<table>
<thead>
<tr>
<th>Technical Note</th>
<th>1966-55</th>
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</thead>
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<tr>
<td>Haystack Pointing System: Scan</td>
<td>W. R. Crowther</td>
</tr>
<tr>
<td>1 November 1966</td>
<td></td>
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</tbody>
</table>

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HAYSTACK POINTING SYSTEM: SCAN

W. R. CROWTHER

Group 62

TECHNICAL NOTE 1966-55

1 NOVEMBER 1966
ABSTRACT

As one of its options, the Haystack Pointing system can superpose a scan on any other pointing task. The available scans include both simple one-dimensional scans and area-covering scans.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office
HAYSTACK POINTING SYSTEM: SCAN

INTRODUCTION

The antenna pointing program for the Haystack Univac 490 computer includes provisions for superposing a variety of possible scans on any of the normal computer-directed antenna pointing modes. The center position of such scanning follows the computed position of the selected target. A description of the possible scans and the program which implements them follows.

PROGRAM INPUTS

1. Time (DSECONDS)
2. Computed Right Ascension (RA)
3. Computed Declination (DEC)
4. Computed Azimuth (AZ)
5. Computed Elevation (EL)
6. Sine and Cos of Track Angle (described below)
7. Complex interaction with an operator via the keyboard and its servicing program "INTERCOM".

Since the main pointing program must have RA and DEC to compute AZ and EL, the scan program is actually called twice, once to scan in RA-DEC and once in AZ-EL. The master control program believes there are two scan programs called AESCAN (for Azimuth-Elevation Scan) and RDSCAN (Right-Ascension-Declination Scan). Actually there are just two entries to one program.

PROGRAM OUTPUTS

1. Right Ascension with Scan Added
2. Declination with Scan Added
3. Azimuth with Scan Added
4. Elevation with Scan Added

COORDINATES

The Scan program recognizes 6 coordinate axes. These are Azimuth, Elevation, Right Ascension, Declination, Along Track, and Across Track. Across Track is
orthogonal to Along Track and the radius vector, and the remainder are self explanatory. For the most part these are treated as similar but independent axes. For example, there is one subroutine which computes a simple back and forth scan, and this subroutine is used six times to get six different scans. For some area-type scans two axes are involved. Again there is only one subroutine involved, but it now provides a pair of displacements which are added to one of the three coordinate pairs. When order of the pair is considered, there are 6 possible scans from this subroutine.

Since Along Track and Across Track are not normal system axes, scans along these axes must be converted to Azimuth and Elevation displacements. This is done using the knowledge of the angle between the two axis-pairs (See Fig. 1).

\[
\begin{align*}
AZ &= AL \cos \theta - AC \sin \theta \\
EL &= AL \sin \theta + AC \cos \theta
\end{align*}
\]

Fig. 1.

The Sine and Cos of the angle \( \theta \) in the figure are among the inputs to the program, if AL and AC are the displacements in Along and Across, then

The implementation of Along - Across in AZ-EL instead of in RA-DEC was a choice of the lesser of evils. In AZ-EL one specified directly the radar angular rate and angular extent of the scan. In RA-DEC, for approximately circular orbits, one specifies quantities more closely related to the velocity in n.m./sec and extent in n.m. In neither case is one scanning in range to stay on the track in that variable.
As scan is constructed, it is impossible to scan in AZ-EL and Along-Across simultaneously.

The axes are related in one further way, which involves the phase of the scans. Time is the key variable for determining the next step in the scan process, and is arranged so that a time of zero corresponds to the low end of the scan. In order to start a scan at a particular place (the center for example) a constant called "Time Zero" is subtracted from time before the various routines are called. There are only two such constants, one for AZ-EL or Along-Across and one for RA-DEC. This has the effect of forcing simultaneous scans in AZ and EL (or RA and DEC) to have the same time zero, or phase, which means there will probably be a discontinuity in one scan when the second is initialized.

