Palestine Polytechnic University
College of Engineering

Measurement of Arden Ratio for Diagnosing Hereditary Retinal Diseases Using EOG System

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Submitted to the College of Engineering

in partial fulfillment of the requirements for the

Bachelor degree in Biomedical Engineering

2019

Palestine Polytechnic University
College of Engineering
Electrical Engineering Department

Hebron- Palestine

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By the Guidance of project's supervisor, and by all members in the testing committee, this project delivered to department of Electrical Engineering in the College of Engineering, to be as a partial fulfillment of the requirement of the department for the degree of B.Sc.

Supervisor signature

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Committee Signature

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D**epartment Headmaster Signature**

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الإهداء

الحمد لله الذي خلق كل شيء فقدره نحمده ونستعينه ونستهديه ونستغفره ونسترشده ونتوب إليه . . . الحمد لله أقصى مبلغ الحمد والشكر له من قبل ومن بعد .

إلى منارة العلم المصطفى الذي علم المتعلمين . . . . إلى سيد الخلق إلى رسولنا الكريم محمد (صلى الله عليه وسلم) .

إلى نبع العطاء إلى من علمني كيف أقف إلى من علمني كيف الصعود وعيونه ترقبني إلى من حصد الأشواك عن دربي ليمهد لي طريق العلم إلى القلب الكبير . . . والدي الحبيب .

إلى نبع الحنان إلى من زرعت في أسمى القيم وطرق الارتقاء إلى من بدعائها كان سر نجاحي إلى من كانت بلسم جروحي إلى أغلى الوجود إلى القلب الناصع بالبياض . . . والدتي الحبيبة .

إلى من أمسكوا بيدي إلى من لهم الفضل بإرشادي إلى طريق العلم والمعرفة . . . أساتذتي الأفاضل.

إلى من كلله الله بالهيبة والوقار إلى صاحب التميز والأفكار النيرة إلى من أعطى وأجزل بالعطاء إلى من ستبقى كلماته نجوم أهتدي بها إلى من كان قدوتي بعد الرسول الكريم محمد (صلى الله عليه وسلم) . . . الدكتور رمزي القواسمة الذي أتوجه له بخالص الشكر والامتنان وأقول له قول الشاعر أحمد شوقي: "قم للمعلم وفّه التبجيلا كاد المعلم أن يكون رسولاً" .

إلى الحضن الكبير الذي يضمنا جميعاً . . . فلسطين الحبيبة .

إلى أسرانا البواسل إلى شهدائنا الأبرار .

تقبلوا مني هذا الإهداء راجية أن لا تكون خانتني كلماتي بعدم تقديم ما يليق بكم . . .شكراً لكم جميعاً .

Abstract

The project helps ophthalmologists to provide correct diagnosis for hereditary retinal diseases that affect the eyes, which are transmitted between generations in a single family.

The project aims to build & implement an EOG system for recording EOG signal in order to diagnosis the Best Vitelliform macular dystrophy (BEST Disease), Retinities pigmentosa, and Stargardt disease.

The EOG system contains different stages of processing and conditioning circuits to obtain the required signal. The recorded signal in light and dark adaptation are transmitted to computer using DAQ for further processing using special designed algorithms in LabVIEW software, for both light and dark adaptation, to calculate the average of value of EOG signal in each minute recording is calculated and then the smoothed light to dark ratio curve is plotted.

The Arden ratio is then calculated by dividing the light peak over the dark trough of the smoothed light to dark curve, when the size of the light peak is compared to the dark trough the relative size should be about 2:1 or greater in normal conditions. A light / dark ratio of less than about 1.5 is considered abnormal.

ملخص المشروع :

يساعد المشروع أطباء العيون على توفير التشخيص الصحيح لأمراض الشبكية الوراثية التي تؤثر على العيون، والتي تنتقل بين الأجيال في العائلة الواحدة.

يهدف المشروع إلى بناء وتنفيذ نظام تسجيل كهربائية العين، للحصول على تسجيل الإشارة الكهربائية للعين الناتجة من حركة عضلات العين، وذلك من أجل تشخيص أفضل ضمور بقعي, مرض العشى الليلي، و مرض ستارغاردت.

يحتوي نظام تسجيل كهربائية العين على مراحل مختلفة من دوائر المعالجة للحصول على الإشارة المطلوبة. يتم إرسال الإشارة المسجلة في تكيف الضوء والظلام إلى الكمبيوتر باستخدام (myDAQ) لمزيد من المعالجة باستخدام خوارزميات مصممة خاصة في برنامج (LabVIEW) لكل من تكيف الظلام والضوء، يتم حساب معدل قيمة الإشارة الكهربائية للعين في كل دقيقة من التسجيل ومن ثم رسم منحنى النسبة بين الضوء والظلام.

