Automated Radio Astronomy Operations

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This article describes improvements in using a computer to drive a DSN 64-meter antenna. The purpose of the development has been to simplify operation, improve antenna safety, reduce antenna wear, prevent the abuse of antenna by mis-operation, increase quantity and quality of data gathered, and give users a greater choice of automatic operations.

I. Introduction

The normal startrack method used in DSN operations has been retained. The year, station number, right ascension, declination, azimuth, and elevation are calculated and used to point the antenna. Many improvements have been added. The major additions are:

(1) Rates and acceleration are program controlled.

(2) Automatic boresite in hour angle, declination, azimuth, and elevation. Method used is to scan through a source while sampling data from an analog-to-digital converter. A curve fit of the data is used to calculate the pointing error.

(3) Limits of elevation are monitored and alarms given on the typewriter.

(4) A schedule of sources can be prepared on paper tape. Selection of tape drive will automatically steer the antenna from source to source at pre-set times.

(5) Data may be recorded on magnetic tape for post-track data reduction.

II. Controlled Rates

Increasing antenna drive velocity is performed by an addition of 0.010 degrees per second until maximum velocity of 0.200 degrees per second is reached. Table 1 shows the relationship between time, distance in degrees, and velocity in degrees per second. Figure 1 is a graph of distance in degrees versus time in seconds. Decreasing drive velocity is determined by subtraction of actual position from desired position. If the difference is greater than 2.090 degrees and maximum velocity has not been reached, the increase in velocity is maintained. If the difference is greater than 2.090 degrees and maximum velocity has been reached, maximum velocity is maintained. If the difference is less than 2.090 degrees, decreasing drive velocity is performed by using a look-up table derived from Table 1, velocity versus distance. A second-degree polynomial may be used instead of a look-up table. The coefficients have been calculated as follows:

$$v = 0.024944 + 0.141604d - 0.028102d^2$$

where

v = velocity in degrees per second
d = distance in degrees from desired position

Also, d is $<$2.090 degrees.

III. Calculating Offsets

The pointing accuracy of the antenna can be determined by scanning through hour angle, declination, azimuth, or elevation. The length of scan is selected from the control panel switches. To obtain very accurate pointing data, it is necessary to scan completely through a source. Consider examining a source at an elevation of 20 degrees – the data gathered from the source could look like Fig. 2. Before curve-fitting, the base and slope are subtracted from the detected output samples. Subtracting the base (a) produces Fig. 3. Subtracting the slope produces Fig. 4. Consider the original data being taken as 162 one-second samples. The slope is subtracted from every sample in the following manner:

Sample	
1	$y_1 - b$
2	$y_2 - \left\{\frac{161}{162} \times b\right\}$
3	$y_3 - \left\{\frac{160}{162} \times b\right\}$
⋮	⋮
162	$y_{162} - 0$

The maximum point of the curve is found by fitting to a second-degree polynomial. The actual formula used is:

$$x_m = \bar{x} + \frac{3}{2} \cdot \frac{3y_1 + 2y_2 + y_3 - y_5 - 2y_6 - 3y_7}{5y_1 - 3y_3 - 4y_4 - 3y_5 - 5y_7}$$

Seven points are required, and an illustration of typical sample points is given in Fig. 5. Figure 5 is a graph of a declination scan at 0.005 degrees per second through source 4C12.6. The receiver was tuned for S-band. At nominal maximum the azimuth was 332.2 degrees and elevation 34.1 degrees. The graph of Fig. 5 shows the seven sample points. The program performs a running mean of the one-second samples from the detector. Each running mean sample is the mean of seven one-second samples. The points used for the second-degree fit are seven seconds apart so all the data points are actually used. Care is needed when choosing rates and distances to scan. Useful figures are tabulated in Table 2. Shorter scans are only possible if the errors are small. Offsets from previous scans can remain in the program so that the nominal maximum occurs near the center of the scan.

