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COMPUTER RECOGNITION OF VARIOUS ASPECTS OF A 35-LEAD ELECTROCARDIOGRAM

BY

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MASTER OF SCIENCE

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I

INTRODUCTION

Computer processing and interpretation of electrocardiograms was originally introduced in the early 1960's as a method to rapidly prescreen a large number of tracings. It had been shown previously that the interpretation of a large number of electrocardiograms, if read in the usual clinical setting, produced a high degree of observer variation [3]. Moreover, the routine inspection of many normal tracings along with the relatively few pathological ones did not represent the best use of the physician's time.

The interpretation of any electrocardiogram is based on the physicians ability to recognize and classify various patterns in light of other clinical data. The physician must recognize the curves by their slope, amplitude, duration, and sequence. He then can classify the waves by comparing them to known standards. Although this comparison is subjective by nature, it is still based on the emperical data obtained from the ECG. Thus, the extraction of the raw data from the tracing is the most important step to electrodiographic analysis by means of a computer system [1].

In 1963, Caceres published a paper in the archives of Internal Medicine describing a computer system for ECG wave interpretation. The system was based on a point recognition technique which recognized the P, QRS and T waves of the electrocardiogram. The values of the amplitude and duration of these waves were printed along with the time relationships between any two of them. Tables were then output to make the manual diagnostic evaluation by physicians somewhat easier.

In 1964, another method of ECG interpretation was introduced bv Yasui.

Whipple and Stark based on a multiple-adaptive-matched-filter technique, used to recognize wave-form patterns [9]. The advantage to this system was the similarity to the human interpretation processes, and the straightforwardness of the computational aspects.

The system is designed to allow a variety of ECG signals to be input to the program. The signals are then compared to one another and if found to be highly correlated, they are combined and the mean value is stored. For those waves which are dissimilar to the previously stored waves, a new filter is created to store that particular wave. The system is initially blank so that the first filter to enter will occupy the initial space, thereby causing the first space to contain its waveform. The process continues until all signals have been classified.

The number of filters is directly correlated to the threshold value used for filter comparison. The higher the correlation coefficient, the greater the number of filters, resulting in a finer categorization.

When the program is run for diagnostic purposes, a patient's unknown wave is identified and classified by comparing it with the fixed library of diagnostic patterns. Each pattern represents a particular diagnosis which is outputted if the correlation coefficient is sufficiently high. This system used only the QRS complex for its interpretation, but the same technique could, in theory, be extended to the P wave, ST-T segments and the T wave. The system based only on the QRS complex correctly classified 58 out of 60 waves when the correlation coefficient was set at .7.

Another approach to the ECG interpretation problem was presented in 1969 by Haywood, et al. [4] Their system was designed as a continuous monitoring system for detection of rhythm changes in a real time environment. The system searched for the R wave by a point recognition technique, and then used the R-R interval to calculate the cycle time. The system saved data for off line additional analysis. The algorithm for this system was straightforward in that it was looking only for variations in the heart beat rhythm. The study was significant since it was among the first to monitor and detect abnormalities in a real time environment.

The system under consideration in this paper can be run either in a real time or batch processing environment. Its function is basically to measure the ST elevation relative to the baseline in the ECG. The baseline is adjusted for drift before the ST elevation is calculated in each lead. The system is based upon the input obtained from a 35 lead electrocardiogram. Each of the leads in the system is analyzed for a period of 5 seconds. In addition to the ST elevation, the program determines the heard beat rate and the R wave amplitudes.

The program and program description are presented along with the results obtained from a sample run. In addition, ten of the waves were analyzed in conjunction with the results obtained manually from the ECG graphs. This comparison is described in the results section at the end of the paper.

This thesis also provides information relavent to the general processing of electrocardiograms. The paper describes the main structures of the ECG and

and the important aspects of those structures to diagnosis of heart disease Moreover, the paper describes techniques which can be used to help the computer analyze ECG waves. These processing techniques include filtering, noise reduction and curve smoothing and are presented in the section on pre-processing.

II

CHARACTERISTICS OF THE ECG

The electrical potential variations within the heart may be recorded in a variety of ways. The method most frequently used is the electrocardiogram. While differences occur in various leads from the same subject, they all tend to conform to a common pattern. The normal electrocardiogram for a single heart beat consists of three main bumps which are designated as the P wave, QRS complex and T wave.

When the heart is at rest, the electrocardiogram displays a straight horizontal line which is known as the base line. The base line represents the zero potential of the heart. Electrical current developed with heart activity is plotted with respect to time and relative to the base line. Positive voltages are represented by upward deflections while downward deflections are representative of negative voltages. The base line is determined by a number of factors such as electrode movement, change in skin resistance and temperature.

Each main wave of the electrocardiogram represents one of the various states of the heart. The P wave results from the depolarization of the atrial muscle. The right atrial depolarization is demonstrated by the initial portion of the wave, while the left atrial depolarization is seen in the terminal portion of the P wave. The duration of the P wave is normally less than .10 seconds, and decreases as the heart rate increases. The amplitude usually remains under .3 mV. Since the deflection direction is dependent on the type of electrocardiogram and the position of the electrode, no indication of positive or negative wave direction can be given. The important characteristic of the P wave is its shape and duration.

