TRANSITIONAL FREQUENCY IN THE ELECTROOCULOGRAM

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ABSTRACT

A data acquisition system using the Intel 486 microprocessor has been implemented to process and analyze a biomedical signal in the form of an Electrooculogram. The frequency spectrum of biomedical signals associated with eye movements is investigated for normal subjects and others suffering from depression. Transition from smooth pursuit to saccadic eye movement are performed at 1.6Hz in 92% of normal subjects, whereas transition is at 1.2Hz in 83% of the depressed subjects. The amplitude of the fundamental component in the signal spectrum has been found to decrease with increasing frequency.

Keywords: Electrooculogram, Biomedical, Smooth pursuit, Saccade Microprocessor

INTRODUCTION

Speed, low cost and availability made the Intel 486 microprocessor suitable for many applications. An attempt has been made in this work to use this processor for biomedical data acquisition and signal processing. Electrooculograms has been collected using the test system shown in Figure A-1 in the Appendix. The signals received are converted from time domain to frequency domain and then processed. In previous work [1] it is found that subjects observing a moving stimulus reproduce the movement of the stimulus.

Smooth pursuit and saccade are functional classification of the eye movement [2]. Smooth pursuit eye movement has always been investigated separately from saccadic eye movement, and are thought of as being of independent nature. Corrective saccades are possible at high speed as stated by Zambarbieri [3]. This work however, investigates the range of frequency through which the smooth pursuit system and the saccadic system operates.

The amplitudes of the fundamental component and the harmonics in the signal spectrum are considered in this work. A sinusoidal signal in the time domain is represented by a single component (the fundamental) in the frequency domain while a non sinusoidal signal is represented by the sum of the fundamental component and the harmonics [4]. The received signal has been processed accordingly to find out the frequency at which the smooth pursuit system is operated before it is replaced by the saccadic system. Since, the signal collected from around the eye is in the time domain and it is transformed into the frequency domain, the analysis of the spectrum has a discrete nature.

Defining the frequency ranges during which the smooth pursuit system is operated and that for the saccadic system, helps in understanding the nature of the eye movement as a function of an increasing stimulus frequency.

METHODOLOGY

The test system given in the Appendix has been used in collecting the required signal, is with the following features:

1. Five silver-silver chloride electrodes.
2. Analog Multiplexer (AD7502) with four differential input channels and a 20-μs settling time.
3. Seventh order band pass filter with cut off frequencies 0.05Hz to 12Hz.
4. Sample-and-hold amplifier (AD583).

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5. (AD4574) ±5V A/D converter with 12-bit resolution and 25-μs conversion time.
6. A 16-bit tristate register (74LS244). The highest four bits are always 0.
7. The Intel 486 microprocessor chip.
8. An 8253-5 Programmable Interval timer operating at 2-MHz clock rate.
9. A digital control circuit for synchronizing the different components.

This microcomputer setup is used for data collection and spectral analysis while a second computer is used for target movement. By influencing the eyes to follow the stimulus motion, at certain frequencies, information can be gathered from the analysis of the received signals [5,6]. Data is collected in the frequency range 0.1Hz and 1.0Hz in steps of 0.1Hz, and between 1.0Hz and 2.0Hz in steps of 0.2Hz, and at 2.5, 3.0 and 4.0Hz, to give a clear picture of the eye movement, while pursuing a target moving at an increasing frequency. Frequency contents are found by computing 256-points long Fast Fourier Transforms. Figures 2-A to A-5 in the Appendix show sample results obtained when tests are made at 0.2Hz and at 2Hz. In these appendices the digital curves represent the time series signal collected from the eyes, and the bars represents corresponding frequency spectra. The resulting harmonics are isolated from 0.1Hz up to 4.0Hz, for each subject tested for future analysis. The amplitude of the fundamental component versus frequency is plotted for each eye. Tests are made on normal and depressed subjects, male and female, of various ages to get a broad range of data for a more comprehensive study.

RESULTS

Normal Females

Table 1 Amplitude of the fundamental component.

Number of subjects tested & State of health	Age years	Frequency Range (Hz)	Ampli-tude	Effect of increasing frequency on Amplitude
32 Normals	18-66	0.1-1.6 1.8-4.0	>1.0 <1.0	Inverse proportionality
18 Depressed subjects	25-79	0.1-1.0 1.2-4.0	>1.0 <1.0	Inverse proportionality

The fundamental component amplitude (referred to as amplitude henceforth) is greater than 1 for eye traveling at frequencies of less than 1.6Hz as can be seen from Figure1 and Table 1. Traveling at higher frequency causes the amplitudes to become less than 1 for both eyes.