يتم حساب نسبة Arden بقسمة أعلى قيمة في الضوء إلى أقل قيمة في الظلام في منحنى الضوء والظلام، عندما يتم مقارنة حجم أعلى قيمة في ضوء إلى أقل قيمة في الظلام يجب أن تكون النسبة حوالي ٢: ١ أو أكبر في الظروف العادية. تعتبر نسبة الضوء / الظلام أقل من حوالي ١,٨ غير طبيعية.

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CHAPTER *ONE*

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1.3 Project Importance
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1.1 Project Overview

There are many diseases that infect the retina such as hereditary diseases of which are transmitted between generations in a single family, so it important to design devices for diagnosing diseases that help qualified ophthalmologists to provide correct diagnosis and treatment for this group of eye diseases.

Such as, the clinical electro-oculogram (EOG) is an electrophysiological test of function of the outer retina and retinal pigment epithelium (RPE) in which changes in electrical potential between the cornea and the ocular fundus, the test subject makes a series of horizontal saccadic eye movements response to a fixation target (led target) at ganzfeld, first dark adaptation and then light adaptation. Electrical potential is obtained by electrodes placed on the skin near the eye, the recording of output signal will be got by the myDAQ hardware acts as the interface between a computer and the design, LabVIEW software used for signal processing, plot Light/Dark curve, then calculate the Arden Ratio for diagnosing genetic retinal diseases.

1.2 Project Aims

The main objective of the project is to design EOG and measure the Arden Ratio for diagnosing hereditary retinal diseases.

- Design and implementation of EOG system for recording EOG signals.
- Connect the designed system with LabVIEW software for signal processing.
- Calculate the Arden Ratio by LabVIEW for diagnosing eye diseases.

1.3 Project Importance

- The electro-oculography exam is used to measure the resting potential of the retina during saccadic eye movement, and potential changes as a function of (dark and light).
- The study of light to dark ratio (Arden Ratio) of the eye is important for diagnosing eyes in many conditions: stress, fear, blink and depression.
- The application of digital computers and software programs. Such as, labVIEW has considerably increased the diagnostic power of this method.
- Diagnosing of hereditary retinal diseases by EOG system, is commonly used in the confirmation of Best Vitelliform macular dystrophy (BEST Disease).

1.4 Methodology

The research methodology in the project includes: several stages of theoretical calculations, electrical design, and software application.

Several stages of calculation are done in order to choose the appropriate value electrical components circuit. Then shows the connections between the project components of (electrical circuit, myDAQ, computer, labVIEW). In addition, the electrical design simulated using MULTISIM program. myDAQ hardware acts as the interface between a computer and the design. LabVIEW will be used for signal processing, plot the Light-Dark curve, calculate and display the Arden Ratio and diagnosing retinal disease.

1.5 Literature Review

- **"ISCEV Standard for Clinical Electro-oculography (EOG) 2006"**

  The clinical electro-oculogram (EOG) is a test of function of the outer retina and retinal pigment epithelium (RPE) in which the change in the electrical potential between the cornea and the ocular fundus is recorded during successive periods of dark and light adaptation. This document sets out a Standard Method for performance of the test, and also gives detailed guidance on technical and practical issues, and on reporting test results [1].

- **"Analysis of Different Level of EOG Signal from Eye Movement for Wheelchair Control"**

  Analyze different levels of eye movement signals strength using Electro-oculography (EOG). A person who has such paralysis is highly dependent on an assistant and a wheelchair for movement. It is not always the case where the helper is with the patient all the time, the signal from the eye muscles that is called electrooculogram is generated at different eye movements directions and levels. The eye movement signals are acquired using USB amp from G.TEC Medical Engineering GMBH by using Ag/AgCl electrodes. The data is then passed to MATLAB software for data analysis. Different directions and strength level of eye movement are fed to a virtual wheelchair model developed in MSC. Visual Nastran 4D software to study the effect of the signals on the distance and rotation travelled by the wheelchair. Simulation exercises has verified that different strength of eye movement signals levels that have been processed could be manipulated for helping tetraplegia in their mobility using the wheelchair [2].

- ***"Automatic detection of saccadic eye movements using EOG for analyzing effects of cognitive distraction during driving "***

  Develop an automatic method for detection of saccades using EOG in driving studies. The resulting algorithm is a combination of two modified existing eye detection algorithms, namely Continuous Wavelet Transform Saccade Detection (CWT-SD) and Shape Features. It is found that the developed algorithm can be used in driving environments if good signal quality can be assured. Results from the validation set reported a score of 0.98 for saccades with amplitudes greater than 20 µV and an overall score of 0.93. In general, therefore, it seems that EOG can be utilized for saccade detection during driving. The second aim of this thesis was to investigate the effects of cognitive distraction on saccades in driving environments. The findings of the study suggest a decrease in saccadic rate during cognitive distraction. The results were found the average saccade amplitude was also found to decrease during cognitive distraction but a statistical significance was only observed between high cognitive load (difficult task) and no cognitive load [3].