Immediately following the P wave on some graphs is the T_p wave. The T_p wave is usually buried within the P-R segment, but is sometimes distinctive. It is of some importance in the presence of tachycardia as it may produce ST segment depression.

The next distinctive waveform is the QRS complex which represents ventricular depolarization and normally follows the P wave and P-R segment. The direction and shape of the QRS complex is dependent on several factors among which are the lead position and the anatomical position of the heart.

If the initial deflection of the QRS complex in a given lead is negative, it is called the Q wave. The first positive deflection in the QRS complex is called an R wave; this may or may not be preceded by a Q wave. Any negative wave in the QRS complex preceded by an R wave is called an S wave. If the wave is just a single negative wave it is called a QS complex.

The duration of the normal QRS complex is .05 to .1 milliseconds. The amplitude and duration of the complex varies from patient to patient, and from lead to lead. The Q wave should not exceed 25% of the amplitude of the succeeding R wave. The R wave should not be below 3 mV in any chest lead. The S wave does not normally exceed the amplitude of the preceding R wave.

The T wave is characteristic of the vetricular repolarization and follows the QRS complex and ST segment. The polarity of this deflection is usually, but not always, in the same direction as the QRS complex. The amplitude of the T wave is correlated in a general way with the height of the preceding QRS. The beginning of the T wave cannot be determined in many cases because of the gradual transition of the preceding S-T segment to the T wave.

There are various segments which lie between the various wave forms and are named for the waves which precede and follow them. These segments are the PR, ST and TP intervals. Of these, the most important for diagnosis and interpretation is the ST segment. The ST segment lies between the end of the QRS complex and the beginning of the T wave and corresponds to the period of complete ventricular depolarization. In tachycardia, the ST segment may start slightly low but then climb steadily, resulting in an upward sloping configuration. In cases where the S wave is missing, the S-T segment often starts slightly high from the decending limb of the R wave resulting in a downward sloping configuration. The segment between the T and P waves is known as the TP segment and is usually taken as a reference for a base line.

Pathological conditions introduce some characteristic changes in the electrocardiogram. These might occur in the form of irregular waves such as saw-toothed waves where the P wave should be (in atrial fibrillation). Other irregularities affect the QRS complex and the R wave itself.

The T wave and the preceding S-T segment, together referred to as the ST-T interval, constitute the most "sensitive" part of the ECG. The most significant change is the elevation or depression of the S-T segment and inversion of the T wave. If these changes occur in conjunction with QRS abnormalities, they are very significant for myocardial infarction, ventricular conduction defect or ventricular hypertrophy.

III

PREPROCESSING OF ECG's

The processing of this electrocardiogram by computer first involves the conversion of the continuous function f(t) over some interval T. The conversion is accomplished by choosing a set of times t_0, $t_1 \ldots\ldots t_n$ within the interval of equal spacing. The process is then to sample f(t) at these discrete points on the wave. One of the primary considerations in analog to digital conversion is the sample rate. A low sample rate results in a general loss of information while a high rate of sampling might result in too much data being generated. In addition, the cost of processing is proportional to the sampling rate.

To obtain the best results, the waveform should be sampled at a rate slightly higher than twice the rate of its highest frequency. In actual practice, biomedical signals are generally more unpredictable than other waves and are usually sampled at a higher rate than posed by theoretical considerations.

From a theoretical point of view, based on the waveform and heart rate, the sampling rate should be about 200 samples per second. In most cases, samples are taken at a rate of 500 to 1000 times per second. Studies have shown that the sampling rate variation from 200 to 1000 produces essentially the same set of measurements [8].

The electrocardiogram signal can be affected by noise from several sources. These produce a variety of unwanted waveforms and wave characteristics. Among the most prevalent are:

Baseline drift - due to body movement or imperfect electrode contact, spikes, and electronic noise. The noise in electrocardiograms is limited mainly to the low-frequency components such as the P wave, the PR segment, the ST segment, and the T wave. In order to compensate for noise introduced into the ECG signal, various preprocessing techniques are utilized to steady the baseline and smooth out the waveform. One of the methods to smooth out noise in the wave is by averaging.

$$Y_i = \frac{1}{N} \Sigma_{j=1}^{N} y_{ij} \quad \text{where } y_i \ (i=1, \ldots m)$$

represents the amplitude measured at time t=i. The Y_j points are a number of consecutive points in the ECG. In addition to removing unwanted spikes, averaging tends to minimize random noise and also tends to produce baseline rectification. Once the base line has been established it can be used as a reference level for the amplitude measurements.

Another method of digital filtering is a symmetrical moving average which is performed on the ECG. In a moving average, each point is replaced by the points around it and containing it. This is shown in the following formula:

$$y_0 = y_0 + \sum_{k=-N}^{N} Y_k/2N+1 \quad \text{for } N = 1, 2, 3, 4$$

for a 9 point moving average.