The effect of age is clear for this group, for instance at 0.6Hz, the amplitude is equal to 19 for subject aged 20 while for subject aged 65 the amplitude is equal to 7.

Depressed subjects amplitudes are >1 when eye travels at frequencies <1.2Hz as can be seen from Figure 2. Traveling above this frequency value reduces the amplitudes to a value less than 1 for both eyes. Age has no effect on this group, for instance at 0.2Hz, the amplitude is equal to 15 for subject aged 65, while for subject aged 37 the amplitude is equal to 6 and 8 for the left and the right eye. Severe fluctuation in amplitude is noted below the frequency of 1.2Hz for both eye, this agreed well with results reported by [7]. From the above results it can be said that for normal female subjects the amplitude decreases as frequency and age increase. For depressed subjects, the amplitude decreases only when the frequency increases.

Normal Males

Table 2 Amplitude of the fundamental component

Number of subjects tested & State of health	Age years	Frequency Range (Hz)	Ampli-tude	Effect of increasing frequency on Amplitude
15 Normals	22-64	0.1-1.6 1.8-4.0	>1.0 <1.0	Inverse proportionality
10 Depressed subjects	20-65	0.1-1.0 1.2-4.0	>1.0 <1.0	Inverse proportionality

It is observed that the amplitudes are less than 1 for eye traveling at frequencies less than 1.6Hz as can be seen from Figure 3 and Table 2. Above this frequency the amplitudes are less than 1 for both eyes. The effect of age on the amplitude of the fundamental component can be observed clearly if the amplitudes of two subjects are compared at 0.5Hz. Subject aged 22 had his amplitude equal to 23, while subject aged 64 had his amplitude equal to 11. Depressed subjects amplitudes were greater than 1 when eyes were traveling at frequencies less than 1.2Hz as can be seen from Figure 4. Above this frequency the amplitudes were less than 1.0 for both eyes. Age did not seem to affect their results. Severe fluctuation in amplitude is noted below 1.2Hz for both eye. It can be said that the amplitude of the fundamental decreases as the target frequency and age increase for normal male subjects. Whereas for depressed subjects the amplitude decreases as the target frequency increases.

