is greatly reduced. Above 60 degrees declination about four seconds is saved. But much more time can be saved by off-line preprocessing.

In tests, a disk file consisting of the set of objects visible to the site for one 10-hour night was built. This file, consisting of about 125 of the about 450 satellites in the catalog, was used by VEC. Run time was 8 - 10 seconds at the apparent synchronous equator using the present algorithm. By subdividing the file into time slices, and perhaps sky area slices, this number can be further reduced to an estimated 6 - 8 seconds. Hence, by implementing all of the above savings, the run time of VEC can be reduced sufficiently to service the rapid search function.

VI. CONCLUSIONS

Position correlation of angles-only data to a satellite catalog, using the technique of resolving the residual vector into in-plane and out-of-plane components, is a viable approach to observation association and subsequent satellite identification. The addition of tracking rate data will aid greatly in the process, drastically reducing the probability of incorrect association. Further refinement of the association selection parameters based on field experience is necessary. Future reductions in run-time through off-line preprocessing and the elimination or postponement of operator aid display data are possible.

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