Analog and digital techniques are employed in the preprocessing of the ECG signal. These techniques provide the input data to the interpretation program with much of the noise and unwanted signals removed. The main processing program can then make various assumptions about the waves it analyzes without taking into consideration noise and spikes. The processing routine can then analyze the data at a higher rate and produce more accurate results.

Noise elimination is less important in situations where the ECG is being read by physicians. This is due to the fact that physicians can "automatically" ignore spikes and noise in the wave. They are also able to adjust for base line drift, since it is easy to recognize in the graph.

IV

PROGRAM DESCRIPTION

The electrocardiogram interpretation program has as its main function the analysis of the ST portion of the entire cardiac graph. The program logic can be broken down into several sub programs, each performing a separate task. The first phase of the program is concerned with the physical input. In this case, an 800 BPI tape is used which contains at least 37 records. With the exception of the first record which is the ID record, each record has 2500 16 bit words. Each data point corresponds to an input sample. The sampling rate is once every two milliseconds, thus every record of 2500 points is for a time duration of 5 seconds. The first record contains the tape identification consisting of the patient's name, the ST map number, and the date. The second record is five seconds of equipment calibration and is ignored by the program.

The tape is read into the computer by the FORTRAN INPUT statement. Since the original data is recorded using 16 bit words, the data must be unpacked to be correctly interpreted on the Sigma 9, a 32 bit machine. The 16 to 32 bit conversion is handled by a subroutine called PARSE. The parse routine, in addition to breaking up the 32 bit word into its components, also scales the numbers to correspond to voltages between the required ± 2 volts. The data points representing the digital voltages as a function of time are stored in the ARRAY A (2500). Should an end of file occur before the 37th record is encountered, the program will terminate without generating an end of file interrupt. The sampling rate of once every two milliseconds is quite high for the type of interpretation being done by this project, so in most analysis of the data, five or six points are skipped.

This speeds the execution of the program but does not destroy the resolution.

The second phase of the program involves determination of the type of record which is currently under consideration. Since we are dealing with 35 separate signals, we can have either positive directed waves or negative directed waves. In this phase of the program we are transversing the wave (with respect to time), checking at each interval to see if we are currently at a main pulse (QRS segment). We are using 10 milliseconds as the time change and approximately .125 volts as the magnitude of change. If the voltage changes absolutely by more than .125, then we check the wave 10 milliseconds later to see if there is either a +.4 magnitude change or a -.4 magnitude change. In the case where we find a ±.4 change, we assume we are on a positive (negative) going wave. The .4 represents the voltage necessary to pick up any QRS complex, but hopefully eliminate picking up spikes and the smaller P and ST waves. It is impossible to determine with certainty whether the change in voltage is really the wave we are searching for or some other aspect of the electrocardiogram. However, by using some heuristic techniques we can always get back on the right path even if one of the waves is not a true QRS wave. This involves the use of six separate peaks when analyzing any wave, and will be discussed in the wave analysis section.

Once we have established either a positive or negative going peak, we next determine the highest (lowest) element of the peak. This is done by performing a bubble sort (once) on the points of the QRS wave complex. The greatest value is saved in the MAX variable and is eventually stored, when the entire wave is transversed, in the R array. The index of the peak point which corresponds to the time at which the peak occurred is stored in the Y array. (An analogous situation, that of the negative going wave, is handled in exactly the same manner using the variable MIN and the S and Z arrays for R and Y respectively.)

The peak analysis is for 50 points. This represents a time of 100 milliseconds, which would cover any QRS complex. When the 50 points have been scanned, the next QRS wave is searched in the current wave. This is done until 6 waves have been found and the greatest (least) element of each wave has been saved. The next peak is always found by jumping ahead 300 milliseconds and then starting the search from the beginning (looking for a change of .125 volts). The 150 point jump will guarantee that we jump past any noise that might exist around the QRS wave and will also insure that we will not pick up the ST-T segment as another heart beat. When all six peaks have been identified, the program control is passed to the next phase; that of wave interpretation. If four peaks cannot be found, the wave is not studied further and an error message is printed stating that the lead was bad and no further processing was done on the lead. (We only look at waves in which four, five or six peaks are found.)

The third phase of the program is the actual wave interpretation. The interpretation of the wave, although primrarily concerned with the ST segment, also determines other pertinent information. The first information derived is the heart rate. This number is calculated by subtracting the time between successive heart beats (as represented by the QRS complex obtained in phase 2).

The next step in the wave analysis is to obtain a base line of the beat sequence. This is done by choosing a cluster of points approximately .6 of the distance between the beats. Twelve samples are taken in this area which should correspond on normal graphs to the TP segment. This is an area of very low potential and represents the unactivated state of the heart. An average is taken of these points and for 4 beats; the result is saved in the B array. Using the B array, a calculation is made to obtain the base line at the ST segment. The base line is basically the average height between two successive beats. This base line is stored in the GR array. GR is the normalized line to which the ST elevation can be compared. The base line analysis is important in the ST wave analysis since we must be certain that the ST elevation we encounter is due to the ST complex and not the general rise of the entire wave. Once we have normalized the wave, the calculation of the ST segment can be compared to one another for elevation differences.