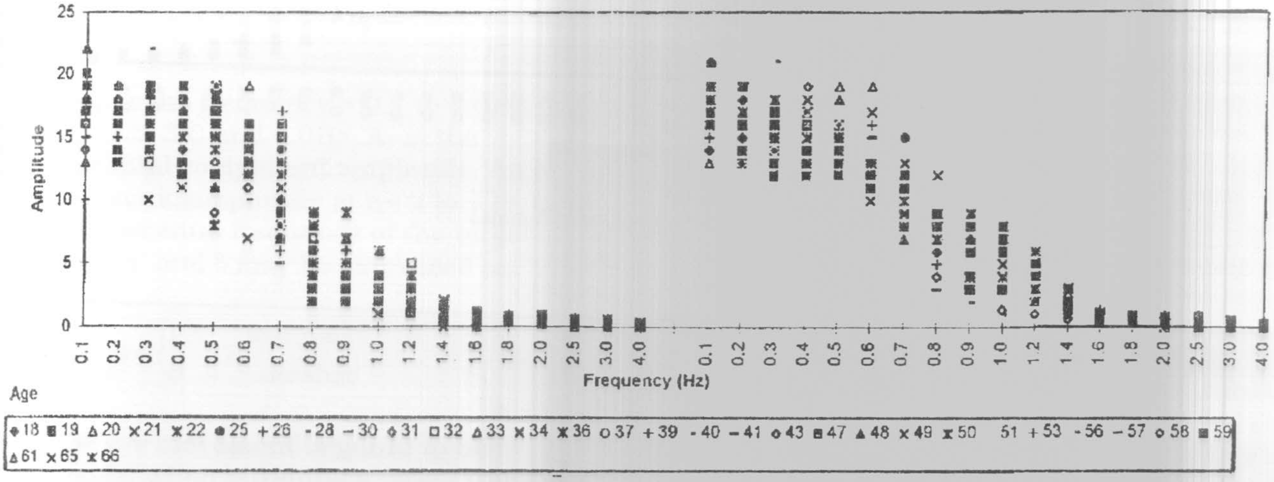

Figure 1 Normal females

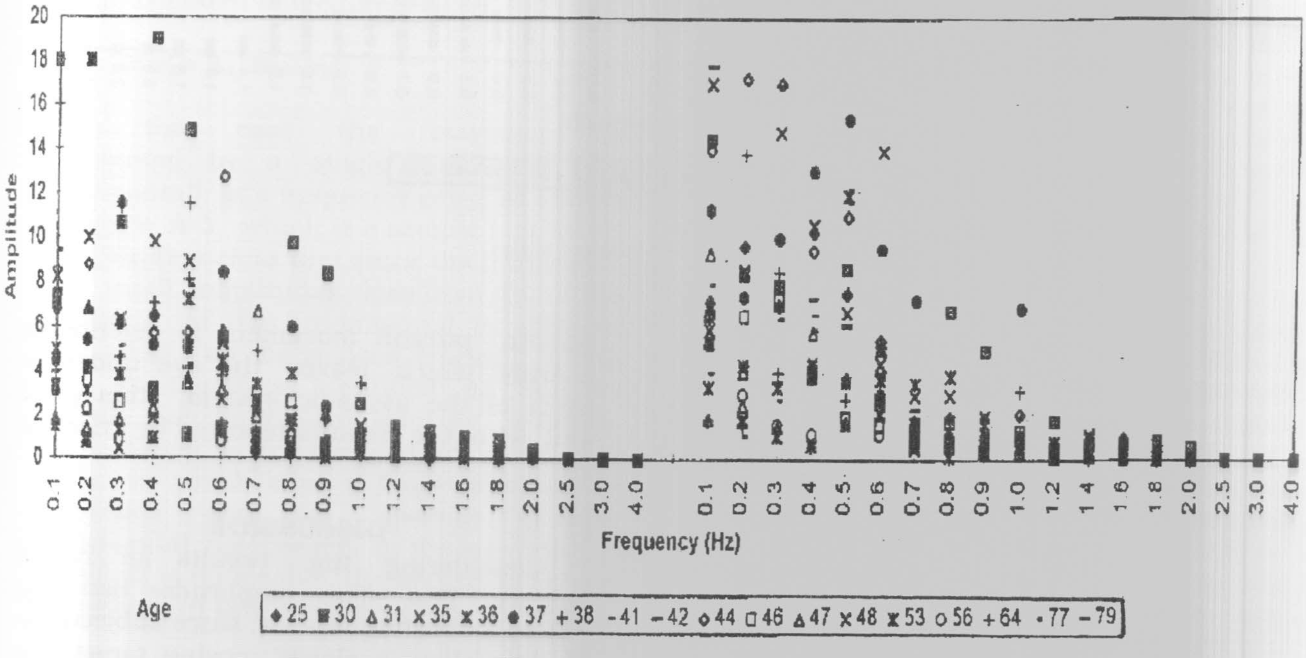

Figure 2 Depressed females

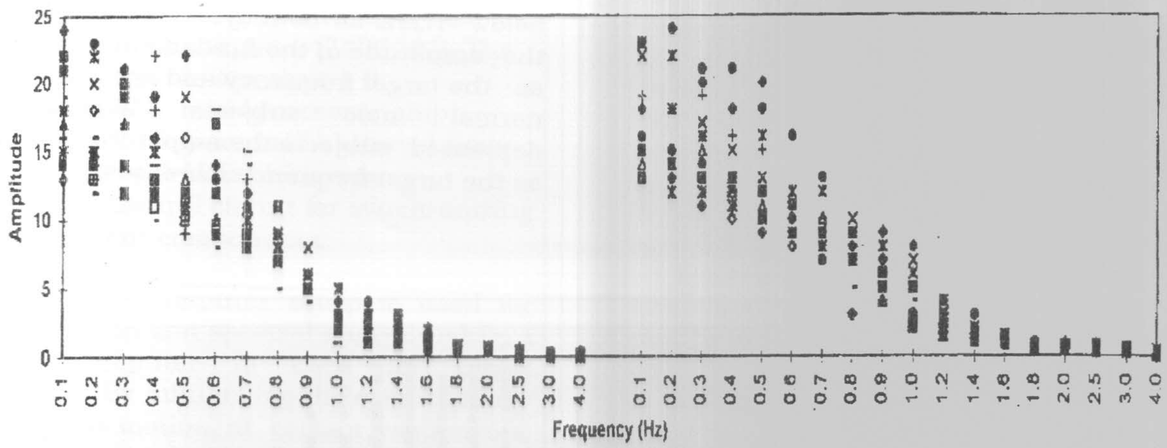

Figure 3. Depressed females

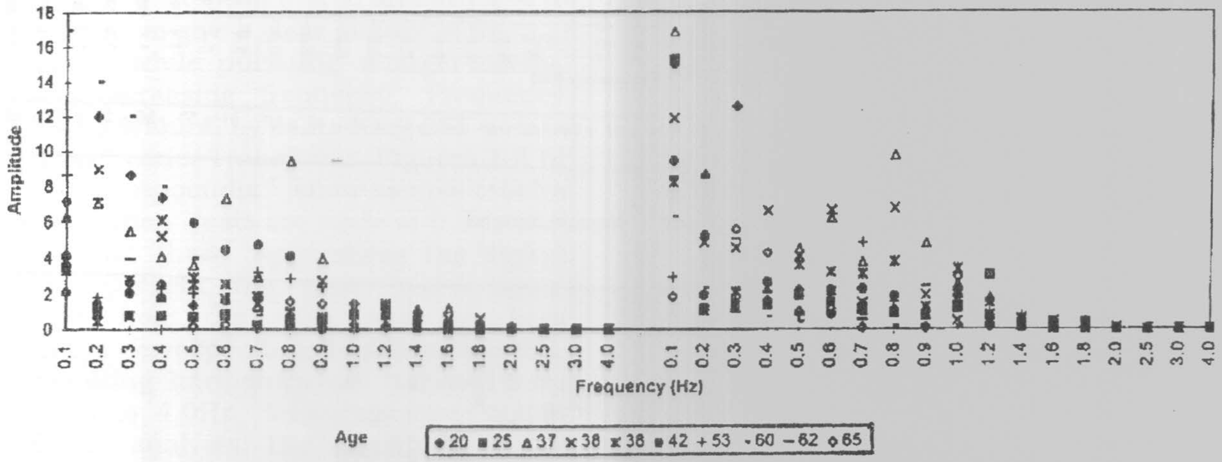

Figure 4 Depressed males

The results presented so far proved that the eye can smoothly pursue a target if this target travels below a certain frequency, if this frequency is exceeded, then the eye is no longer moving smoothly. The amplitude of the fundamental component is decreased as the target frequency is increased because the movement of the eye is changed from the sinusoidal nature to that of saccadic nature i.e. square wave nature . The small value of the fundamental component and the presence of harmonics means non sinusoidal eye tracking. Therefore; the smooth pursuit movement is deteriorated sharply which leaves the eye under the effect of the saccadic system, this agreed well with the results reported by Friedman [8].

DISCUSSION

Considering the results for normal subjects first. The amplitudes had large values at low frequencies, since subjects can easily follow a slowly moving target. The physiological reason behind this, is that at low frequency the subject can memorize the trend of the motion and hence, could predict the new position of the target [9]. Consequently, the eye moves to this position sinusoidally without making any jump. But when the target frequency is high, its position becomes unpredictable, and hence The spectrum of the signal may be expressed as:

$$F(\omega) = A_1\delta(\omega-\omega_o) + \sum_{n=2}^{N} A_n \delta(\omega-n\omega_o) \qquad (1)$$

