GENERAL PURPOSE ALGORITHMS FOR CHARACTERIZATION OF SLOW AND FAST PHASE NYSTAGMUS

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In the overall aim for a better understanding of the vestibular and optokinetic systems and their roles in space motion sickness, the eye movement responses to various dynamic stimuli are measured. The vestibulo-ocular reflex (VOR) and the optokinetic response, as the eye movement responses are known, consist of slow phase and fast phase nystagmus.

The specific objective of this study is to develop software programs necessary to characterize the vestibulo-ocular and optokinetic responses by distinguishing between the two phases of nystagmus. The overall program is to handle large volumes of highly variable data (nystagmus waveforms) with minimum operator interaction. The programs include digital filters, differentiation, identification of fast phases, and reconstruction of the slow phase with a least squares fit such that sinusoidal or psuedorandom data may be processed with accurate results. The resultant waveform, slow phase velocity eye movements, serves as input data to the spectral analysis programs previously developed for NASA, Johnson Space Center, Neurophysiology Laboratory to analyze nystagmus responses to psuedorandom angular velocity inputs. NASA Colleague: Millard Reschke, Ph.D., SB X2381
Introduction

Stimulation of the vestibular system by angular acceleration during head movements results in a reflexive eye movement called nystagmus. The resulting response (nystagmus) resembles a sawtooth waveform of which slow rotation of the eyes to maintain gaze on an object are related to the stimulus (slow phase) while rapid resets of the eye position are related to some centering mechanism (fast phase). Quantitative properties of nystagmus are important in the characterization of the vestibular and ocular systems. Thus, the specific objective of this study is to develop the necessary software programs to characterize the vestibular and optokinetic responses to sinusoidal stimuli by distinguishing between the two components of nystagmus.

Background

The methods used to analyze nystagmus vary from manual, to real-time automated processing in the time domain. Massoumnia presented models of the slow and fast phase velocities to establish that the slow and fast phase velocity spectra were superimposed. Thereby, he concluded that it was not possible to distinguish between the slow phase velocity and the fast phase velocity by analysis in the frequency domain (7).
In general, there are two time domain methods for identification of a fast phase event. One method is based on the analytical geometric property that points at which the first derivative waveform equals zero correspond to point at which the position waveform is an extremum (maximum or minimum). This method involves digital filtering and differentiating the ocular position signal prior to detecting the fast event with some velocity criterium. The second method is based on identification of the position waveform extrema by a search algorithm. Then a pseudo position waveform is obtained by connecting straight line segments between maxima and minima. The pseudo position waveform is used to calculate slopes (velocities), position changes, and time durations which in turn, are used to identify the fast phase events (8). An assumption of the method is that the information of value which is contained in the nystagmus can be obtained by replacing the detailed time-varying path of the EOG with straight-line approximations between points of maxima and minima. Seven parameter can be extracted by the method as is shown in figure 1. To date, one major vestibular research laboratory in the United States, out of the seven major laboratories which were selected for this study, uses the pseudo waveform method.
Fig. 1. Upper trace shows the psuedo position EOG waveform superimposed on the raw data. Lower drawing is an expanded version of the straight line approximation between points of extrema (MAX and MIN). SA denotes slow phase amplitude, FA is fast phase amplitude, SV is slow phase velocity, FV is fast phase velocity, SD is the slow phase duration, FD is the fast phase duration and T is the period; where frequency is 1/T.
**Characteristic Parameters**

In characterizing the slow phase velocity component vestibular researchers have used the engineer's approach to the analysis of a system, i.e., observe the response to a predetermined excitation in order to determine the system's transfer function. Knowledge of the system's transfer function permits prediction of the system response to other deterministic excitations. The most commonly used excitation signals in signal analysis are single frequency sinusoid, step, and impulse functions. The most popular analytical method is the use of a single frequency sinusoidal stimulus which applies only to linear systems analysis. The only parameters that can vary are the magnitude and phase of the resulting sinusoid. The frequency of the input and output are unchanged unless the system is nonlinear. Thus, gain (the ratio of output magnitude to input magnitude) and phase (the delay of signal transmission through the system) at a constant frequency are the only two parameters necessary to characterize the slow phase velocity systems.

Characterization of the fast phase velocity components of nystagmus (saccades) is not obtained by the frequency response method but rather by identifying true saccades, then measuring the maximum velocity of the fast phase segment (saccade), the total change of amplitude from the
start to the end of the fast phase segment, and the duration of the saccade. A least square exponential curve fit to the saccade maximum velocity versus total change of the saccade amplitude data results in two best fit coefficients. In addition saccade velocity, accuracy, and reaction time were used test the oculomotor system (2,3,4 and 5).