The ST segment is located by scanning the wave approximately 120 milliseconds past the peak of the QRS complex. Samples are taken ± 8 milliseconds.

An average of the points found is determined and the final ST elevation is stored in the ST array. For the six beats taken in the earlier phase, only four ST segments are studied. For each of the 4 ST values saved, a pair wise comparison is made to determine which pairs of ST values are the closest in value. The pair of ST values found to be closest are used to determine an average ST elevation for the six-beat graph under consideration.

V

RESULTS

Several variations of the final program were tested using a tape of a typical 35-lead electrocardiogram. The program submitted represents the best performance in terms of accuracy and tolerance.

The program determined the following information for each of the 35 leads input:

R wave peak reading
Time of peak reading
Heart rate
Baseline reference
    ST segment elevation
    Average ST-elevation

The program was able to find at least four QRS complexes for each of the leads and thus produced results on each of the 35 leads.

To check the validity of the results obtained by the program, plots were made of ten of the 35 leads. These plots were taken directly from the 8-track tape, and no preprocessing was done on the data prior to the plotting. The results of the comparison are shown in tables 1-10. The tables contain the results obtained by hand calculation of the QRS (time), QRS (volts), Baseline and ST-elevation and are found in the rows marked actual. The rows marked prog. contain the numbers produced by the interpretation program submitted with this paper.

The program performed very well in determining the QRS amplitude and baseline readings. In all but two of the ten waves, the program values do not differ significantly from those obtained by hand calculation. In the two leads where there is significant differences, they can be explained by noting that the first R wave starts almost immediately in the particular record under consideration. This could cause the program to miss the start of the wave and pick up the ST elevation as the actual wave. Thus, it is possible to pick up the wave as negative when it is really a positive going wave. Once the direction of the wave has been established, it is impossible to change the direction of the analysis routine as the program is currently written.

In lead 14 the first R wave occurs .02 seconds after the start of the record. In this case, the R wave is completely missed by the program, but the remaining waves are picked up and interpreted correctly. This is due to the fact that the program did not set up any logic based on the direction of the initial R wave. The wave was completely skipped.

In lead 12, the second lead in which an improper interpretation was generated we see the record starting with a T wave. This then caused the baseline to be misinterpreted as the QRS complex resulting in an incorrect analysis.

The baseline calculation in virtually all the graphs was correct. This is due to the relatively long period of time during which the baseline can be calculated, and the fact that an averaging technique was used. Even in the waves where the QRS complexes were miscalculated, we find the baseline calculation does not differ significantly with the calculated (actual) value.

The last statistic given on the table (column 4) is the ST-elevation. This is the value of the ST segment relative to the baseline. Although the numbers calculated by hand are close approximations to the ST elevation, they cannot be compared statistically with the values obtained from the program. This is due to the fact that the algorithm used to calculate the ST elevation in the program differed from the method used to calculate the ST elevation by hand. In the hand calculation, the base line drift was not accounted for and the ST interval was estimated by eye only. The closeness of the values indicates, however, that the area used by the program for ST elevation calculations was indeed in the correct area for those calculations.

VI

DISCUSSION AND CONCLUSIONS

The program presented in this paper has demonstrated that it can accurately identify the various gross structures of the ECG wave. The program was able to correctly identify the wave features in 80% of the waves tested. In the two cases where the wave was improperly categorized, the problem stemmed from the program's inability to correctly adjust itself when the record started on one of the wave peaks (R wave or T wave).

It would be helpful if there was some system of syncronization established between the computer recorder and the ECG input. If we could start all records at one particular point on the wave we could avoid many of the difficulties encountered in this program. We would thus eliminate all of the special cases which would have to be accounted for to properly interpret the wave starting at any given point on the wave. Another interesting aspect of this program is that it could be developed to run in a real time environment. In this mode, the program could monitor patients looking for a change in the ST elevation. In the event where there was a significant change in the ST elevation, the program could output a warning signal for human intervention.

The entire program is written in FORTRAN IV (extended) and is completely self-contained. It requires no preprocessor and runs directly on the 8-track tape produced from the ECG.

