Boresighting Techniques for the Antenna Control Assembly (ACA)

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Comparison of four scanning schemes including CONSCAN indicates that CONSCAN with signal cleanup and protection processes has the greatest merit in terms of accuracy, dependability and automatic unattended operation. Specific problem areas, error sources, and corrective measures are discussed.

I. Introduction

CONSCAN has been used in the DSN since early work showed its usefulness (Refs. 1 and 2). There have been many problems attributed to CONSCAN. Some of these are due to the present operational CONSCAN scheme being a very austere program, some are due to unrealistic expectations from any automatic scheme, and some are due to operator misunderstandings or errors. Several other automatic boresighting schemes exist, and interest is high in replacing CONSCAN with one or more of these new schemes such as STEPSCAN or TRISCAN. Further requirements of unattended operation and of K-band commitments make this a timely investigation.

II. Goals

The purpose of the study was to provide a recommendation for automatic acquisition and boresighting, by 64- and 34-meter antennas, of spacecraft and extragalactic radio sources within specified error limits. The gain loss limits considered for pointing were 0.05 dB and 0.1 dB from peak signal for 64-meter and 34-meter antennas respectively. The study was also required to assess the problems with respect to CONSCAN, such as the effects of signal level variation, signal dropouts, and automatic gain control (AGC) changes. Trade-offs were to be made to evaluate comparative merits of different acquisition schemes such as raster, spiral or stepped scan.

III. Types of Problems

There are several types of problems which can affect the performance of an automatic boresighting system. Prime among these is the sensitivity of the boresighting system to anomalous or unexpected variations in the signal level. Common problems of this type include temporary loss of signal, signal level change due to spacecraft transmit mode change, and periodic cycling of spacecraft. Other significant problems are the sensitivity of performance to shape of the antenna beam, the computation requirements for the algorithms employed, and the effect of angle encoder quantization errors. All of these were considered in this study.

Certain types of problems were not to be considered in this study since they were not expected to affect tradeoffs between the candidate boresighting schemes. The problems not considered included consideration of refraction models, gravity droop, temperature effects and the manner of generating and updating a correction matrix for improving pointing predictions. Fully electronic boresighting schemes were not to be considered, nor were schemes such as monopulse which would require antenna feed modification.

IV. Comparison of Candidate Boresighting Schemes

Table 1 presents a comparison of the candidate boresighting schemes on the basis of several different points. The four schemes compared are described briefly in the Appendix. The points of comparison are grouped by importance with respect to accuracy and dependability during unattended operation. Each of the criteria for comparison will now be described.

(1) *Overall accuracy.* This criterion includes consideration of accuracy under ideal conditions and also when signal anomalies occur. Under ideal conditions, all four of the schemes are nearly equivalent. CONSCAN is slightly better in this case because the other three schemes require settling time during the scan.

(2) *Insensitivity to signal anomalies.* It is highly desirable that an unattended boresighting system be insensitive to changes of signal level or dropouts such as mentioned in Section III. It is assumed that all four schemes will be implemented with algorithms to test the data for these problems. CONSCAN is much better suited for these tests since the signal power will nominally be constant throughout the CONSCAN cycle. The other three schemes spend much of the time in a transient mode and do not readily permit detection of signal level changes.

(3) *Efficiency*. CONSCAN is using all of the data all of the time. The other schemes have the requirement for settling times during the scans. Hence, CONSCAN more efficiently uses the available data and has a somewhat better accuracy under ideal conditions.

(4) *Insensitivity to beam shape*. All four of the schemes have a degree of sensitivity to the asymmetry of the antenna beam shape. TRISCAN has the most sensitivity since it samples the beam in only three places; STEPSCAN is next, and CONSCAN has the least sensitivity since it averages around the entire scan. SINGLE-AXIS SCAN is in between because it averages, but only in one dimension.

(5) *Computation for scan.* CONSCAN has the largest computation requirement for the scan control because of the large number of distinct pointing commands which must be generated. SINGLE-AXIS SCAN is less complex because of only one axis motion. STEPSCAN and TRISCAN are simplest because of few points to command during a scan.

(6) *Computation for correction*. CONSCAN has the largest computation requirement for the correction calculation due to the crosscorrelation calculations needed for the two coordinates. SINGLE-AXIS SCAN has less correlation requirement and STEPSCAN and TRISCAN are the simplest.

In several respects all four schemes have comparable quality, specifically:

(1) Each scheme can be run for a while to update pointing and then have the scan turned off and "coast" for a substantial period. The advantage of this feature is that there would be no possibility of the antenna accidentally moving off the source due to some totally unexpected anomaly.

(2) Each scheme can be run with an error correction matrix to utilize empirically determined corrections for improvement of pointing predictions.