where ω is the frequency = 0.1 to 1.0Hz, 1.2 to 2Hz, 2.5, 3.0 and 4.0Hz, A_1 is the fundamental component amplitude. An is the harmonic amplitude at n= 2 to 128, ω_o is the fundamental frequency of the target movement and δ may be expressed as:

$$\delta\ (\omega-\omega_0) = \begin{cases} 1 & \text{for } \omega = \omega_0 \\ 0 & \text{elsewhere} \end{cases}$$

The eye movement is found to be sinusoidal when pursuing a target travels at a frequency of less than 1.6Hz, the spectrum of the eye movement in this case may be approximated and expressed as:

$$F(\omega) = A_1\ \delta(\omega-\omega_0) \qquad (2)$$

In this case the movement is represented by a single component (the fundamental) at a frequency $\omega=\omega_0$, as shown in Figure A-3, which is a sample test taken at 0.2Hz. It is clear that since the harmonics have small amplitudes less than 4% of the amplitude of the fundamental component their effect can be ignored, tracking in this case is therefore identified as Smooth pursuit. Non sinusoidal tracking is noted, while target is traveling at frequencies > 1.6Hz, in which case a large presence of harmonics and an absence of the fundamental component in the spectrum of the signal is noticeable, the spectrum for eye movement in this is case may be expressed as:

$$F(\omega)= \sum_{n=2}^{N} A_n\ \delta(\omega-n\omega_0) \qquad (3)$$

a loss of target is expected. In this case the eye tend to jump to catch up with the target. These jumps in the time domain are represented by harmonics in the frequency domain, which are found to be of a large size.