1.6 List of Abbreviation

Abbreviations	Full Word
EOG	Electo-oculogram
LabVIEW	Laboratory Virtual Instrumentation Engineering Workbench.
RPE	Retinal Pigment Epithelium
DT	Dark Trough
LP	Light Peak
INA	Instrumentation Amplifier
CMRR	Common Mode Rejection Ratio
HPF	High Pass Filter
LPF	Low Pass Filter
NI	National Instrument
VI	Virtual Instrument

1.7 Economical Study

This section lists the overall cost of the project components that are considered in implementing this system.

The table (1.1) contains the main required hardware components of the project design, cost and its quantity.

Table (1.1): The Project Components Cost.

Component	Cost ($).	Quantity
Ag/AgCl electrode	15	2
Lead Wire	85	5
IC	50	8
Resistors and Capacitors	10	30
myDAQ	Available at ppu lab	1
Battery	7	2
Screw and Connectors	3	4
Printed Circuit Board (PCB)	30	1
Total Cost	200	-

1.8 Scheduling Table

The Table (1.2) and Table (1.3) shows the activities that done in the project in both semesters and the time of each one.

Table (1.2): Activities Schedule of the First Semester**.**

Weeks Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
System Definition																
System Analysis																
System Design																
Presentation Preparing																
Documentation																

Table (1.3): Activities Scheduling Table of the Second Semester.

Weeks Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
System Definition																
System Analysis																
System Design																
Presentation Preparing																
Documentation																

1.9 Project Content

The content of the documentation of the project is divided into five chapters, each is briefly explained as following:

Chapter 1: Introduction

This chapter presents overview, project aims, methodology, project importance, literature review, and scheduling table.

Chapter 2: Human Eye Anatomy & Physiology

This chapter contains information about: the human eye anatomy, eyeball movement description, signal generated by horizontal movement of the eyes, and saccadic eye movement.

Chapter 3: EOG & Genetic Retinal Diseases Related to Eyes

This chapter includes the standard method, Arden ratio, and genetic retinal diseases.

Chapter 4: Project System Design

This chapter contains the project components, general block diagram of the project was discussed, Surface Electrode Placement, Instrumentation Amplifier, High-Pass Filter, Low-Pass Filter, Non-Inverting Amplifier, and Power Supply.

Chapter 5: Software Application

This chapter contains signal acquisition, signal processing and diagnostic of retinal diseases.

CHAPTER TWO

Human Eye Anatomy & Physiology

2.1 Introduction
2.2 Human Eye Anatomy
2.3 Eyeball Movement Description
2.4 Signal Generated by Horizontal Movement of the Eyes
2.5 Saccadic Eye Movement

2.1 Introduction

The human eye is a complex anatomical device that remarkable demonstrates the architectural wonders of the human body. Eye is very important organ of the human body which located in the head, that gives us the sense, gives help to provide a three-dimensional moving image, and see color in daylight, which allows to observe and know the surrounding world. We use the eye in all activity, whether working, use mobile, reading, writing, watching television, ...etc.

2.2 Human Eye Anatomy

The eye is the organ of the body responsible for detection location, and analysis of the light, and represents the core of one of the sensory systems, called "vision". Figure (2.1): illustrate the main components of human eye.

- Conjunctiva: is the clear, thin membrane that covers part of the front surface of the eye and the inner surface of the eyelids. It keeps the inner surface of the eyelids moist and lubricated so they open and close easily without friction or causing eye irritation, Protect the eye from dust, debris and infection-causing microorganisms.
- Cornea: is the clear front surface of the eye. It lies directly in front of the iris and pupil, and it allows light to enter the eye.
- Sclera: is the white part of the eye that surrounds the cornea. In fact, the sclera forms more than 80 percent of the surface area of the eyeball, maintains the shape of the eyeball, nature of the sclera also protects the eye from serious damage. It is a strong layer made of collagen fibers. The tendons of the six extra ocular muscles attach to the sclera.

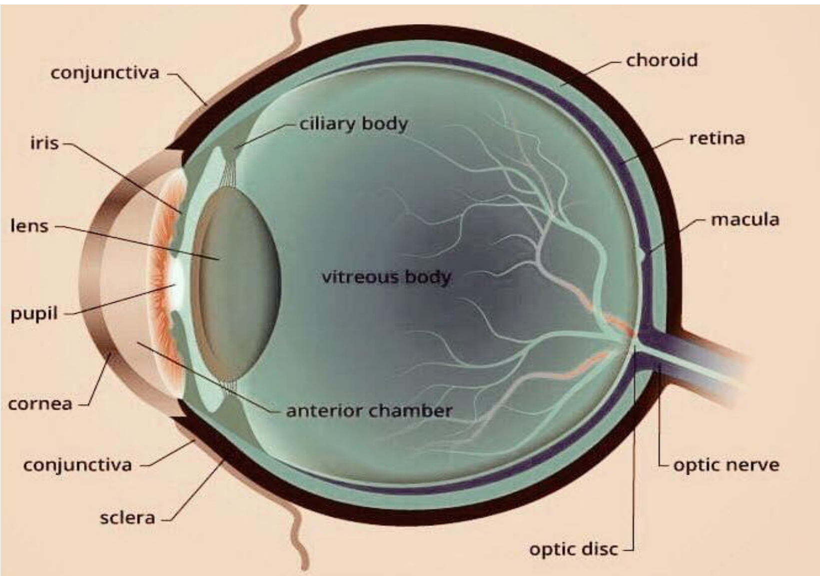

Figure (2.1): Components of the eye [4].