In conclusion, I feel the program should be developed further so that it can either recover when started on a wave, or the input be changed so that it is wave syncronized.

```
C .......  ...............................................................
C
C  THE FOLLOWING ARE THE DECLARATIONS FOR THE PROGRAM
C
C      A(2500) VECTOR TO STORE THE 5 SECOND EKG RECORD
C      T(6) DISTANCE BETWEEN BEATS WITHIN RECORD
C      GR(6) BASELINE ANALYSIS
C      Q(6)
C      SS(6)ST ELEVATION ANALYSIS VECTOR
C      R(6),S(6) POSITIVE AND NEGATIVE ARRAYS FOR PEAK STORAGE
C      B(8) BASELINE STORAGE
C      ST(6) FINAL ST AVERAGE ANALYSIS
C      DB(12) BASE LINE ANALYSIS
C      TT(35) HEART RATE
C      AST(35) ST ELEVATION
C      ID(10) IDENTIFICATION FROM RECORD 1
C      MAX MAXIMUM VALUE FOR BEAT
C      MIN MINIMUM VALUE FOR BEAT
C      TAPE(1250) INPUT TAPE ARRAY RECORD- PACKED
C      DECD(1250) ARRAY FOR DECODING THE TAPE RECORD
C      IXM(10) ID INPUT VECTOR
C      Y(6),Z(6) INDEX ARRAYS FOR MAX AND MIN VALUES
C      LEAD(35) CURRENT LEAD NUMBER
C
C ...  .....  .......  ...  ..............................................
C
C
      REAL A(2500),T(6),GR(6),Q(6),SS(6)
      REAL R(6),S(6),B(8),ST(6),DB(12)
      REAL TT(35),AST(35),ID(10),MAX,MIN
      INTEGER TAPE(1250),DECD(1250),IXM(10)
      INTEGER N(6),X(6),Y(6),Z(6),HR(36),U
      INTEGER LEAD(35)
C
C
C        PRELIMINARIES--------------------------------------------------------
C
C
      C=1.;L=0
      STSUM=0
C
C
C        .   .........  ...  ...  ..........................................
C
C      INPUT ROUTINE AND DECODE/PARSE ROUTINES.
C
C        ..............................................................
C
C
C       GET ID RECORD
C
```

```
      CALL BUFFER IN (109,0,IXH,10,II)
      DECODE (40,91,IXH)(ID(K),K=1,10)
C
C      PRINT THE ID RECORD
C
      WRITE (108,70)(ID(K),K=1,10)
C
C      SKIP THE CALIBRATION RECORD
C
      CALL BUFFER IN (109,0,TAPE,1250,II)
C
C        ..............  ..   .    ....   ...............................................
C
C     START OF MAIN EXECUTION LOOP
C     GET THE NEXT RECORD-TEST FOR POSITIVE OR NEGATIVE GOING WAVE
C     SORT THE WAVE - DETERMINE THE BASSE LINE - FIND THE ST ELEVATION
C
C      .  ..........................................................................
C
12    L=L+1
      U=0
C
C  -  TEST FOR COMPLETION 35 RECORDS TO A TAPE
C
      IF (L.GE.36) GOTO 800
      WRITE (108,999)L
999   FORMAT(...,5X,'LEAD NUMBER: ',I2,'.',//,5X, -------------
C
C     GET THE NEXT RECORD IN
C
      CALL BUFFER IN(109,0,TAPE,1250,II)
11    GOTO (11,16,9000,16),II
16    DECODE (5000,50,TAPE)(DECD(K),K=1,1250)
C
C
C
C
C       UNPACK THE 2 16 BIT WORDS PER 32 BIT WORD
C
C
      DO 17,K=1,1250
      KJ=2*K-1
      CALL PARSE(DECD(K),IS1,IS1,S1,S1)
      A(KJ)=S1
      A(KJ+1)=S1
17    CONTINUE
C
C
      I=20
C
C     INITIALIZE THE Y AND Z ARRAYS
C
      DO 555 N=1,5
      Z(N)=0
```

```
555     Y(N)=0
C
C
C
C
C       TEST FOR ABSOLUTE DIFFERENCE FOR POSITIVE/NEGATIVE GOING WAVE
C
C
100     IF(ABS(A(I+1)-A(I)).GE..125) GOTO 155
        I=I+1
        IF (I.GE.2490)GOTO 301
        GOTO 100
C
C
C
C       FOUND POSITIVE
C
155     IF(A(I+6)-A(1).GE..4)U=1;  GOTO 200
C
C       FOUND NEGATIVE
C
      - IF((A(I+5)-A(I)).LT.-.4)U=-1;  GOTO 400
C
C       NO POS OR NEGATIVE WAVE LET GET NEXT POINT
C
        I=I+1
        IF(I.GE.2490)GOTO 301
        GOTO 100
C
C
C       POSITIVE   GOING   WAVE
C
C
200     K=0
        GOTO 202
201     IF (I.GE.2490) GOTO 301
        IF (A(I+5)-A(I).GE..4)  GOTO 202
        I=I+1
        GOTO 201
C
C
C       SORT POSITIVE PEAK.
C
C
202     N=1;MAX=-99.;K=K+1
        IF (K.GE.6) GOTO 301
204     IF (MAX.GT.A(1)) GOTO 203
        MAX=A(I);Y(K)=I
203     N=N+1
        I=I+1
        IF(N.GE.50) I=I+150;R(K)=MAX;GOTO 201
        GOTO 204
C
C
```

```
C       NEGATIVE GOING WAVE
C
C
400     K=0
        GO TO 402
401     IF(I.GE.2490) GO TO 301
        IF((A(I+5)-A(I)).LE.-.40) GOTO 402
        I=I+1
        GOTO 401
C
C
C       SORT NEGATIVE PEAK
C
C
402     N=1;MIN=99.;K=K+1
        IF(K.GE.6) GOTO 301
404     IF (MIN.LT.A(I)) GOTO 403
        MIN=A(I);Z(K)=I
403     N=N+1
        I=I+1
        IF (N.GE.50) I=I+150;S(K)=MIN; GOTO 401
        GOTO 404