Equation 3 is derived from Equation 1 at the point where the amplitude of the fundamental component is less than 4% of the amplitude of any of the next 10 harmonics. This is the nature of Saccadic tracking as it is shown in Figure A-5. This increase in the amplitude of the harmonics may be related to the inability of the eye to follow the target movement at high frequency. This results in the loss of coordination between target and eye movements which forces the eye to jump in order to catch up with the target. This jump is an error in the collected time domain signal. This error is represented by the presence of harmonics in the spectrum of the signal. Large harmonics are detected for those large jumps and, consequently eye movement is not smooth, this agreed well with results reported by Ohashi [10] and Juhola [11]. Applying the inverse transform to the amplitudes of the harmonics at their corresponding frequencies resulted in a square wave signal as shown in the curve plot in Figure A-4. This fact indicates that the eye behaves as a square wave generator, this agreed well with published results [12,13]. This work however; specified the frequencies at which the eye is found to behave as a square wave generator. These frequencies are found to be 1.6Hz for normal subjects and 1.2Hz for depressed subjects. Therefore; if the eye movement exceeds these two frequency limits the nature of travel changes from smooth pursuit to saccade. A factor common to all groups is the decrease of the amplitude of the fundamental component with increasing frequency. Comparing the results of figure 5 indicates that normals amplitudes are approximately 300% the amplitudes of the depressed subjects. This huge difference ascertain the importance of this approach as a diagnostic procedure, and validates the test setup used in this work.

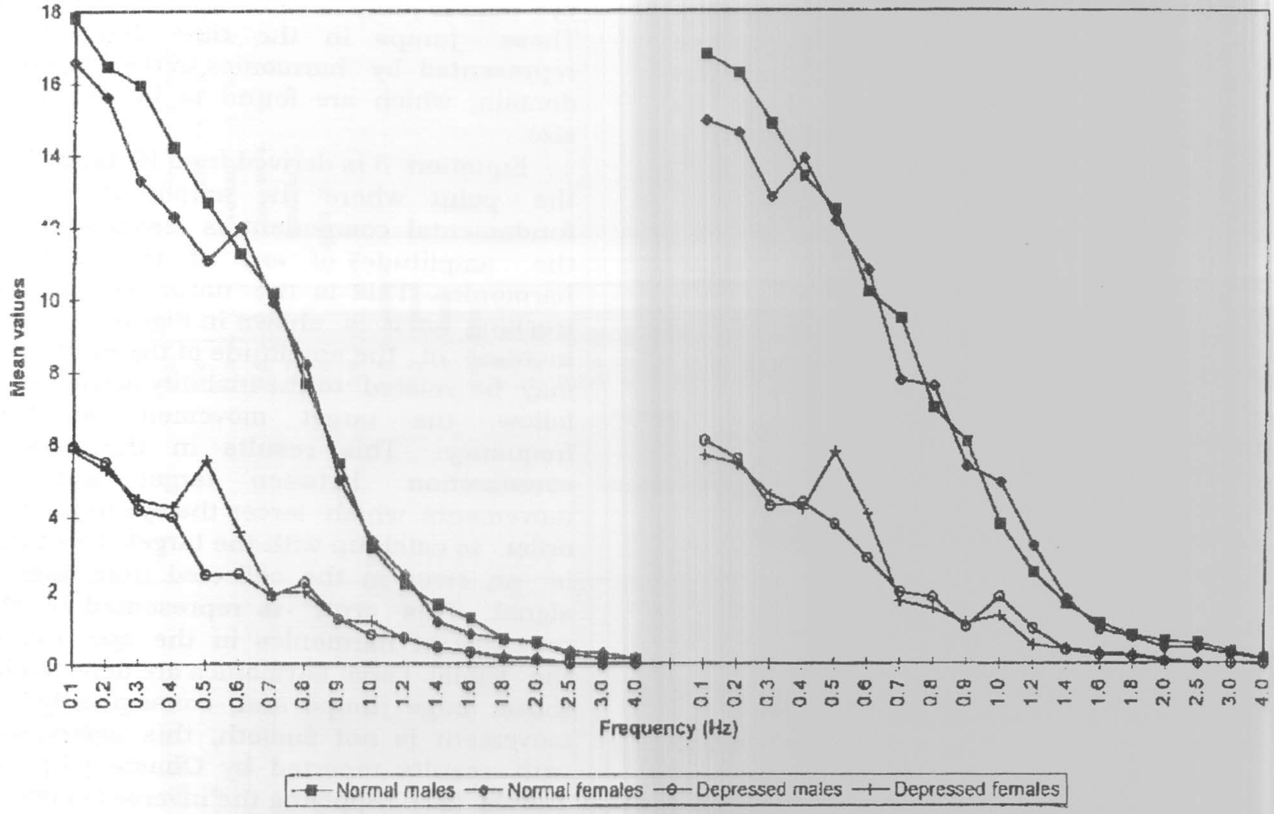

Figure 5 Mean values of amplitudes of the fundamental components

CONCLUSIONS

This paper analyzed the spectra of smooth pursuit eye movements, which proved to be a valuable tool for quantitative measurement of the parameters of interest. The paper also presented a comparative evaluation of such movements for normal controls and depressed subjects. A close agreement is found between the results obtained in this work with results reported previously. Different limits of frequency are identified, these are; 1.6Hz and 1.2Hz. Subjects have high amplitudes of the fundamental component below these frequency limits. The following points summaries the conclusions:

1. The amplitude of the fundamental component is inversely proportional to frequency.
2. The presence of harmonics results due to the loss of coordination between the eye movement and the target movement.
3. Amplitude of harmonics is directly proportional to frequency.
4. Large harmonics are detected for eye movements above 1.6Hz for normal subjects and above 1.2Hz for depressed subjects.
5. Smooth pursuit transition into saccade is measured at frequencies above 1.6Hz for normal subjects and above 1.2Hz for depressed subjects.
6. The eye behaves as a square wave generator at frequencies above 1.6Hz for normal subjects and above 1.2Hz for depressed subjects.
7. Good tracking is achieved at low values of frequency.

8. Amplitude of the fundamental component is inversely proportional to age for normal subjects.
9. normals amplitudes are approximately 300% the amplitudes of the depressed subjects.
10. The computerized test system used is adequate for eye movement detection and analysis.
11. This test can be considered as a diagnostic procedure.

APPENDIX

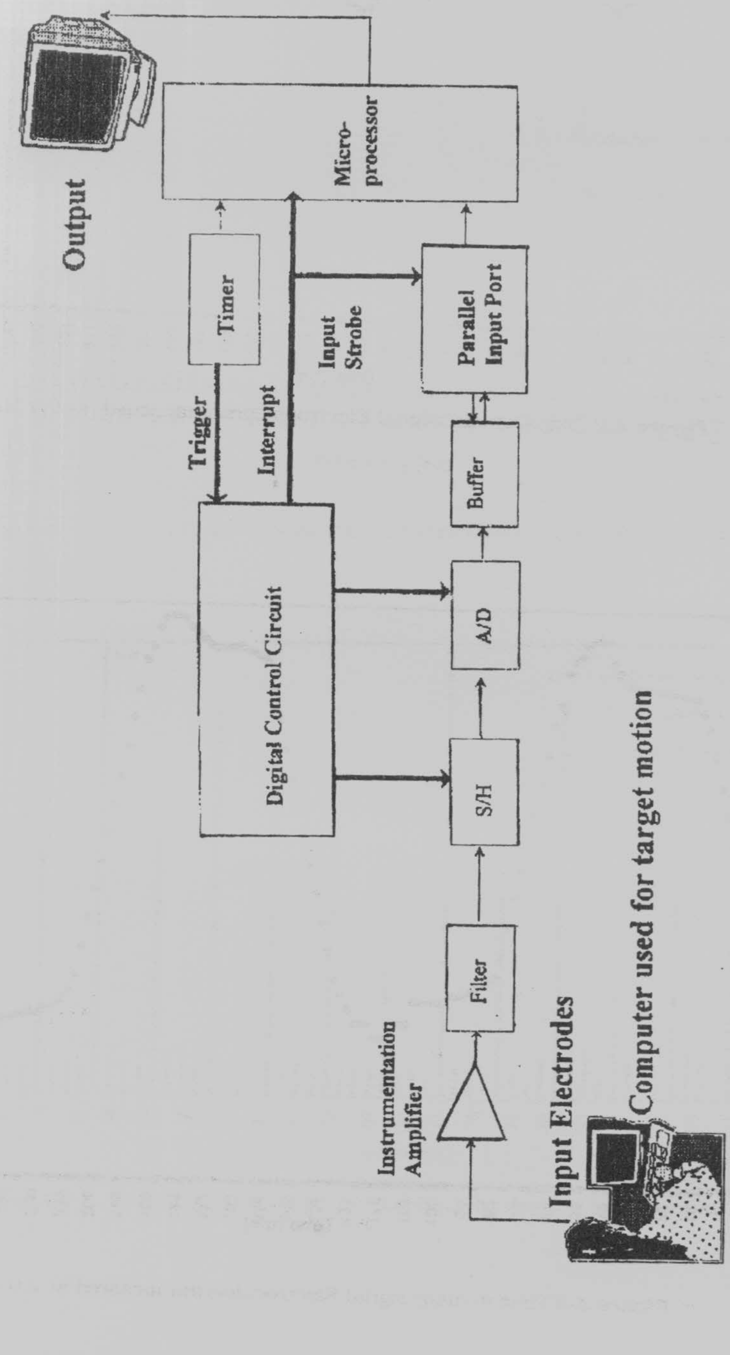

Figure A-1 Test System

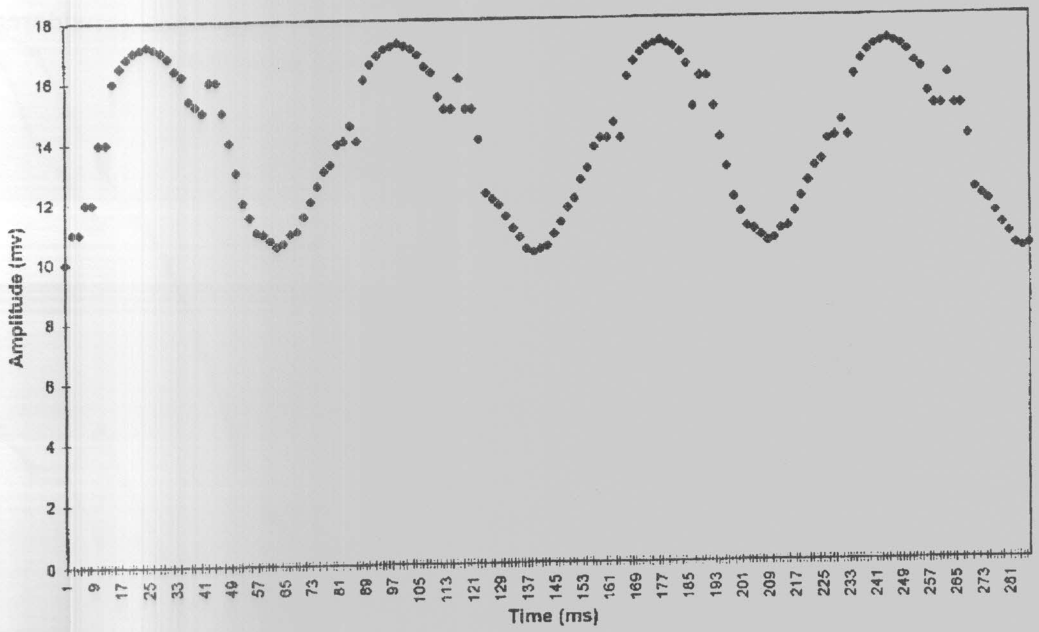

Figure A-2 Time Domain Signal Electroculogram measued at 0.2 Hz

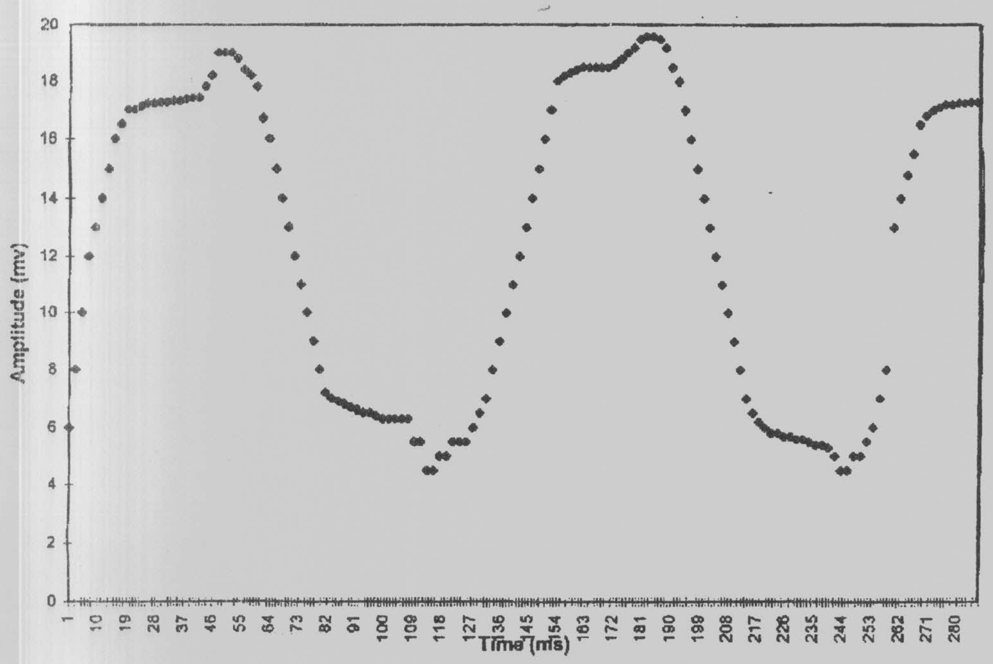

Figure A-3 Time domain signal Electroculogram measred at 2.0 Hz

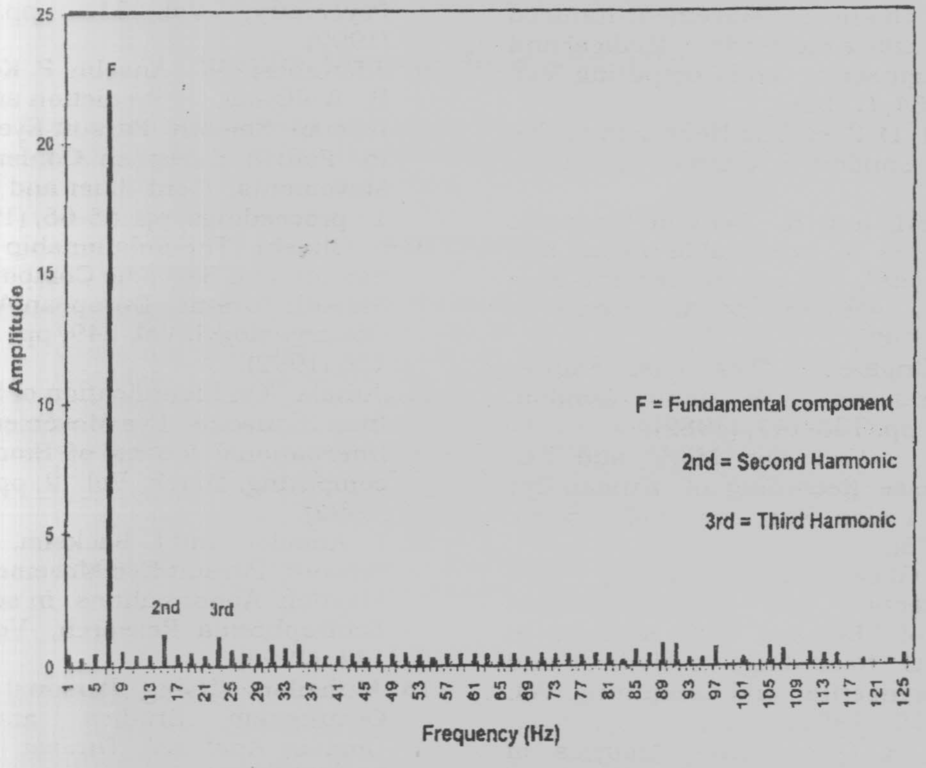