IV. Schedule on Paper Tape

A program has been written for 910/920/930 computers that produces a punched paper tape of schedules for VLBIs or any other radio astronomy experiment such as Quasar Patrol. The tape can be edited, listed, or copied in advance of the experiment. A conversion routine has been included to change TTY code to the XDS code. The schedule can then be sent by line and converted to the correct format for driving the antenna. The data on the tape have a format close to the binary-coded decimal input to the Antenna Pointing Subsystem from the control panel. Parameters used are right ascension, declination, and end time of the source. Tape samples are read into the program by selecting tape drive. RA, DEC, and end time are output on the typewriter. Long schedules of over 12 hours and 100 sources have been used in practice, and proved to be more efficient and easier to run than the manual method.

V. Recording on Magnetic Tape

A 480-word record is written once per minute. Each 8-word line is one second's worth of data, consisting of day of year, time, hour angle, declination, azimuth, elevation, and sample value. The magnetic tape facility has proved to be very successful in an intensive observing period using the DSS 42/43 short-baseline interferometry. Over 350 sources were observed, and fringes have been observed in all sources.

VI. Conclusion

Using software techniques it is possible to control the 64-meter antenna safely and automatically. Wear and tear are greatly reduced. Better use is made of scheduled time, thus increasing productivity.

Acknowledgment

Thanks are due Dr. D. L. Jauncey (Australian Commonwealth Scientific Industrial Research Organisation) for valuable advice on desirable methods of star tracking.

Table 1. Time, distance, and velocity from static start

Time, s	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Distance, deg	0.01	0.03	0.06	0.10	0.15	0.21	0.28	0.36	0.45	0.55	0.66	0.78	0.91	1.1	1.2	1.4	1.5	1.7	1.9	2.1
Velocity, deg/s	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20

Table 2. Time required for various scans (distance must be exactly divisible by rate)

Band	Rate, deg/s	Distance off, deg	Time required, min:s
S	0.005	0.300	2:32
S	0.004	0.244	2:22
S	0.003	0.090	1:08
X	0.001	0.083	2:54
X	0.001	0.034	1:15