Current Processing

A general review of the analog and digitizing processes used by the laboratory reveals no agreement on filtering or digitizing as seen in Table I. Most laboratories used DEC LSI-11 computers with 12 bit analog-to-digital converters. The sampling rate at which the EOG data is digitized depends upon the objective of the analysis. If the principle goal is to identify and quantify the characteristics of the fast phase velocity components of nystagmus (saccades) as a means of diagnosing vestibulo-ocular disorders (3), then the data is sampled at 200 samples per second. Whereas, if the primary interest is solely on removal of the fast phases as a means of obtaining a more accurate estimate of the slow phase velocity parameters, then lower sampling rates are used.

The algorithms for processing the eye movements vary in structure primarily because of the ultimate aim of the analysis. Laboratories interested in retaining fast phase
TABLE I
Comparison of Analog Antialiasing Filtering and Digitizing in Vestibular Laboratories

<table>
<thead>
<tr>
<th>LAB</th>
<th>ANALOG</th>
<th>PREAMPS</th>
<th>FILTER TYPE</th>
<th>CUTOFF (Hz)</th>
<th>GAIN</th>
<th>DIGITAL</th>
<th>COMPUTER</th>
<th>A/D (Bits)</th>
<th>SAMPLING RATE (S/S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>IH</td>
<td>IH</td>
<td>IH</td>
<td>IH</td>
<td>IH</td>
<td>IH</td>
<td>IH</td>
<td>12</td>
<td>122.8</td>
</tr>
<tr>
<td>B</td>
<td>IH</td>
<td>6-pt Bessel</td>
<td>none Bu Bu</td>
<td>35</td>
<td>41.6</td>
<td>80</td>
<td></td>
<td>12</td>
<td>200</td>
</tr>
<tr>
<td>C</td>
<td>IH</td>
<td>2-pt Bessel</td>
<td>none Bu Bu</td>
<td>35</td>
<td>41.6</td>
<td>80</td>
<td></td>
<td>12</td>
<td>200</td>
</tr>
<tr>
<td>D</td>
<td>IH</td>
<td>none</td>
<td>Bu</td>
<td>35</td>
<td>41.6</td>
<td>80</td>
<td></td>
<td>12</td>
<td>200</td>
</tr>
<tr>
<td>E</td>
<td>IH</td>
<td>Bu</td>
<td>Bu</td>
<td>35</td>
<td>41.6</td>
<td>80</td>
<td></td>
<td>12</td>
<td>200</td>
</tr>
<tr>
<td>F</td>
<td>IH</td>
<td>Bu</td>
<td>Bu</td>
<td>35</td>
<td>41.6</td>
<td>80</td>
<td></td>
<td>12</td>
<td>200</td>
</tr>
<tr>
<td>G</td>
<td>IH</td>
<td>Bu</td>
<td>Bu</td>
<td>35</td>
<td>41.6</td>
<td>80</td>
<td></td>
<td>12</td>
<td>200</td>
</tr>
</tbody>
</table>

IH Fabricated in-house
Bu Butterworth filter
S/S Samples per second
information use higher bandwidth digital filters in order to maintain waveform and timing accuracy.

Two laboratories use optimal band limited derivatives (BLD) in lieu of some smoothing routine followed by a two-point central difference equation (CDE). The two-point central difference is popular as a first order differentiator because of its speed, simplicity, accuracy and low pass filtering (1). The laboratories using optimal filtering techniques convolve a finite impulse response (FIR) filter with a finite impulse differentiator to obtain velocity or acceleration filters. TABLE II compares the digital processes for eye movement analysis used by the seven vestibular laboratories.

It is interesting to note that three laboratories identify three classes of fast phase events but only one laboratory uses the saccade velocity information. In the evaluation of the slow phase velocity, most laboratories have algorithms which remove the fast phase events and fill-in the removed points with a linear extrapolation across either the position or velocity waveform. Two laboratories use a least squares sinusoidal fit to the velocity curve without filling the gap between slow velocity segments. Three laboratories have equally spaced intervals after the waveform reconstruction and only two of those laboratories
TABLE II
Comparison of Digital Processes
For Eye Movement Analysis
Laboratory