C        .....  .......   ........................................................
C
C       HEART RATE DETERMINATION AND WAVE CALCULATIONS
C
C        ...  ..  ....  ..................................................
301     IF (K.LT.4) GOTO 700
        IF (U.EQ.-1) GOTO 320
        IF(U.EQ.1) GOTO 310
        GOTO  00
C
C       DETERMINE THE HEART RATE
C
310     DO 11 J=1,4
11      T(J)=Y(J+1)-Y(J)
        GOTO 13
320     DO 22 J=1,4
22      T(J)=Z(J+1)-Z(J)
C
C
C
C
13      IF(T(2)-T(1).GE.0)GOTO 31
        TT(L)=T(1)
        GOTO 19
31      TT(L)=T(2)
19      CONTINUE
C
C
C       TEST FOR POSITIVE OR NEGATIVE WAVE
C
C
        IF (U.EQ.-1) GOTO 42
```

```
      IF(U.EQ.1) GOTO 41
      GOTO 700
C
C
C     FIND THE AREA OF LOWEST POTENTIAL AND USE FOR THE BASE LINE
C     CALCULATION.
C
C
41    DO 20 J=2,5
      DO 25 I=1,12
25    DB(I)=A(Y(J-1)+IFIX(.6*T(J-1))-(I-7))
20    B(J)=(DB(1)+DB(2)+DB(3)+DB(4)+DB(5)+DB(6)+DB(7)+DB(8))/8.
C
C
      WRITE (108,1)(Y(I),I=1,5)
      WRITE (108,2) (A(Y(I)),I=1,5)
1     FORMAT(11X,'Y-PEAK POINTS',6(1X,I4))
2     FORMAT(11X,'R-PEAK READINGS',6(1X,F8.4))
      GOTO 59
C
C
C     CALCULATION FOR BASELINE OF NEGATIVE GOING PEAK
C
C
42    DO 46 J=2,5
      DO 47 I=1,12
47    DB(I)=A(Z(J-1)+IFIX(.6*T(J-1))-(I-7))
46    B(J)=(DB(1)+DB(2)+DB(3)+DB(4)+DB(5)+DB(6)+DB(7)+DB(8))/8.
C
C
      WRITE(108,3)(Z(I),I=1,5)
      WRITE(108,4)(A(Z(I)),I=1,5)
3     FORMAT(11X,'Z-PEAK POINTS:',6(1X,I4))
4     FORMAT(11X,'S-PEAK READINGS:',6(1X,F8.4))
C
C
C     B IS BASE
C
C
59    CONTINUE
C
C
C     GR IS THE BASE LINE AT THE ST SEGMENT
C
C
      DO 30 J=2,4
      GR(J)=.5*(B(J+1)-B(J))+B(J)
30    CONTINUE
C
C
C
C
      IF (U.EQ.-1) GOTO 72
      IF (U.EQ.1)GOTO 71
```

```
      GOTO 700
C
C
C     ST ELEVATION CALCULATION RELATIVE TO THE BASELINE
C     TWO CALCULATIONS ARE MADE ONE FOR POSITIVE AND ONE FOR NEGATIVE
C     GOING WAVES.  ST HOLDS THE VALUE OF THE ST ELEVATION AVERAGE
C
C
71    DO 40 J=2,4
      DO 44 I=1,6
44    SS(I)=A(Y(J)+60+(I-4))-GR(J)
      ST(J)=(SS(1)+SS(2)+SS(3)+SS(4)+SS(5)+SS(6))/6.
40    CONTINUE
      GOTO 89
C
C
C     NEGATIVE GOING ST ELEVATION CALCULATION
C
C
72    DO 81 J=2,4
      DO 45 I=1,6
45    SS(I)=A(Z(J)+20-(I-4))-GR(J)
      ST(J)=(SS(1)+SS(2)+SS(3)+SS(4)+SS(5)+SS(6))/6.
81    CONTINUE
C
C
C     COMPARISION OF ST VALUES TO FIND THE CLOSEST PAIR
C
C
89    D1=ABS(ST(2)-ST(3))
      D2=ABS(ST(4)-ST(3))
      D3=ABS(ST(4)-ST(2))
C
C     CLOSEST ST VALUES ARE AVERAGED AND USED FOR THE ST ELEVATION VALUE
C
      IF(D1.LE.D2)GOTO 111
      IF(D2.LE.D3)GOTO 220
C
C
      AST(L)=(ST(2)+ST(4))/2. ; GOTO 444
111   IF(D1.LE.D3) GOTO 330
220   AST(L)=(ST(4)+ST(3))/2. ; GOTO 444
330   AST(L)=(ST(3)+ST(2))/2.
444   CONTINUE
C
C
C     CALCULATE THE RATE PER MINUTE AND CHECK RANGE OF THE ST ELEVATION
C
C
670   HR(L)=60000./(2*TT(L))
      IF(AST(L).GE.ABS(1.5)) AST(L)=0
      IF(AST(L).LT.0) AST(L)=0
C
C     PRINT THE HEART RATE, THE BASEE LINE, THE ST ELEVATION AND THE
```

```
C      AVERAGE ST VALUE
C
       WRITE (108,60) HR(L)
       WRITE (108,65) (B(J),J=2,5)
       WRITE (108,66) (ST(J),J=2,4)
       WRITE (108,67) AST(L)
C
C
C
C
       I=0
900    GOTO 12
C
C
C
C
700    WRITE(108,88)
88     FORMAT(11X,'BAD LEAD OR INSIGNIFICANT INPUT')
       AST(L)=0
       GOTO 12
C
C
C      CALCULATE THE ST ELEVATION SUM AND OUTPUT THE RESULT
C
C
800    DO 79 I=1,35
79     STSUM=STSUM+AST(I)
       WRITE (108,92) STSUM
92     FORMAT(10X,'THE ST ELEVATION SUM IS: ',F11.4)
C
C
C
C
55     FORMAT (11X,'INSIGNIFICANT R-WAVE')
C
56     FORMAT (11X,'INSIGNIFICANT S-WAVE')
C
60     FORMAT (11X,'HEART RATE IS:      ',I3)
C
65     FORMAT (11X,'BASE REFERENCE:   ',5(F6.4,1X))
C
66     FORMAT (11X,'ST SEGMENT ELEVATION:     ',5(F8.4,1X))
C
67     FORMAT (11X,'AVERAGE ST-ELEVATION IS:     ',F10.6)
C
68     FORMAT(11X,'BAD R-WAVE',5X,5(F8.4,1X),/,27X,2(F8.4,1X),
     ### GO TO NEXT BEAT ##')
C
69     FORMAT (9X,'#### IRREGULAR HEART RATE ####')
C
70     FORMAT ('IID: ',10A4)
C
90     FORMAT (1250A4)
C
```

```
91      FORMAT (10A4)
9000    END
        SUBROUTINE PARSE(IWJ, ISI, IS1, SI, S1)
        JW=IWJ
        ISI=ISA(JW, -16)
        SI=(ISI*10)/32767.
        JW=IWJ
        JW=ISL(JW, 16)

        IS1=ISA(JW, -16)
        S1=IS1*10./32767.
        RETURN
        END
```