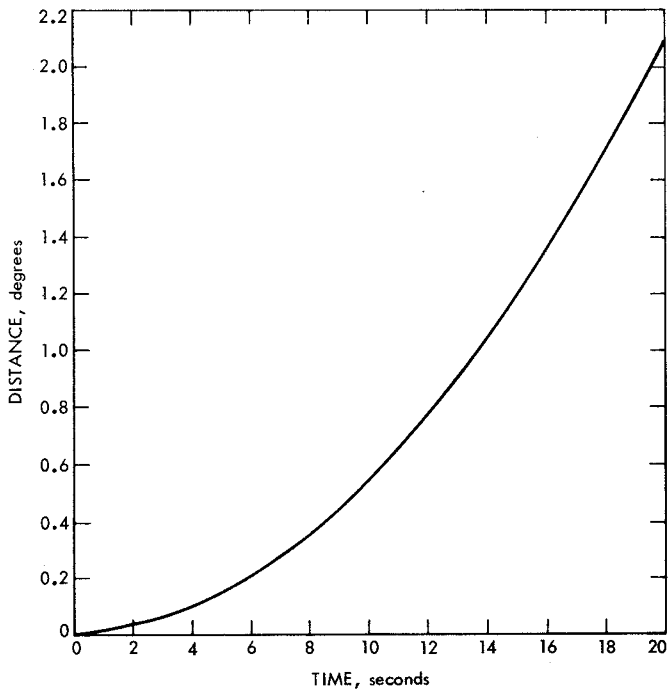

Fig. 1. Distance from static position versus time

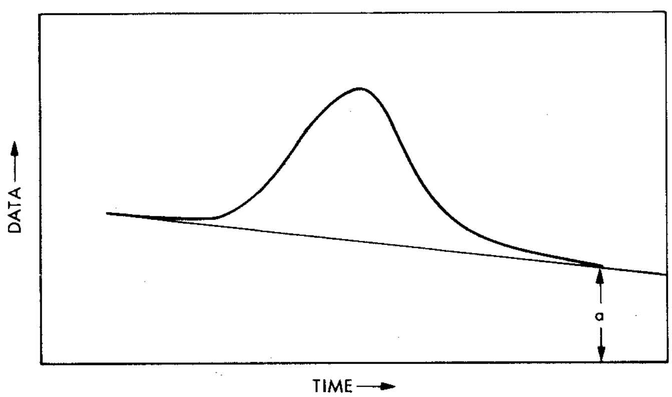

Fig. 2. Square law detector output versus time (S-band total scan is 0.5 deg at 0.004 deg/s)

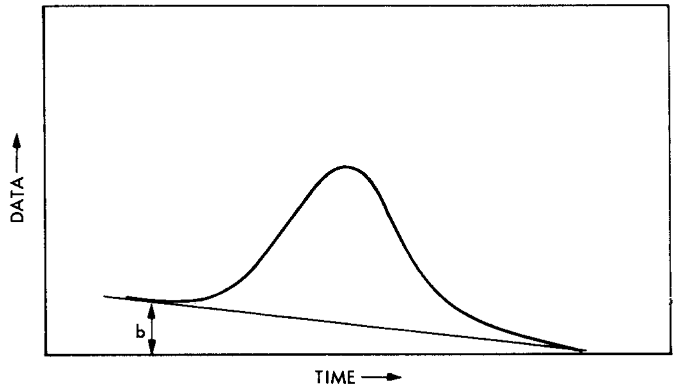

Fig. 3. Bias subtracted from gathered data

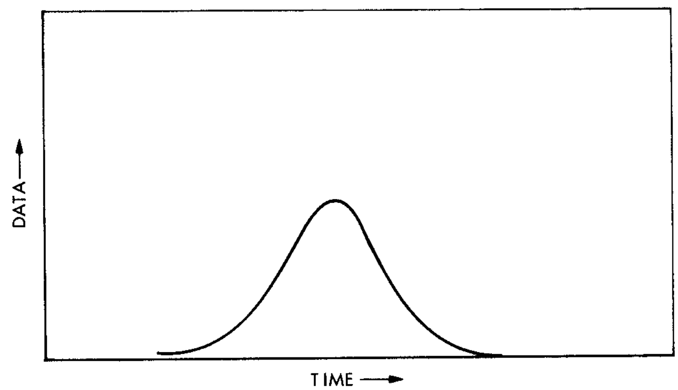

Fig. 4. Slope and bias subtracted from gathered data

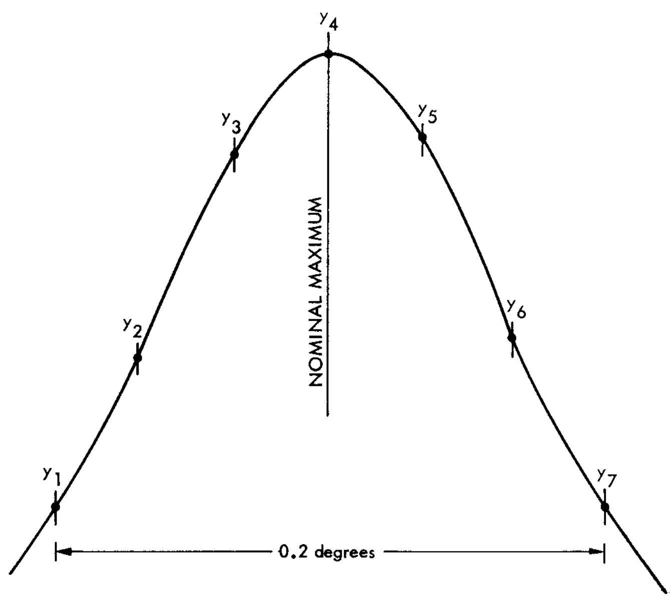

Fig. 5. Actual graph of a declination scan through source 4C12.6 at rate of 0.005 deg/s (slope and bias have been subtracted by pointing program)