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
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<tr>
<td>FILTER TYPE</td>
<td>BLD</td>
<td>None</td>
<td>7-pt</td>
<td>LP</td>
<td>BLD</td>
<td>None</td>
</tr>
<tr>
<td>CUTOFF (Hz)</td>
<td>--</td>
<td>--</td>
<td>20</td>
<td>LP</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>DERIVATIVES</td>
<td></td>
<td></td>
<td></td>
<td>R̂F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>2-pt</td>
<td>2-pt</td>
<td>3-pt</td>
<td>2-pt</td>
<td>3-pt</td>
<td>4-pt</td>
</tr>
<tr>
<td>2nd</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>VEL. FILTER CUTOFF</td>
<td>31-pt</td>
<td>25</td>
<td>9-pt</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>ACCEL. FILTER CUTOFF</td>
<td>61-pt</td>
<td>30 Hz</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
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<tr>
<td>EXTRAPOLATION</td>
<td>Lin</td>
<td>Lin</td>
<td>None</td>
<td>None</td>
<td>Lin</td>
<td>Lin</td>
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<td>SLOW PHASE WAVE RECONSTRUCTION</td>
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<td>Vel</td>
<td>None</td>
<td>None</td>
<td>Vel</td>
<td>Pos</td>
</tr>
<tr>
<td>FAST PHASE CLASSIFICATION</td>
<td>3</td>
<td>--</td>
<td>3</td>
<td>3</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>LEAST SQUARES TRANSFORM</td>
<td>--</td>
<td>--</td>
<td>Sin</td>
<td>Avg</td>
<td>--</td>
<td>Sin</td>
</tr>
<tr>
<td>DIRECT FOURIER TRANSFORM</td>
<td>--</td>
<td>yes</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>FFT</td>
<td>yes</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>yes</td>
</tr>
</tbody>
</table>

CDE Central difference equation
FWD Forward difference equation
FFT Fast Fourier Transform
Vel Velocity
Sin Sinusoidal
Pos Position
Lin Linear
Ref Recursive Filter

21-10
use a fast fourier transform to obtain the frequency response parameters.

NASA FPID Program

Development of the fast phase identification (FPID) program began prior to evaluation of the seven U.S. laboratories. The engineering approach dictated the analytical geometric method. Horizontal eye movements (VOR) response to a sinusoidal stimulation of the vestibular system is digitized at 120 samples per second (Fig 2) and filtered with a digital 15-point, low-pass, finite-impulse-response (FIR) filter. The FIR filter cutoff is set at 25 Hz. The signal at 36 Hz is -40.1 db. Several FIR filters and smoothing routines were evaluated before selection of the final 15-point, FIR filter. The filtered EOG (position) signal is shown in figure 3.

The filtered signal is then differentiated with a central difference equation. The program permits the operator to select the polynomial order of the differentiator up to a sixth order central difference equation with error of order \( (h^6) \), where \( h \) is the sampling interval of 0.00833 seconds (8.33 msec.). Higher order equations result in better accuracy, but increase computation time. Hence, the fourth order (4-point) central difference equation with error of order \( (h^4) \) is used to obtain the first derivative of the EOG since it gives
Fig. 2. Raw horizontal eye movements are shown after removal of the D.C. offset.
Fig. 3. Horizontal eye movements after FIR filtering.
accurate results with only two points on either side of center (fig. 4).

The second derivative is obtained by differentiating the filtered EOG position signal with a 5-point, second derivative central difference equation of error order (h^2). The second derivative is shown in figure 5. The third derivative of the EOG position signal was also obtained with a 7-point central difference equation (6). The third derivative waveform was noisier than the lower derivative filters so it was removed from the program.

Following differentiation, the program computes the root-mean-square (RMS) value of the various derivatives waveforms in order to set a threshold value above the noise level so as to reduce false detection errors. From RMS values and approximate signal-to-noise ratios of each derivative waveform, detection of a fast velocity event is based on exceeding the first derivative threshold value rather than the second derivative as used by Massoumnia (7). The first derivative offered the least amount of noise and the best signal-to-noise ratio for threshold detection.

Once the threshold of the EOG velocity signal is exceeded the search point is moved backward to find where the derivative zero crossing occurs. This point is flagged as the beginning of the fast phase event and the search is
Fig. 4. First derivative of the filtered eye movements. The RMS value is 585 A/D counts for 2.08 seconds of data. The signal-to-noise ratio is 3:3:1.
Fig. 5. The second derivative of the filtered eye movements. The RMS value was $485 \times 10^2$ A/D counts for 2.08 seconds of data. The signal-to-noise ratio is 2.3:1.
reversed (forward direction) until a zero crossing occurs. This point was flagged as the end of the fast phase event.

In the next steps, the program uses the filtered eye position (EOG) waveform to perform a least squares linear regression on the slow phase velocity segment preceding the starting index of the current fast phase event. Then the points between start and end of the fast phase event are extrapolated and added to the position waveform.

Prior to output of the reconstructed slow phase EOG signal, a correction of slow segment height is necessary. This is accomplished by obtaining the change of position (height) from the last point of the extrapolated EOG position (end of fast phase index) and the start of the following slow phase segment (end point + 1). Height corrections are cumulative and must carry the proper sign. The reconstructed slow phase EOG position waveform is shown in figure 6. The FPID program listing is given in the appendix.