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TABLE 1

LEAD 2

	QRS(TIME)	QRS(VOLTS)	BASELINE	ST-ELEVATION
BEAT 1 PROG.	.19	-2.85	-.206	.130
ACTUAL	.18	-2.89	-.18	.142
BEAT 2 PROG.	1.10	-3.08	-.188	.120
ACTUAL	1.10	-3.09	-.18	.146
BEAT 3 PROG.	2.02	-2.87	-.169	.140
ACTUAL	2.02	-2.88	-.18	.122
BEAT 4 PROG.	2.92	-2.82	-.256	
ACTUAL	2.92	-2.74	-.185	
BEAT 5 PROG.	3.38	-3.03		
ACTUAL	3.83	-3.05		
BEAT 6 PROG.				
ACTUAL				

TABLE 2

LEAD 4

	QRS (TIME)	QRS (VOLTS)	BASELINE	ST-ELEVATION
BEAT 1 PROG.	.138	-.099	-.319	.071
ACTUAL	.04	-2.61	-.320	.160
BEAT 2 PROG.	.98	-.093	-.334	.156
ACTUAL	.88	-2.70	-.40	.24
BEAT 3 PROG.	1.81	-.153	-.341	.126
ACTUAL	1.74	-2.63	-.34	.16
BEAT 4 PROG.	2.68	-.126	-.279	
ACTUAL	2.58	-2.53	-.280	
BEAT 5 PROG.	3.54	-.020		
ACTUAL	3.45	-2.64	-.30	
BEAT 6 PROG.				
ACTUAL	4.33	-2.60	-.34	

TABLE 3

LEAD 6

	QRS (TIME)	QRS (VOLTS)	BASELINE	ST-ELEVATION
BEAT 1 PROG.	.294	-.87	-.169	.081
ACTUAL	.300	-.87	-.18	.11
BEAT 2 PROG.	1.21	-.922	-.166	.107
ACTUAL	1.21	-.920	-.18	.11
BEAT 3 PROG.	2.13	-.792	-.116	.108
ACTUAL	2.13	-.790	-.120	.11
BEAT 4 PROG.	3.10	-.782	-.128	
ACTUAL	3.06	-.78	-.11	
BEAT 5 PROG.	3.98	-.801		
ACTUAL	3.98	-.810		
BEAT 6 PROG.				
ACTUAL				