- The uvea: is the pigmented middle layer of the eyeball. It has three segments: the iris, the ciliary body, and the choroid.
- Iris**:** is the thin, circular structure made of connective tissue and muscle that surrounds the pupil. The color of our eyes is determined by the amount of pigment in the iris.
- Ciliary body: the second part of the uvea. It surrounds the iris, it contains the ciliary muscle that controls accommodation of the eye.
- Choroid: the posterior portion of the uvea is the choroid, which is sandwiched between the tough outer sclera of the eyeball and the retina in the back of the eye. It contains many tiny blood vessels and has the vital role of nourishing the retina.
- Pupil: is the circular opening (aperture) of the eye. It is surrounded by the iris where light is allowed to continue its passage. In bright light it is constricted and in dim light is dilated.
- Lens: the lens is a transparent structure behind the iris. The lens bends light rays so that they form a clear image at the back of the eye on the retina. As the lens is elastic, it can change shape, getting fatter to focus close objects and thinner for distant objects.
- Retina: is the sensory membrane that lines the inner surface of the back of the eyeball. It's composed of several layers, including one that contains specialized cells called photoreceptors, which cells take light focused by the cornea and lens and convert it into chemical and nervous signals which are transported to visual centers in the brain by way of the optic nerve in the visual cortex of the brain, these signals are converted into images and visual perceptions, there are two types of photoreceptors cells in the human eye which are rods and cones, behind the photoreceptors cones is the retinal pigment epithelium (RPE).
- Retinal Pigment Epithelium (RPE): is a layer of cells deep in the retina, which is a very thin cell layer, plays a key role in support of photoreceptor functions by processing vitamin A product, absorbing light, and transporting nutrients in and out of the photoreceptor cells. Figure (2.2): the retinal cellular structure.

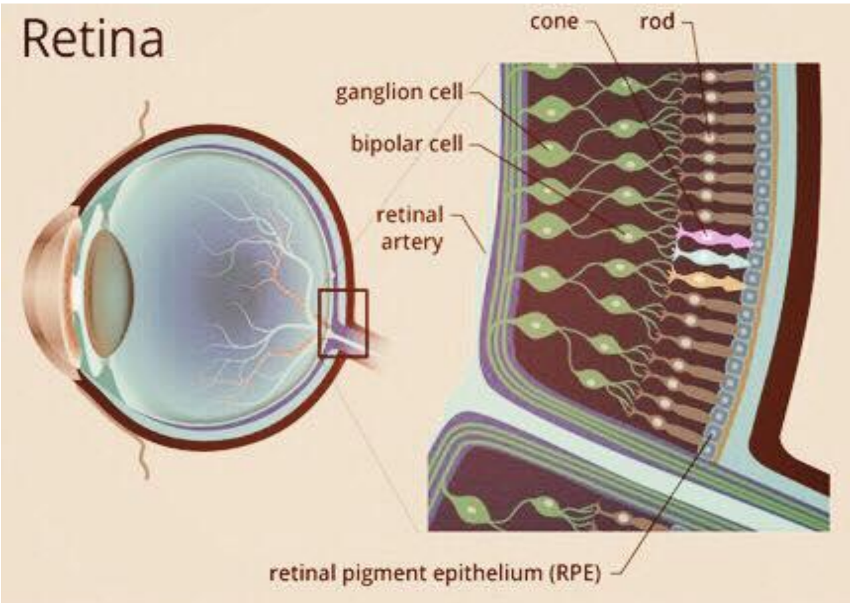

Figure (2.2): The retinal cellular structure [5].

- Macula: the macula is a small, specialized area of the retina that has very high sensitivity and is responsible for central vision.
- Fovea: is specialized area of the retina that sub serves most acute vision. It directly opposite the pupil and contains only cones cells (Yellow Spot).
- Optic Nerve: the optic nerve connects each eye to the brain. It is a structure that sends the picture seen by the eye to the brain so that they can be processed.

2.3 Eyeball Movement Description

We move our eyes constantly during our daily activities to keep our line of sight pointed at a target of interest. In order eye movement are produced by the contraction or relaxation of six extra ocular muscles. As figure (2.3): these muscles surround each eye and can rotate the eye in any direction. The distribution of the muscles for controlling the two eyes is symmetrical.