BACK AND FORTH SCAN

The "back and forth" Scan is the basic scan. It is used as six different scan options (one for each coordinate axis), and is also used as a component of the Area-Oriented "Box Scans." See Fig. 2 for a sketch of this basic scan.

The back and forth scan is computed in 4 symmetrical sections, (AB, BC, CD, DE in Fig. 2) each section consisting of a period of constant acceleration and a period of constant velocity. The acceleration is always for three seconds, * unless the total

*3 secs of max. antenna acceleration produces maximum antenna velocity.
time available is less than 3 seconds per section, in which case the acceleration is continuous through the whole scan. The acceleration is computed so that the scan is completed in the allotted period:

\[
\frac{1}{2} a(3)^2 + 3a(p/4 - 3) = A \quad p > 12
\]

or

\[
\frac{1}{2} a(p/4)^2 = A \quad p \leq 12
\]

where \( a \) = acceleration

\( A \) = half Arc (Amplitude) of scan

\( p \) = period of scan

The constant velocity of course is \( 3a \).

Simplifying and solving for \( a \):

\[
a = \frac{4A}{3 \cdot \frac{p}{p - 6}} \quad p > 12
\]

\[
a = \frac{32A}{p^2} \quad p \leq 12
\]

In actuality, scan does not produce a continuous output, but rather discrete points every interpolation interval. Whether scan actually follows the desired curve depends on a complex interaction with the interpolation program and the antenna servo.

The program that computes a back and forth scan compares time* to period to discover where it is on the scan. It then divides the scan into two similar half scans (increasing and decreasing) which are processed by a single subroutine. This subroutine further divides each half scan into two quarter scans processed by a second subroutine.

That routine divides the quarter into an accelerating part and a coasting part using the formulas above to determine velocity and acceleration, and computes actual position. The output of the "BACK AND FORTH" routine is a displacement which will be added to the appropriate center position to create a scan.

*Remember that the zero of time has been set artificially to start the scan at its center.
BOX SCAN

The "Box Scan" is an area-covering scan. It is used in 3 different coordinate systems, and applied in 2 different ways in each system. The output of the BOX SCAN routine is two values, which produce a Box-Like scan when added to the appropriate center positions. Figure 3 is a sketch of this basic scan.

The comments under back and forth scan about the discrete spacing of the actual scan output apply here also, and in fact the BOX SCAN does a back and forth scan in one coordinate while simply stepping the other coordinate at the end points. This discontinuity in the second coordinate produces an error as the antenna servo tries to cope with infinite acceleration, but it was felt that the step would be small and relatively infrequent, so that the transient would not matter. At the end of the box the whole scan repeats, causing another transient as the antenna moves back to the initial corner of the box. There is no limit to the number of lines per box, and the number may be odd or even. The illustration (Fig. 4) is perhaps unrealistic in having so few lines (4) but more present a bit of a drawing problem.

The Box Scan program compares time to the overall period to determine location in the scan. It then uses that part of the back and forth routine which processes half a period (one line) to get displacement 1 and computes the simpler displacement 2 itself.

CONVENIENCE SCANS

There are a number of scan options which are not really scans but are included here for lack of a more appropriate place. They include constant offsets, which are simply added to the center positions before any other action; holding all scans, which is accomplished by presenting the scans with a phony time set at the time of the hold; restarting which undoes the hold and moves the time origin so that the scan picks up where it left off; and clearing all scans.

INTERNAL LOGIC

This section presents in a more organized way the block diagram implied by the discussion above, and includes a list of key registers with their actual program names.
Fig. 3. Example of one full period of the box scan.