Conclusion and Recommendations

Although the fast phase identification (FPID) and slow phase reconstruction appear to work, the program needs to be evaluated with various types of VOR and OKN data. At the present time only short segments of data can be analyzed. The program needs a circular buffer, so that long data records can be analyzed. Additionally, the reconstructed
Fig. 6. The reconstructed slow phase horizontal eye movements.
wave must be written to a new data file prior to being used by the spectral programs written for NASA last summer.
REFERENCES


APPENDIX

FAST PHASE IDENTIFICATION
(FPID)

PROGRAM LISTING
PROGRAM FD

INTEGER Z(512), DSKINC, NBLK, IPOSN(10), MAX(10), ICHNUM(10), LENGTH
REAL AMPL, PERIOD, INTRAT, HFOG(512), XT, S:2, COEF(15),
1 YHEOG(512), SDEOG(512), SFEOG(512), SFYHFOG(512), FDEOG(512)

EQUIVALENCE (AMPL, Z(150)), (PERIOD, Z(151)), (INTRAT, Z(152)),
1 (DSKINC, Z(167)), (NBLK, Z(172)), (ICHNUM, Z(177)),
2 (IPOSN, Z(225)), (MAX, Z(241))

COEF(1) = .0037165603
COEF(2) = .020336427
COEF(3) = .013399956
COEF(4) = -.040643737
COEF(5) = -.066073574
COEF(6) = .061152643
COEF(7) = .30294424
COEF(8) = .43047285
NEH = 8
DO 5 N = 1, 7
COEF(16-N) = COEF(N)
CONTINUE

HHT = 0.
THT = 0.
ISLG = 0

INTEGER BUF2(1024), IERR
BYTE FILNAM(12)
DO 20 K = 1, 12
FILNAM(K) = 0
TYPE 30
FORMAT (' ENTER COMPLETE FILENAME/ ', FILENAME ? ', ')
ACCEPT 40, FILNAM
FORMAT (12A1)
CALL DISKIO(FILNAM, -3, Z, 256, 0, NDUM, Y, IERR)
IF (IERR .NE. 0) TYPE *, ' ERROR CODE', IERR, ' DURING READING'

42 TYPE *, ' CHAN NO.,'
ACCEPT **K

45 TYPE *, ' ENTER THE NUMBER OF DATA POINTS FOR EOG'
ACCEPT **LENGTH
C TYPE *, ' DO YOU WANT FILES LEFT OPEN? (1=YES)
C ACCEPT **LOPEN
LOPEN = 1

TYPE *, ' ENTER STARTING BLOCK NUMBER'
ACCEPT **IBLK
C TYPE *, ' DO YOU WANT TO PLOT EVERY POINT? ENTER STEP SIZE!
C ACCEPT **ISTEP
ISTEP = 1

NRDS = DSKINC* 256
ITEMP = 0
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0010 50 FORMAT (' HBLK=',I5,' NWRDS=',I5,' IBLK=',I5,' DSKINC=',I5)
0020 51 FORMAT (' MAX(K)=',I5,' IP(N(K))=',I5)

C
0040 52 CALL DISKIO(FILNAM,IRMODE,BUFR2,NWRDS,IBLK,NDUMM,Y1ER)  
C
0050 53 IF (IERR .NE. 0) TYPE *,' ERROR CODE ',IERR,' DURING READ' 
C
0060 54 NPTS = (MAX(K)-IP(SN(K)+1)/ISTEP 
0070 55 DO 57 L = 1,NPTS 
0080 56 HEOG(L+ITEMP) = BUFR2(IP(0SN(K) + L*ISTEP) 
0090 57 CONTINUE 
C
0100 58 DO 950 I = 1,26 
0110 59 TYPE 951, I, HEOG(I)  
0120 60 FORMAT (' I=',4X,'HEOG=',F12.5) 
0130 61 TYPE 950 CONTINUE 
C
0140 62 DO 961 I = LENGTH-26,LENGTH 
0150 63 TYPE 961, I, HEOG(I)  
0160 64 FORMAT (' I=',4X,'HEOG=',F12.5) 
0170 65 TYPE 960 CONTINUE 
C
0180 66 TYPE 962, NPTS,ITEMP 
0190 67 FORMAT (' NPTS=',I8,'ITEMP=',I8) 
0200 68 TYPE *,' WAITING TYPE 1' 
0210 69 ACCEPT*,ISN 
C
0220 70 IBLK = IBLK + DSKINC 
0230 71 ITEP = ITEP + NPTS 
C
0240 72 XLGT = FLOAT(LENGTH) 
0250 73 TYPE 50, NBLK, NWRDS, IBLK, DSKINC 
C
0260 74 DO 60 J = 1,LENGTH 
0270 75 XT(J) = FLOAT(J) 
0280 76 CONTINUE 
C
0290 77 TYPE *,' SET YMIN!' 
0300 78 ACCEPT *,YMIN 
0310 79 TYPE *,' SET YMAX!' 
0320 80 ACCEPT *,YMAX 
C
0330 81 ILFT = 600 
0340 82 IRT = 3500 
0350 83 IBOT = 1000 
0360 84 ITOP = 2500 
0370 85 XMIN = 0. 
0380 86 XMAX = XLGT 
C
0390 87 TYPE *,' DO YOU WANT TO REMOVE D.C.? (YES=1)' 
0400 88 ACCEPT *,YES 