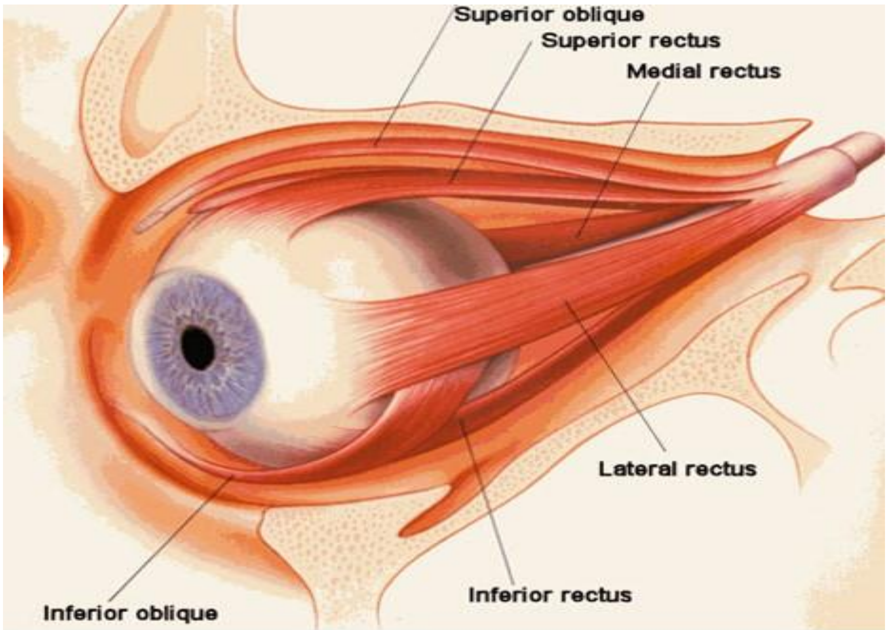

Figure (2.3): Muscles of the eye [6].

Table (2.1): Eye muscle, location, and action of the eye muscle [7].

Muscles	Location	Action
Superior Rectus	Superior and central part of eyeball.	Moves eyeball superiorly (elevation) and medially (adduction), and rotates them medially.
Inferior Rectus	Inferior and central part of eyeball.	Moves eyeball inferiorly (depression) and medially (adduction), and rotates them medially.
Lateral Rectus	Lateral side of eyeball.	Moves eyeball laterally (abduction).
Medial Rectus	Medial side of eyeball.	Moves eyeball medially (adduction).
Superior Oblique	Eyeball between superior and lateral rectus.	Moves eyeball inferiorly (depression), and rotates them medially.
Inferior Oblique	Eyeball between inferior and lateral rectus.	Moves eyeball superiorly (elevation), and rotates them laterally.

2.4 Signal Generated by Horizontal Movement of the Eyes

Figure (2.4): illustrates the measurement of horizontal eye movements by the placement of an electrode at the outside and inside of the left and right eye, with the eye at rest the electrodes are effectively at the same potential and no voltage is recorded.

The rotation of the eye to the right and left results in a difference of potential, with the electrode in the direction of movement becoming positive relative to the second electrode [8]. The calibration of the signal may be achieved by having the patient look consecutively at two different fixation points located a known angle apart and recording EOG signal.

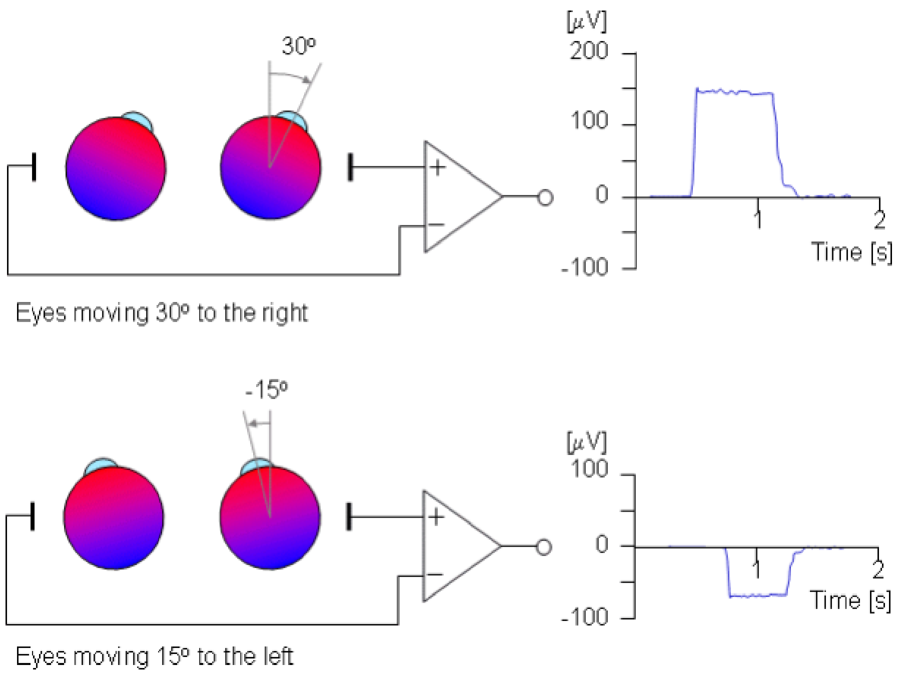

Figure (2.4): An illustration of EOG signal generated by horizontal movement of the eyes [8].