(3) Each scheme is about equally sensitive to the quantization error in the digital shaft angle encoders. In all cases the scanning is superimposed upon the nominal predicted position of the radio source or spacecraft which is moving with respect to the Earth. Hence, all schemes are vulnerable to this type of pointing error. It has been claimed that TRISCAN is "exact" because it can use an integral number of encoder steps, while CONSCAN cannot (Ref. 3). This is not true because even with TRISCAN the antenna is constantly drifting through encoder quantization steps. In all cases, however, a significant averaging effect occurs due to the slow response time for the antenna. This then results in an antenna position versus time which is quite smooth and relatively unaffected by encoder quantization. A common question about CONSCAN is what effect there is due to the circular scan being an irregular polygon due to discretization in both time and angle. The argument above indicates that the response time of the antenna system causes an averaging effect which results in a very circular scan even though the commands are irregularly spaced around the scan.

V. Signal Cleanup and Protection During Track

No matter what scheme is to be employed, it is mandatory that a substantial effort be applied to provide cleanup of the raw input data (automatic gain control or radiometer output). This is not done effectively with the current CONSCAN system, and it is probably the main reason that CONSCAN has received some bad publicity in the past. At the end of a study, several suggestions were made for the formal implementation of CONSCAN in the DSN. Very few of these suggestions were implemented due to a lack of memory in the APS computer. As a result, CONSCAN was able to do some bizarre things on occasion, which would not have happened had the recommended data quality tests and limit tests been implemented.

VI. Proposed Signal Cleanup and Protection During Track

The signal inputs are, (1) Automatic Gain Control (AGC) voltage for spacecraft tracking and (2) square law detector output for radio sources. The anomalies that are likely to occur that will affect the received signal power level may be listed as follows:

(1) Change in spacecraft transmitter or antenna mode.

(2) Signal dropout due to momentary receiver lockout, operator error, or some unexpected transient (glitch) in the receiving system.

(3) Spacecraft antenna pointing direction change with spacecraft limit cycling, thermal variation in radio source, or some other change on board the spacecraft causing variation in the downlink signal strength.

(4) In the case of spin-stabilized spacecraft, modulation in the signal level due to the spin rate.

The procedure for testing for the above anomalies may be according to an algorithm encompassing the following steps.

(1) Expected signal level should be provided to the antenna control assembly (ACA) so that a signal level test can be performed to verify that boresight is close to the spacecraft.

(2) For radio sources, the system temperature and expected radio source temperature should be provided so a check can again be run. This will entail a precise setup for the radiometer gain to ensure accurate comparisons. A table of temperatures for common radio stars could easily be put into system memory.

(3) The signal level at the beginning and end of scan should be tested for near equality.

(4) If slow cycling is a problem, a multiple scan least squares curve fit should be implemented to subtract off the ramping from the signal level.

(5) Once ramping is removed, the sine and cosine correlations can be performed to find the sine wave component. This can then be subtracted to give residuals whose rms value can then be calculated and tested against an anomaly limit.

(6) In lock test: Receiver signal level (binary) monitoring during CONSCAN operation will effectuate correction whenever in-lock status is indicated.

Calculation for correction is carried out by correlating sine and cosine components (Ref. 1). The corrections thus obtained should be tested against previously specified limits. The limits may be broadly categorized as "First Limit," and "Second Limit." If the calculated correction exceeds the first limit, but is less than or equal to the second limit, the correction will be effected at the first limit value. If the succeeding calculated correction *also* exceeds the first limit, no correction will be made and a warning must go to the responsible operator. Of course if any calculated correction exceeds the second limit, no correction will be made, and the responsible operator will be warned.

The corrected pointing of the antenna must be continuously compared to the predicted pointing. The difference will be due to the accumulation of residuals. This total offset must be compared to two other (previously specified, a priori) limits. The error is permitted to exceed the first limit; the operator must be kept informed. CONSCAN operation is not affected thus far. However, as soon as the second limit is reached, manual intervention by the operator becomes imperative; the operator will receive an urgent warning that CONSCAN is trying to correct an out-of-limit condition. To avoid false alarms during acquisition or encounter, this limit may be made larger or overridden altogether with the approval of a next higher ranked operator.

VII. Needed CONSCAN Improvements

In response to criticism due to problems encountered in the current operation of CONSCAN, improvements in automatic gain control (AGC) calculations, acquisition mode, and tracking mode must be effected to enhance accuracy and dependability.

(1) For spacecraft tracking, the AGC voltage automatically is scaled so the open loop gain remains fixed for CONSCAN. Hence, the response time stays fixed, independent of signal level.

(2) For radio source tracking, there is no AGC. Therefore, the receiver noise temperature and radio source temperature must be used as inputs to allow the CONSCAN algorithm to calculate the gain needed within the algorithm to provide a desired response time.