Figure A-4 Frequency Spectrum for electroculogram measured at 2 Hz.

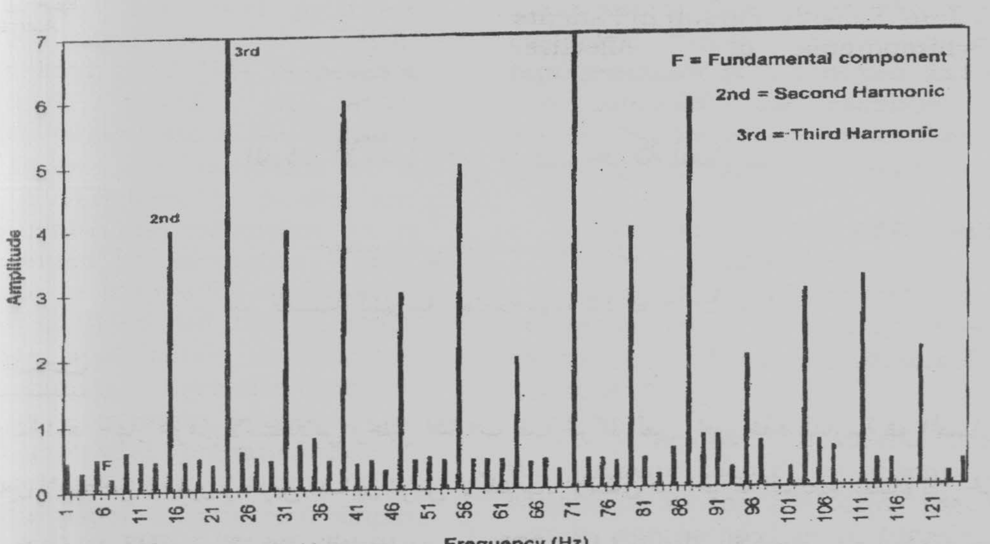

Figure A-5 Frequency Spectrum for Electroculogram Measured at 2 Hz

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التردد الانتقالى فى طيف حركة العين

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ملخص البحث

تم عمل واستخدام جهاز مبرمج لاستخلاص وتحليل اشارات طبية بحركة العين. محور هذه الدارسة هو المجال الترددى لحركة العين لاشخاص سليمين وأخرين مصابين بمرض الاكتئاب. الانتقال من الحركة التتابعية الملساء الى الحركة الفجائية للعين كان عند تردد 1.6HZ للاشخاص العاديين وبنسبة 92% . اما فيما يتعلق بالاشخاص المصابين فقد حصل الانتقال عن تردد 1.2HZ وبنسبة 83%. وكذلك فقد وجد أن قيمة التوافقية الاساسية تقل كلما زاد التردد.