21-23
IF (IY,  NE. 1) GO TO 142

C
COMPUTE THE MEAN OF THE DATA
XSUM = 0.0
DO 58 I = 1, LENGTH
XSUM = XSUM + HEOG(I)
58 CONTINUE
XMEAN = XSUM/XLGT
DO 59 I = 1, LENGTH
HEOG(I) = HEOG(I) - XMEAN
59 CONTINUE
C
CALL TSXCKH
CALL GRINIT(4014,4631,1)
CALL CHRSIZ(2)
CALL ERASE
CALL GRID(IO,IO,ILFT,IRIT,IBOT,ITOP,97)
CALL ANOTAT(IO,IO,ILFT,IRIT, IBOT,ITOP,XMIN,XMAX,YMIN, YMAX)
CALL XYPLOT(XT,HEOG,LENGTH,ILFT,IRIT,IBOT,ITOP,XMIN,XMAX, YMIN,YMAX)
CALL MPLOT(ILFT+500,ITOP+300,-1)

C
CALL HFLLOT(ILFT+500,ITOP+300,-1)

C
TYPE 61
FORMAT( '+RAW DATA ')

C
TYPE *, 'DO YOU WANT A HARD COPY? (YES=1)'
ACCEPT *,IS
IF (IS .NE. 1) GO TO 62
C
CALL COPY(0)

C
DO 500 I = 3, LENGTH-2
YHEOG(I) = .11*(HEOG(I-2)+HEOG(I+2))+.22*(HEOG(I-1)+HEOG(I+1))
1 + .33*HEOG(I)
500 CONTINUE

C
YHEOG(1) = YHEOG(3)
YHEOG(2) = YHEOG(3)
YHEOG(LENGTH) = YHEOG(LENGTH-2)
YHEOG(LENGTH-1) = YHEOG(LENGTH)
C
DO 510 I = 1, LENGTH
HEOG(I) = YHEOG(I)
510 CONTINUE

C
NCO = 15
C
TYPE *, 'FILTERING DATA WITH 15-POINT FIR FILTER!'

C
DO 80 I = 2, LENGTH+NCO
SUM = 0.0
DO 70 J = 1,NCO
L = J
IF (J .GE. I) GO TO 70
70 SUM = SUM + HEOG(J)
80 CONTINUE
21-24
0134    H = COEF(J) * HEDG(I-J)
0135    SUM = SUM + H
0136   70    CONTINUE
0137    YHEDG(I-1) = SUM
0138   80    CONTINUE
  C
0139    J2 = 14
0140   DO 81 J = 15, LENGTH+J2
0141   YHEDG(J-J2) = YHEDG(J)
0142   81 CONTINUE
  C
0143   DO 630 I = 1, 14
0144  YHEDG(LENGTH-I-1) = YHEDG(LENGTH-14)
0145  630 CONTINUE
  C
0146 CALL TSEXCHK
0147 CALL GRINIT(4014,4631,1)
0148 CALL CHRSIZ(3)
0149 CALL ERASE
0150 CALL GRID(10,10,ILFT,IRIT,IBOT,ITOF,97)
0151 CALL ANOTAT(IO,IO,ILFT,IRIT,IBOT,ITOF,XMIN,XMAX,YMIN,YMAX)
0152 CALL XYFLOT(XT,CHEO,LENGTH,ILFT,IRIT,IBOT,ITOF,XMIN,XMAX,
  1 YMIN,YMAX,1,0)
  C
0153 CALL MPLOT(ILFT+500,ITOF+300,-1)
0154   TYPE 261
0155   261 FORMAT('+ FIR FILTERED DATA ')
  C
0156   TYPE *, ' DO YOU WANT A HARD COPY? (YES=1) '
0157   ACCEPT *,IS
0158   IF (IS .NE. 1) GO TO 83
  C
0159   CALL COPY(O)
0160   H = FLOAT(ISTEP)/120.
0161   83    L = LENGTH
0162   TYPE *, ' SET DESIRED HALF ORDER OF DIFFERENTIATOR '
0163   ACCEPT *,NDIF
0164   GO TO (84,86,88),NDIF
  C
0165   84    DO 85 I = 2, LENGTH
0166   FDEOG(I) = (YHEDG(I+1) - YHEDG(I-1))/(H * 2.)
0167   85 CONTINUE
0168   FDEOG(1) = FDEOG(2)
0169   FDEOG(L) = FDEOG(L-1)
0170   GO TO 1000
  C
0171   86    DO 87 I = 3, L-2
0172   FDEOG(I) = ((YHEDG(I-2) - YHEDG(I+2)) + 8.*(YHEDG(I+1) -
  1 YHEDG(I-1)))/((H*12.)
0173   87 CONTINUE
0174   FDEOG(1) = FDEOG(3)
0175   FDEOG(2) = FDEOG(3)
0176   FDEOG(L) = FDEOG(L-2)