(3) In acquisition/tracking modes a continuous CONSCAN mode of operation is recommended. An optional mode of periodic update (by CONSCAN), say for 5 minutes every 30 to 60 minutes, should be available when (continuous) CONSCAN is not being executed. Provision should be made such that an operator can be flagged by the program when the signal level is dropping so that he may initiate a predetermined period of CONSCAN update.

The AGC and radiometer data testing for anomalies, and algorithm for implementing corrections to the pointing offset, should follow the procedure outlined in Section VI.

VIII. Conclusions

The primary conclusion of the study is that CONSCAN is the best overall scheme to implement for the Antenna Control Assembly. Under unattended automatic operation, CONSCAN has the major advantage of being able to readily detect anomalous conditions and then to reject bad data. It is necessary that the new CONSCAN implementation includes many features not presently employed. These features concern various signal cleanup and limit tests to preclude wild behavior under unusual circumstances. Substantial work on details of these features is underway and will be reported subsequently.

References

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2. Gosline, R. M., "CONSCAN Implementation at DSS 13," Technical Report 32-1526, pp. 87-90, Jet Propulsion Laboratory, Pasadena, Calif., April 15, 1973.

3. Bunce, R. C., "TRISCAN: A Method of Precision Antenna Positioning," *TDA Progress Report 42-59, July and August 1980*, Jet Propulsion Laboratory, Pasadena, Calif., Oct. 15, 1980.

Table 1. Comparison of candidate boresight schemes[a]

	CONSCAN	STEPSCAN	TRISCAN	SINGLE-AXIS SCAN
High importance				
a. Overall accurracy	5	4	4	4
b. Insensitivity to signal anomalies	5	4	4	2
Moderate importance				
c. Efficiency	5	4	4	4
d. Insensitivity to beam shape	5	4	4	4
Low importance				
e. Computation for scan	Much	Little	Little	Medium
f. Computation for correction	Much	Little	Little	Medium

[a]Scale of 0 to 5, with 5 best.

Appendix A
Candidate Boresighting Schemes

I. STEPSCAN

STEPSCAN is an automatic boresighting scheme which measures signal power at a small angle off boresight along one axis (two points) or along two orthogonal axes (four points). Comparison of the signal powers measured then provides a measurement of the boresight error in one or both axes.

II. TRISCAN

TRISCAN is very similar to STEPSCAN except that only three points are used and measurements of errors in both axes are provided.

III. CONSCAN

CONSCAN obtains angle error measurements by continuously scanning the antenna beam at a constant angle offset (squint) from the boresight axis, resulting in a circular scan pattern. Angle error information is obtained by correlating the received signal power level with two quadrature sinusoids which are synchronous with the scanning in order to provide elevation and azimuth corrections.

IV. SINGLE-AXIS SCAN

SINGLE-AXIS SCAN is a boresighting scheme wherein the antenna scans once along one axis at constant rate through the anticipated boresight position. By fitting the measured signal power to a nominal beam shape, the peak gain angle can be determined for that axis. Repeating this procedure for the other axis then permits a boresight to be obtained.

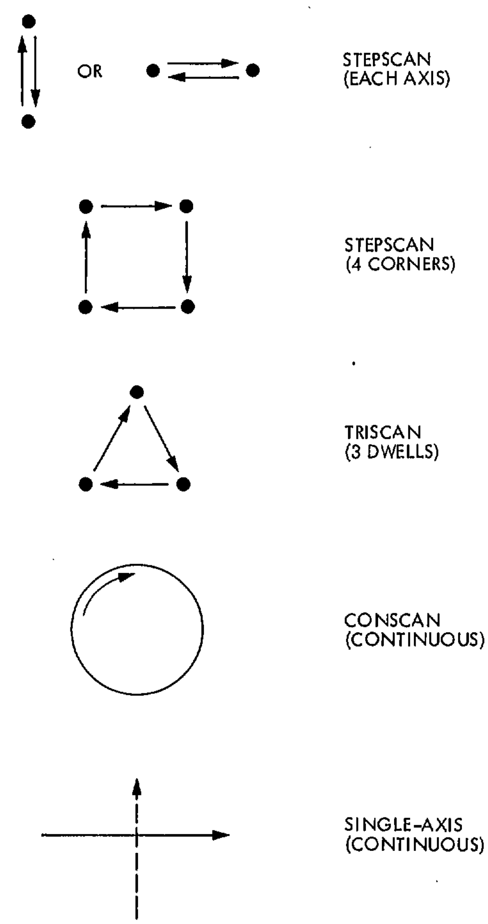

Fig. A-1. Candidate boresighting schemes