2.5 Saccadic Eye Movement

Saccadic movements describe quick jumps of the eye from one fixation point to another. The speed may be 20 - 700°/s. The angular motion is in the range of 1 - 30°. A normal saccadic response to a rapidly moving target is described in figure (2.5). The stimulus movement is described here as a step. The object of the oculomotor system in a saccade is to rapidly move the sight to a new visual object in a way that minimizes the transfer time.

The parameters commonly employed in the analysis of saccadic performance are the maximum angular velocity, amplitude, duration, and latency. Typical values of these parameters are 400°/s for the maximum velocity, 20° for the amplitude, 80 ms for the duration, and 200 ms for the latency. When following a target moving in stepwise jumps, the eyes normally accelerate rapidly, reaching the maximum velocity about midway to the target [8].

When making large saccades (>25°), the eyes reach the maximum velocity earlier, and then have a long deceleration. Normally the duration and amplitude are approximately linearly correlated to each other. Several factors such as fatigue, diseases, drugs, and alcohol influence saccades as well as other eye movements [8].

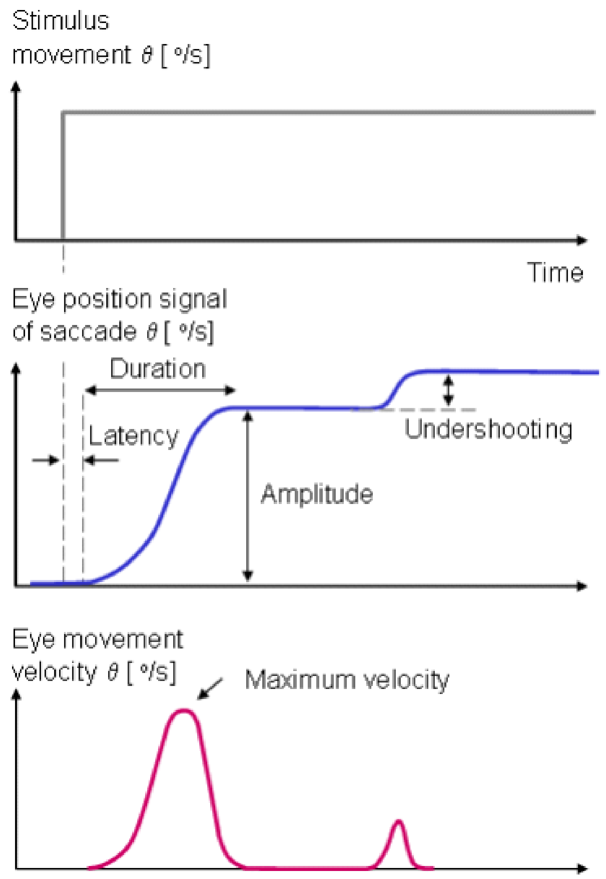

Figure (2.5): An illustration of the eye movement response to a step stimulus [8].

CHAPTER THREE

EOG & Genetic Retinal Diseases Related to Eyes

3.1 Introduction

3.2 The Standard Method for Performance of the EOG Recording

3.3 Arden Ratio

3.4 Genetic Retinal Diseases

3.1 Introduction

Electro-Oculogram: Emil du Bois-Reymond (1848) observed that the cornea of the eye is electrically positive relative to the back of the eye. Since this potential was not affected by the presence or absence of light, it was thought of as a resting potential. It is not constant but slowly varying and is the basis for the electro-oculogram (EOG) [8].

The electro-oculogram (EOG) measures the standing potential between the electrically positive cornea and the electrically negative back of the eye. It reflects the activity of the RPE and the photoreceptors. This means that an eye blinded by lesions proximal to the photoreceptors will have a normal EOG [9].

The eye movements behave as if it were a single dipole oriented from the retina to the cornea. Eye movements thus produce a moving (rotating) dipole source and accordingly signals that are a measure of the movement may be obtained. The main application of the EOG is in the measurement of eye movement [8].

3.2 The Standard Method for Performance of the EOG Recording

At first trains the patient in the eye movements, and the pupils should be dilated maximally before recording means less variability in the light entering the eye. The standing potential of the eye may be assessed using skin electrodes placed near the outer and inner canthi of each eye to record successive horizontal saccadic eye movements. Then start the standard method, the standard method explains as below:

3.2.1 Ganzfeld (Stimulator)

Ganzfeld (Stimulator) must be used to:

- Provide uniform luminance entire visual field of the patient. This is usually achieved using a dome this should be as large as practicable to allow adequate distance from eye to fixation lights.
- It should have a chin rest to ensure stable head position, and it should have two fixation lights located 15 degree left and right of center.
- Fixation lights (fixation targets): these should be small, red, be bright enough to be just visible to the patient during the light and dark adaptation [10].
- The back-ground intensity should be stable. In the middle of the test, the light is turn on [10].