21-25
REAL XMFSD
C
TYPE *' SETTING MULTIPLYING FACTOR FOR 2ND DERIVATIVE' ACCEPT * XMFSD
C
XMFSD = .01
C
DO 400 I = 1, L
SDEOG(I) = XMFSD*SDEOG(I)
400 CONTINUE
C
FDRMS = 0.
SSFD = 0.
DO 700 I = 1, LENGTH-20
SSFD = SSFD + FDEOG(I)**2.
700 CONTINUE
SSMFD = SSFD/FLOAT(LENGTH-20)
FDRMS = SQRT(SSMFD)
TYPE 725,FDRMS
FORMAT (" RMS OF 1ST DERV. =",F8.3)
C
SDFMS = 0.
SSID = 0.
DO 750 I = 1, LENGTH-20
SSID = SSID + SDEOG(I)**2.
750 CONTINUE
SSMSD = SSID/FLOAT(LENGTH-20)
SDFMS = SQRT(SSMSD)
TYPE 775,SDFMS
FORMAT (" RMS OF 2ND DERV. =",F8.3)
C
TYPE *' WAITING! TYPE 1 TO CONTINUE.' ACCEPT*, JES
GO TO 90
C
DO 89 I = 4, L-3
FDEOG(I) = ((YHEOG(I+3) - YHEOG(I-3)) + 9.*(YHEOG(I-2) - 1 YHEOG(I-1)) + (45.*(YHEOG(I+1) - YHEOG(I-1))))/(H**60.)
89 CONTINUE