Time per Line = 30 sec
# Lines per Box = 4 (normally one would use more, but it clutters the picture)
Length of Box = .81 degrees
Line Spacing = .133 degrees

Fig. 4. Box scan as seen in space coordinates.
AZ-EL Entry
Move Input AZ-EL
To Output AZ-EL, Adding
AZ, EL, Along, and Across
Offsets in the Process
Compute Internal Time
Do AZ SCAN if requested (use BACK AND FORTH)
Do EL SCAN if requested (use BACK AND FORTH)
Do AZ-EL BOX SCAN if requested (use BOX SCAN)
If AZ-EL is Really Along-Across rotate the above answers through the angle \theta
Add the Scans into the output
Return

RA-DEC Entry
Move Input RA-DEC to Output RA-DEC, adding RA and DEC Offsets in the process
Compute Internal Time
Do RA Scan If Requested (use BACK AND FORTH)
Do DEC Scan If Requested (use BACK AND FORTH)
Do RA-DEC BOX SCAN If Requested (use BOX SCAN)
Add the Scans into the Output
Return

BACK AND FORTH: Break the scan in half and use LINE
LINE: Break the line in half and use LINEX
LINEX: \[ a = \frac{4/3}{p - 6} \quad p > 12 \]

\[ \frac{8A}{p} \quad p \leq 12 \]

\[ \text{displacement} = \frac{1}{2} a(T)^2 \quad T \leq 2 \]

\[ \frac{1}{2} a3^2 + 3a(T - 3) \quad T > 2 \]

where \( T \) = Time from the acceleration end of the half line.

**BOXSCAN:**
- Compute displacement 1 using LINE
- Compute displacement 2

**KEY REGISTERS**

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<tr>
<th>NAME</th>
<th>MEANING</th>
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<tr>
<td>M1</td>
<td>0 means no AZ-EL box scan</td>
</tr>
<tr>
<td>M2</td>
<td>0 means no AZ scan</td>
</tr>
<tr>
<td>M3</td>
<td>0 means no EL scan</td>
</tr>
<tr>
<td>M4</td>
<td>0 means no RA-DEC box scan</td>
</tr>
<tr>
<td>M5</td>
<td>0 means no RA scan</td>
</tr>
<tr>
<td>M6</td>
<td>0 means no DEC scan</td>
</tr>
<tr>
<td>M7</td>
<td>1 means AZ-EL is really along-across</td>
</tr>
<tr>
<td>M8</td>
<td>0 means lines along AZ in AZ-EL box</td>
</tr>
<tr>
<td>M9</td>
<td>0 means lines along RA in RA-DEC box</td>
</tr>
<tr>
<td>M10</td>
<td>1 means hold scan</td>
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<td>KKAL</td>
<td>Azimuth offset in revolutions B27</td>
</tr>
<tr>
<td>KKEL</td>
<td>Elevation offset in revolutions Ba7</td>
</tr>
<tr>
<td>KKRL</td>
<td>RA offset in revolutions B27</td>
</tr>
<tr>
<td>KKDL</td>
<td>DEC offset in revolutions B27</td>
</tr>
<tr>
<td>KKCL</td>
<td>Across offset in revolutions B27</td>
</tr>
<tr>
<td>KKLL</td>
<td>Along offset in revolutions B27</td>
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<td>KET</td>
<td>Elevation period in seconds</td>
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<td>KDT</td>
<td>DEC period in seconds</td>
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<td>NAME</td>
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</tr>
<tr>
<td>-------</td>
<td>--------------------------------------------------</td>
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<tr>
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<td>Elevation whole arc length in revolutions B27</td>
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<tr>
<td>KRL</td>
<td>RA whole arc length in revolutions B27</td>
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<td>NULL</td>
<td>Time origin for RA-DEC scans</td>
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<tr>
<td>NULLY</td>
<td>Time origin for AZ-EL scans</td>
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<td>AEBOX</td>
<td>Total time per box in seconds (AZ-EL)</td>
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<tr>
<td>+ 1</td>
<td>Box length in revolutions B27 (AZ-EL)</td>
</tr>
<tr>
<td>+ 2</td>
<td>Number of lines per box (AZ-EL)</td>
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<tr>
<td>+ 3</td>
<td>Line spacing in revolutions B27 (AZ-EL)</td>
</tr>
<tr>
<td>+ 4</td>
<td>Time per line in sec (AZ-EL)</td>
</tr>
<tr>
<td>+ 5</td>
<td>0 means lines along AZ in AZ-EL box (AZ-EL)</td>
</tr>
<tr>
<td>RD BOX</td>
<td>Like AE BOX</td>
</tr>
</tbody>
</table>