3.2.2 Recording of Saccades

Making saccades movement in light and dark adaptation. The EOG potentials are recorded during one minute. Figure (3.1): show example of 10-s saccadic records with a blink artifact at approximately 4000 ms. Measure the average of the amplitudes of every minute, should overshoot or irregular (artifactual) saccades should not be measured or included in calculations.

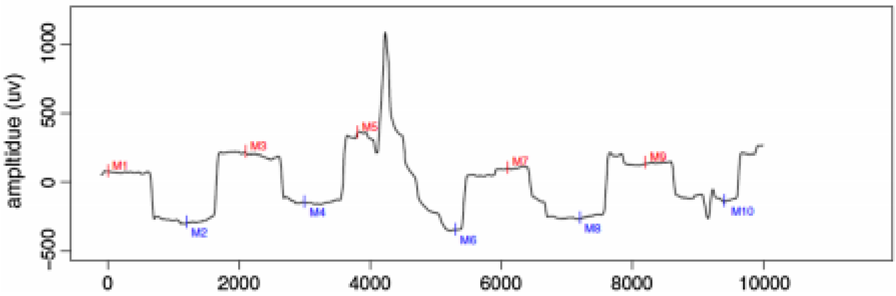

Figure (3.1): Examples of 10-s saccadic records with a blink artifact at approximately 4000 ms [11].

3.2.3 Dark Adaptation

Start with dark phase, the dark phase should be total darkness. It maintains total darkness for 15 min, EOG recordings should be made once a minute. Which the standing potential usually reaches a minimum level (dark trough/DT). The operator should have a concurrent view of the recordings to check for patient compliance and for errors such as noise or overshoot [11].

3.2.4 Light Adaptation

The light phase requires even lighting through the dome and the room. It maintains total lightness for 15 min EOG recordings should be made once a minute with eyes open, which the standing potential achieves the highest value (light peak/LP). This adapting light should be appearing white and have a luminance of 100 cd/m^2 as measured with a photometer. Its light sources of different types. Such as, tungsten, LED and fluorescent. Example of EOG eye movement recordings show as a figure (3.2).

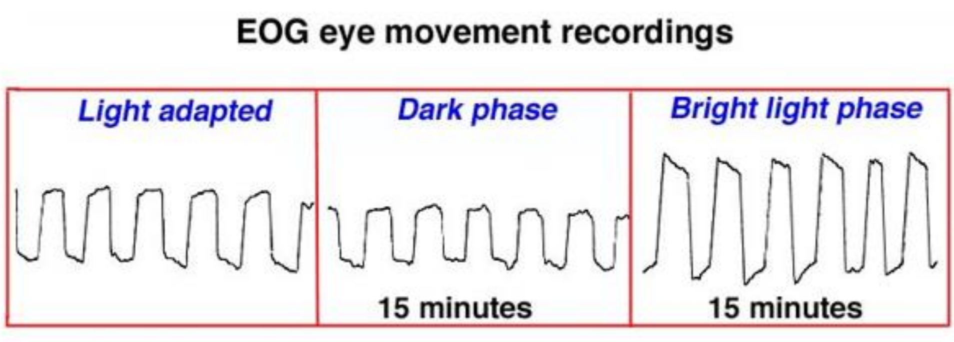

Figure (3.2): Example of EOG eye movement recordings [12].

3.2.5 Dark Trough and Light Peak (Smoothing)

The average EOG amplitude calculated from each 10-s should be plotted. There is always ‘‘noise’’ in physiological recordings, and the goal of the EOG measurement is to record the underlying DT and LP, rather than the lowest or highest single values at recording. The first critical step is that the underlying smoothed light to dark ratio curve be recognized and drawn, in order to derive reliable DT and LP amplitudes, Light peak-to-dark trough ratio calculation the LP:DT ratio of the EOG is computed by dividing the smoothed LP by the DT amplitudes. Figure (3.3): example of smoothing recordings defines the dark trough and light peak amplitudes from which to calculate the light LP: DT ratio**.**

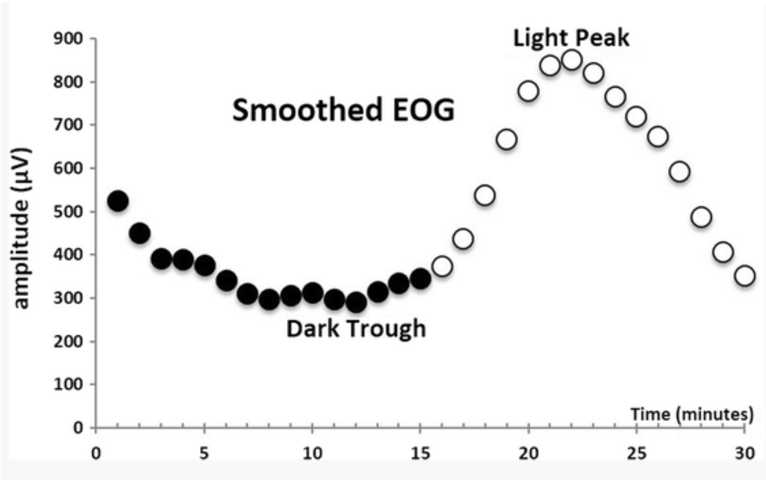

Figure (3.3): Example of smoothing recordings defines the dark trough and light peak amplitudes from which to calculate the LP: DT ratio [11].