C
FDEOG(1) = FDEOG(4)
FDEOG(2) = FDEOG(4)
FDEOG(3) = FDEOG(4)
FDEOG(L) = FDEOG(L-3)
FDEOG(L-1) = FDEOG(L-3)
FDEOG(L-2) = FDEOG(L-3)
C
0222  GO TO 1000
C
0223  90  YMIN = YMIN*10.
0224  YMAX = YMAX*10.
0225  CALL TSXCHK
0226  CALL GRINIT(4014,4631,1)
0227  CALL CHRSIZ(3)
0228  CALL ERASE
0229  CALL GRID(10,10,ILFT,IRIT,IBOT,ITOP,97)
0230  CALL ANOTAT(10,10,ILFT,IRIT,IBOT,ITOP,XMIN,XMAX,YMIN,YMAX)
0231  CALL XYPLLOT(XT,SDEOG,LENGTH,ILFT,IRIT,IBOT,ITOP,XMIN,XMAX,
1  YMIN,YMAX,1,0)
C
0232  CALL MPLLOT(ILFT+500,ITOP+300,-1)
0233  TYPE 282
0234  282  FORMAT ('+ FIRST DERIVATIVE OF DATA')
0235  TYPE **' DO YOU WANT A HARD COPY? (YES=1)'
0236  ACCEPT **,IS
0237  IF (IS .NE. 1) GO TO 283
C
0239  CALL COPY(0)
C
0240  283  TYPE **' DO YOU WANT A SINGLE CURVE PLOT? (YES=1)'
0241  ACCEPT **, YES
0242  IF (YES .NE. 1) GO TO 210
0243  CALL TSXCHK
0244  CALL GRINIT(4014,4631,1)
0245  CALL CHRSIZ(3)
0246  CALL ERASE
0248  CALL GRID(10,10,ILFT,IRIT,IBOT,ITOP,97)
0249  CALL ANOTAT(10,10,ILFT,IRIT,IBOT,ITOP,XMIN,XMAX,YMIN,YMAX)
0250  GO TO 250
0251  210  IBOT = 1250
0252  ITOP = 2750
0253  250  CALL XYPLLOT(XT,SDEOG,LENGTH,ILFT,IRIT,IBOT,ITOP,XMIN,XMAX,
1  YMIN,YMAX,1,0)
C
0254  CALL MPLLOT(ILFT+500,ITOP+300,-1)
0255  TYPE 382
0256  382  FORMAT ('+ SECOND DERIVATIVE OF DATA')
0257  TYPE **' DO YOU WANT A HARD COPY? (YES=1)'
0258  ACCEPT **,IS
0259  IF (IS .NE. 1) GO TO 92
C
0261  CALL COPY(0)
C
0262  92  TYPE **' ANOTHER DIFFERENTIATOR? (YES=1)'
0263  ACCEPT **,IS
0264  IF (IS .EQ. 1) GO TO 83
C
0266  CALL ERASE
0267  TYPE **' IDENTIFICATION OF FAST PHASES'
0268  FDRMSTH = FDRMS*2.
0269  TYPE 410, FDRMSTH
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0270 410 FORMAT (' 1ST DERIV. RMS THRESHOLD = ', F9.3)
C
0271 110 LTERM = LENGTH - ISLG
0272 DO 112 J = 1, LTERM
0273 IF (ABS(FDEOG(ISLG+J)) .GT. ABS(FDRMSTH)) GO TO 115
0275 112 CONTINUE
C
0276 115 ITLST = J + ISLG
0277 TYPE 411, ITLST
0278 411 FORMAT (' INDEX TSH EXCD AT I = ', I5)
C
0279 IF (FDEOG(ITLST) .GE. 0.) GO TO 120
0281 TYPE ** ' NEGATIVE VALUES START'
0282 DO 117 L = 1, 10
0283 IF (FDEOG(ITLST - L) .GE. 0.) GO TO 124
0285 117 CONTINUE
0286 TYPE ** ' POSITIVE VALUES START'
0287 DO 120 L = 1, 10
0288 IF (FDEOG(ITLST - L) .LT. 0.) GO TO 128
0290 122 CONTINUE
0289 TYPE ** ' NEGATIVE VALUES END'
0292 124 ISTRT = ITLST - L
0293 TYPE 412, ISTRT
0294 412 FORMAT (' STRT NEG INDEX AT I = ', I4)
C
0295 DO 126 K = 1, 30
0296 IF (FDEOG(ITLST + K) .GE. 0.) GO TO 135
0298 126 CONTINUE
0299 TYPE ** ' POSITIVE VALUES END'
0300 128 ISTRT = ITLST - L
0301 TYPE 414, ISTRT
0302 414 FORMAT (' STRT POS INDEX AT I = ', I4)
C
0303 DO 130 LN = 1, 30
0304 IF (FDEOG(ITLST + LN) .LT. 0.) GO TO 134
0306 130 CONTINUE
0307 134 ISTP = ITLST + LN
0308 TYPE 415, ISTP
0309 415 FORMAT (' END POS INDEX AT I = ', I4)
0310 GO TO 136
C
0311 135 ISTP = ITLST + K
0312 TYPE 416, ISTP
0313 416 FORMAT (' END NEG INDEX AT I = ', I4)
C
0314 136 XN = 10.
0315 DXSUM = 0.
0316 DXSSUM = 0.
0317 DYSUM = 0.
0318 DXYSUM = 0.
0319 DO 140 ISL = ISTRT-10, ISTRT
0320 FI2 = FLOAT(ISL)
0321 DXSUM = DXSUM + FI2