INITIALIZATION

The function of initialization is to set up the 38 key registers described in the Logic Section, so that the operating part of the program can do its job. Mostly, initialization simply asks the operator for each number it should use. See Appendix A for a complete run through of all the possible scan questions with typical answers.

Initialization is called in two different modes by the master control program. In Mode 1 it performs the clear all scan function, an option which is also available to the operator. (This amounts to zeroing registers M0 through M10.) In Mode 2 initialization asks the operator to set up a scan: when he has done so, it asks for another, and so on indefinitely. Mode 1 is used when master control wants to start over. Mode 2 when scan has been requested via the attention symbol.

When a scan is selected initialization must set the appropriate zero point of time. This is done by putting either the current time or current time plus a quarter period in the appropriate zero register. It is probable that one will be off by a second or two, because there is an unknown delay between the time of striking a key and the operation of scan initialization, and a further unknown delay between scan initialization
and scan operation. When a scan is "held" initialization tries as best it can to stop at the time of the struck key, but there is an obvious difficulty, compounded by the fact that the system is 6 seconds ahead of real time. (This is not the appropriate place to discuss the complex subject of system timing - I merely wish to explain why the hold option is not a good way to come to a precise stop.)

It is possible to ask for an unreasonable acceleration, for example by selecting a zero period. Whenever this might occur, initialization computes the period corresponding to a $3^0/sec^2$ acceleration. \( p = 6 + \frac{4}{\pi} A \pi > \frac{27}{2}, \quad p = 4.273 A \)

If the chosen period is too small initialization uses the computed period and tells the operator what has happened.

Initialization rounds all odd periods to the next lower even period, for internal convenience.

If one asks for a zero spacing of lines in a box, initialization will substitute one beamwidth. This is perhaps of some convenience in the AZ-EL Box Scan.
APPENDIX A
* 
SIGN OFF(1) MOD(2) NEXT RUN(3) PRINT(4) 2*
AZ-EL(1) DATA PROCESSING(2) SCAN(3) RECORDING(4) TIMING(5) OTHER(6)
3*

SELECT SCAN OR OFFSET
CLEAR(0),HOLD(1),RESUME(2)
AZSCAN(3),ELSCAN(4),AZELBOX(5),AZOFFSET(6),ELOFFSET(7)
RASCAN(3),DECSCAN(9),RADECBOX(10),RAOFFSET(11),DECOFFSET(12)
ORBIT- CROSSSCAN(13),ALONGSCAN(14),BOX(15),CROSSOFFSET(16),ALONGOFFSET(17)
DRIFT SCAN(18) 8*