TABLE 4

LEAD 8

	QRS (TIME)	QRS (VOLTS)	BASELINE	ST-ELEVATION
BEAT 1 PROG.	.454	-1.97	.701	.135
ACTUAL	.45	-2.04	.72	.06
BEAT 2 PROG.	1.37	-2.035	.700	.130
ACTUAL	1.37	-2.00	.72	.06
BEAT 3 PROG.	2.33	-2.122	.763	.146
ACTUAL	2.33	-2.12	.73	.16
BEAT 4 PROG.	3.29	-2.065	.769	
ACTUAL	3.29	-2.11	.780	
BEAT 5 PROG.	4.22	-1.826		
ACTUAL	4.22	-1.83		
BEAT 6 PROG.				
ACTUAL				

TABLE 5

Lead 10

	QRS(TIME)	QRS(VOLTS)	BASELINE	ST-ELEVATION
BEAT 1 PROG.	.264	-2.10	1.80	.288
ACTUAL	.260	-2.11	1.79	.360
BEAT 2 PROG.	1.136	-1.93	1.769	.339
ACTUAL	1.14	-1.86	1.89	.480
BEAT 3 PROG.	2.01	-2.29	1.761	.362
ACTUAL	2.02	-2.29	1.75	.43
BEAT 4 PROG.	2.94	-2.23	1.871	
ACTUAL	2.94	-2.20	1.90	
BEAT 5 PROG.	3.85	-1.78		
ACTUAL	3.86	-1.79		
BEAT 6 PROG.				
ACTUAL				

TABLE 6

LEAD 12

	QRS(TIME)	QRS(VOLTS)	BASELINE	ST-ELEVATION
BEAT 1 PROG.	.676	1.00	.837	.288
ACTUAL	.78	-.67	.85	.21
BEAT 2 PROG.	1.78	1.09	.916	.266
ACTUAL	1.69	-.51	.90	.20
BEAT 3 PROG.	2.69	1.14	.940	.249
ACTUAL	2.63	-.43	.95	.25
BEAT 4 PROG.	3.63	1.19	.970	
ACTUAL	3.54	-.46	.98	
BEAT 5 PROG.	4.54	1.19		
ACTUAL	4.46	-.49		
BEAT 6 PROG.				
ACTUAL				

TABLE 7

LEAD 14

	QRS (TIME)	QRS (VOLTS)	BASELINE	ST-ELEVATION
BEAT 1 PROG.	missed	missed	missed	missed
ACTUAL	.02	1.73	.85	.03
BEAT 2 PROG.	.91	1.782	.869	.049
ACTUAL	.92	1.79	.88	.00
BEAT 3 PROG.	1.84	1.832	.871	.030
ACTUAL	1.84	1.82	.88	.030
BEAT 4 PROG.	2.808	1.694	.835	.065
ACTUAL	2.80	1.70	.84	.01
BEAT 5 PROG.	3.754	1.587	.820	
ACTUAL	3.76	1.57	.94	
BEAT 6 PROG.	4.33	1.28	SPIKE	
ACTUAL	4.34	1.28	SPIKE	

TABLE 8

LEAD 16

	QRS (TIME)	QRS (VOLTS)	BASELINE	ST-ELEVATION
BEAT 1 PROG.	.56	-3.80	1.53	.474
ACTUAL	.50	-3.80	1.63	.49
BEAT 2 PROG.	1.49	-3.65	1.48	.482
ACTUAL	1.50	-3.72	1.69	.33
BEAT 3 PROG.	2.45	-3.77	1.45	.543
ACTUAL	2.44	-3.77	1.63	.33
BEAT 4 PROG.	3.44	-3.78	1.47	
ACTUAL	3.44	-3.78	1.50	
BEAT 5 PROG.	4.41	-3.75		
ACTUAL	4.42	-3.79		
BEAT 6 PROG.				
ACTUAL				

TABLE 9

LEAD 18

	QRS (TIME)	QRS (VOLTS)	BASELINE	ST-ELEVATION
BEAT 1 PROG.	.500	-.929	1.455	.312
ACTUAL	.49	-.95	1.48	.31
BEAT 2 PROG.	1.45	-.966	1.401	.321
ACTUAL	1.45	-.97	1.38	.34
BEAT 3 PROG.	2.41	-.988	1.417	.325
ACTUAL	2.41	-.99	1.44	.25
BEAT 4 PROG.	3.40	-.935	1.394	
ACTUAL	3.38	-.95	1.40	
BEAT 5 PROG.	4.34	-.994		
ACTUAL	4.34	-.99		
BEAT 6 PROG.				
ACTUAL				

TABLE 10

LEAD 20

	QRS(TIME)	QRS(VOLTS)	BASELINE	ST-ELEVATION
BEAT 1 PROG.	.074	2.476	1.464	.093
ACTUAL	.08	2.49	1.47	.13
BEAT 2 PROG.	1.01	2.374	1.433	.077
ACTUAL	1.02	2.36	1.45	.09
BEAT 3 PROG.	1.93	2.378	1.508	.094
ACTUAL	1.92	2.38	1.52	.08
BEAT 4 PROG.	2.87	2.530	1.536	
ACTUAL	2.88	2.53	1.52	
BEAT 5 PROG.	3.84	2.513		
ACTUAL	3.84	2.58		
BEAT 6 PROG.				
ACTUAL				