ORIGINAL PAGE IS
OF POSTSCRIPT

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FORMAT (= DXSUM = DXSUM + FI2*FI2
DYSUM = DYSUM + YHEOG(ISL)
DXYSUM = DXYSUM + FI2*YHEOG(ISL)
CONTINUE
C
DENOM = (XN*DXSUM - DXSUM*DXSUM)
SLOPE = (XN*DYSUM - DXSUM*DYSUM)/DENOM
YINT = (DYSUM*DXSUM - DXSUM*DYSUM)/DENOM
TYPE 417, SLOPE, YINT
FORMAT (' SLOPE = ',F12.5, ' YINT = ',F12.5)
C
DO 142 ILF = ISTRT, ISTP
XILF = FLOAT(ILF)
YHEOG(ILF) = SLOPE*XILF + YINT
TYPE *, ILF, YHEOG(ILF)
CONTINUE
C
TYPE *, TO CONTINUE TYPE: 1
ACCEPT *, IX
CALL ERASE
C
TYPE **, RECONSTRUCT SLOW PHASE'
C
HHT = HHT + YHEOG(ISTP) - YHEOG(ISTP+1)
TYPE 420, HHT
FORMAT (' HEIGHT CORRECTION = ',F12.5)
C
TYPE 421, ISLG, ISTP
FORMAT (' STRT SP INDX = ',I4, ' STP SP INDX = ',I4)
C
DO 145 I = ISLG+1, ISTP
SPEOG(I) = YHEOG(I) + THT
TYPE *, I, SPEOG(I)
CONTINUE
C
THT = HHT
ISLG = ISTP
TYPE 425, ISLG
FORMAT (' NEW SEARCH STARTS AT I = ',I4)
TYPE **, TO CONTINUE TYPE: 1
ACCEPT *, IXS
C
IF (ISLG .LT. LENGTH) GO TO 110
C
TYPE **, PLOT RECONSTRUCTED SLOW WAVE? (YES = 1)
ACCEPT *, IYES
IF (IYES .NE. 1) GO TO 149
C
YMIN = YMIN*1.1
YMAX = YMAX*1.1
C
CALL TSXCHK
CALL GRINIT(4014,4631,1)
CALL CHRSIZ(3)
CALL ERASE
CALL GRID(10,10,ILFT,IRIT,IBOT,ITOP,97)
CALL ANOTAT(10,10,ILFT,IRIT,IBOT,ITOP,XMIN,XMAX,YMIN,YMAX)
CALL XYFLOT(XT,SPYEOG,LENGTH,ILFT,IRIT,IBOT,ITOP,XMIN,XMAX,
1 YMIN,YMAX+1,0)
CALL MFLOT(ILFT+500,ITOP+300,-1)
TYPE 882
FORMAT(*+ RECONSTRUCTED SLOW PHASE EOG POSITION DATA*)
TYPE *, ' DO YOU WANT A HARD COPY? (YES=1)'
ACCEPT *,I8
IF (I8 .NE. 1) GO TO 149
CALL COPY(O)
TYPE _,' DO YOU WANT 5-POINT SMOOTHING? (YES=1)'
ACCEPT *,IYES
IF (IYES .NE. 1) GO TO 149
DO 600 I = 3, LENGTH-2
SPYEOG(I) = .11*(SPYEOG(I-2)+SPYEOG(I+2))+.22*(SPYEOG(I-1)
1 +SPYEOG(I+1)) +.33*SPYEOG(I)
CONTINUE
SPYEOG(1) = SPYEOG(3)
SPYEOG(2) = SPYEOG(3)
SPYEOG(LENGTH) = SPYEOG(LENGTH-2)
SPYEOG(LENGTH-1) = SPYEOG(LENGTH)
CALL TSXCHK
CALL GRINIT(4014,4631,1)
CALL CHRSIZE(2)
CALL ERASE
CALL GRID(10,10,ILFT,IRIT,IBOT,ITOP,97)
CALL ANOTAT(10,10,ILFT,IRIT,IBOT,ITOP,XMIN,XMAX,YMIN,YMAX)
CALL XYFLOT(XT,SPYEOG,LENGTH,ILFT,IRIT,IBOT,ITOP,XMIN,XMAX,
1 YMIN,YMAX+1,0)
CALL MFLOT(ILFT+500,ITOP+300,-1)
TYPE 82
FORMAT(*+ FIR FILTERED AND 5-PT SMOOTHED DATA*)
TYPE *, ' DO YOU WANT A HARD COPY? (YES=1)'
ACCEPT *,I8
IF (I8 .NE. 1) GO TO 149
CALL COPY(O)
TYPE _,' DO YOU WANT A 15-PT FIR FILTER? (YES=1)'
ACCEPT *,IYES
IF (IYES .NE. 1) GO TO 150
DO 100 I = 2, LENGTH+NCO
DSUM =0.0
DO 95 J = 1, NCO
IF (J .GE. I) GO TO 95
IF (I - J .GT. LENGTH) GO TO 95
DH = COEF(J) * SFEOG(I - J)
DSUM = DSUM + DH
95 CONTINUE
96 CONTINUE
97 CONTINUE
DO 101 M = 15, LENGTH + J2
98 SFHFOG(M - J2) = SFHFOG(M)
101 CONTINUE
DO 102 I = 1, 14
99 SFHFOG(LENGTH - I - 1) = SFHFOG(LENGTH - 14)
102 CONTINUE
CALL TSXCHK
CALL GRINIT(4014, 4631, 1)
CALL CHRSIZ(3)
CALL ERASE
CALL GRID(10 * 10, ILFT, IRIT, IBOT, ITOP, 97)
CALL ANOTAT(IO, IO, ILFT, IRIT, IBOT, ITOP, XMIN, XMAX, YMIN, YMAX)
CALL XYFLOT(XT, SFHFOG, LENGTH, ILFT, IRIT, IBOT, ITOP, XMIN, XMAX, YMIN, YMAX, 1 YMIN, YMAX, 1 * 0)
CALL MPLOT(ILFT + 500, ITOP + 300, -1)
104 TYPE 104
105 FORMAT ('+ 15-PT FILTERED SLOW PHASE EOG DATA')
CALL COPY(0)
150 IBLK = IBLK - 3
IF (IBLK .LT. NBLK) GO TO 48
104 TYPE *,' ANOTHER CHANNEL OF DATA? (YES=1,)
105 ACCEPT *, JES
106 IF (JES .EQ. 1) GO TO 42
104 TYPE *,' TRY ANOTHER FILE? (I=YES) ?'
105 ACCEPT * MORE
106 IF (MORE .EQ. 1) GO TO 10
STOP
END
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