CLEARED-RESELECT AT WILL 1*
HELD-RESELECT AT WILL 2*
RESUMED-RESELECT AT WILL 3*
AZ SCAN
PERIOD IN SEC = 30*
HALF-ARC IN DEGREES 1*
SCANNING-RESELECT AT WILL 4*
EL SCAN
PERIOD IN SEC = 30*
HALF-ARC IN DEGREES 1*
SCANNING-RESELECT AT WILL 5*
AE BOX SCAN
ARC IN DEGREES 1*
LINES PER BOX = 10*
SPACING IN DEG= .25*
TIME/LINE(SEC): 10*
LINES PARALLEL TO AZ(0),EL(1) 2*
SCANNING-RESELECT AT WILL 6*
AZ OFFSET IN DEGREES 10*
OFFSET-RESELECT AT WILL 7*
EL OFFSET IN DEGREES 10*
OFFSET-RESELECT AT WILL 8*
RA SCAN
PERIOD IN SEC = 30*
HALF-ARC IN DEGREES 1*
SCANNING-RESELECT AT WILL 9*
DEC SCAN
PERIOD IN SEC = 30*
HALF-ARC IN DEGREES 1*
SCANNING-RESELECT AT WILL 10*
RA-DEC BOX SCAN
ARC IN DEGREES 1*
LINES PER BOX = 10*
SPACING IN DEG= .25*
TIME/LINE(SEC) = 10*
LINES PARALLEL TO RA(O),DEC(1) 0*
SCANNING-RESELECT AT WILL 11*
RA OFFSET IN DEGREES 45*
OFFSET-RESELECT AT WILL 12*
DEC OFFSET IN DEGREES 25*
OFFSET-RESELECT AT WILL 13*
ACROSS SCAN
PERIOD IN SEC = 30*
HALF-ARC IN DEGREES 1*
SCANNING-RESELECT AT WILL 14*
ALONG SCAN
PERIOD IN SEC = 30*
HALF-ARC IN DEGREES 1*
SCANNING-RESELECT AT WILL 15*
AL-ACR BOX SCAN
ARC IN DEGREES 1*
LINES PER BOX = 10*
SPACING IN DEG= .25*
TIME/LINE(SEC) = 10*
LINES PARALLEL TO ORBIT(O),ACROSS ORBIT(1) 0*
SCANNING-RESELECT AT WILL 16*
CROSS-ORBIT OFFSET (DEG) 45*
OFFSET-RESELECT AT WILL 17*
ALONG-ORBIT OFFSET (DEG) 30*
OFFSET-RESELECT AT WILL 18*
RA OFFSET IN DEGREES 45*
DEC OFFSET IN DEGREES 45*
CARRIAGE RETURN TO START DRIFT SCAN *
DRIFTING-RESELECT AT WILL
### APPENDIX B

#### SPURT OUTPUT NO. 110

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<thead>
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<th>L1 TO LABEL</th>
<th>TA STATEMENT</th>
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01012  CL A  00751  11000  00000
01013  ADD A*0202660266*AP05  00752  20630  02130
01014  CL A  00753  11000  00000
01015  SUB A*0002660266  00754  21050  02131
01016  STR A+W(E2)  00755  15030  63056
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01020  JP SCAN2Q  00757  61000  00617
01021  SCAN1 JP  0  00760  61000  00000  LAT LONG ENTRY
01022  ENT A+W(RA1)  00761  11050  63002
01023  ADD A+W(KKRL)  00762  20050  63514
01024  STR A+W(RA2)  00763  15050  63004
01025  ENT A+W(DN1)  00764  11030  63003
01026  ADD A+W(KKDL)  00765  20050  63515
01027  STR A+W(TN2)  00766  15030  63005
01030  ENT A+W(TYNE)  00767  10030  63141
01031  ENT A+W(M10)*AZERO  00770  11430  63511
01032  ENT A+W(TOME)  00771  10030  63520
01033  SUB A+W(NULL)  00772  27030  63531
01034  STR A+W(TT)  00773  14030  00002
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01036  JP P4  00775  61000  01014  (BOX SCAN)
01037  MOVE @RD000X*BOX  00776  12700  00005
01038  RJP DBOX  00777  10037  01311
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01044  RPL Y+*W(RA2)  01003  10030  01335
01045  ENT A+W(M9)  01004  11430  63510
01046  ENT A+W(BOXOUT2)*AZERO  01005  34130  63005
01047  RPL Y+*W(RA2)*SKIP  01006  34030  63004
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01053  JP P3  01012  34030  63005
01054  ENT A+W(KRT)  01013  61000  00760
01055  ENT A+W(KKL)  01014  11530  63504
01056  RJP BKANDFORTH  01015  61000  01022  (ASC SCAN)
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M. L. Meeks  
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Group 62 Files (5)
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