3.3 Arden Ratio (Light /Dark ratio – LP: DT)

Light / Dark ratio is the ratio between the light peak and the dark trough of the smoothed light to dark ratio curve [11], an Arden ratio of 1.80 or greater is normal, and less than 1.8 is abnormal [9]. Figure (3.4): show example of smoothed light to dark ratio curve recordings of a normal person.

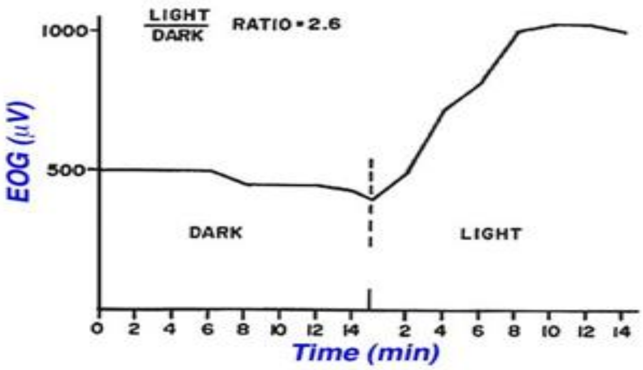

Figure (3.4): Show example of smoothed light to dark ratio curve recordings for a normal person [12].

3.4 Genetic Retinal Diseases

EOG is a very useful tool in diagnosing hereditary macular diseases. It used for help in understanding the disease states that affect the EOG make it easier to explain the results. It can be useful in diagnosing various progressive retinal disorders, such as Best vitelliform macular dystrophy (BEST Disease), Retinities pigmentosa, and Stargardt disease.

Treatment is available for some retinal diseases, that Depending on your condition, the goal of the treatment is to stop or slow down the diseases and restore your vision. If you leave some retinal diseases untreated, it can cause severe loss of vision or blindness.

3.4.1 Best Vitelliform Macular Dystrophy (BEST Disease):

- General Discussion:

Best vitelliform macular dystrophy is also called Vitelliform dystrophy, or BEST disease, is an autosomal dominant genetic form of macular degeneration that usually begins in childhood. Which is characterize by atrophy of the retinal pigment epithelium [12].

- Symptoms:

Symptoms of adult vitelliform macular dystrophy typically begin during mid-adulthood. At the time of diagnosis mild blurring or mildly distorted vision may be present. In most cases, the cells underlying the macula become more damaged over time, which can cause slowly progressive vision loss, usually affects both eyes.

- Cause:

BEST disease is caused by changes (mutations) in the BEST1 gene. This gene gives the body instructions for making a protein called bestrophin. It is thought that mutations in the *BEST1* gene affect the shape of the channel and its ability to properly regulate the flow of chloride [13].

- Diagnosis:

BEST vitelliform macular dystrophy be diagnosed by EOG exam reflected by an Arden (light-peak/dark-trough) ratio of 1.1-1.5, and by the family history [13].

- Treatment & management:

There is no treatment and medical or surgical management for BEST disease [12].

3.4.2 Retinities Pigmentosa

- General Discussion:

Retinitis pigmentosa is a group of rare, genetic disorders that involve a breakdown and loss of cells in the retina [14].

- Symptoms:

Common symptoms include difficulty seeing at night and a loss of side vision, the early stages of retinitis pigmentosa, rods are more severely affected than cones. As the rods die and happen progressive loss of the visual field. The loss of rods eventually leads to a breakdown and loss of cones [14].

- Causes:

Cause of retinitis pigmentosa is an inherited disorder that results from harmful changes in any one of more than 50 genes. These genes carry the instructions for making proteins that are needed in cells within the retina. Some of the changes, or mutations, within genes are so severe that the gene cannot make the required protein, limiting the cells function. Other mutations produce a protein that is toxic to the cell [15].

- Diagnosis:

Retinitis pigmentosa be diagnosed by EOG exam reflected by an Arden ratio, and by the family history.

- Treatment & management:

Available treatments aim to slow the progression of the disease. Such as:

  - Light avoidance and the use of low-vision aids.
  - Vitamin A as a possible treatment option.
  - Current research is focused on the development of new treatments including gene therapy, retinal transplantation [15].

3.4.3 Stargardt Disease

- General Discussion:

Stargardt disease is also called Stargardt macular dystrophy, juvenile macular degeneration, is an inherited disorder of the retina. It is one of several genetic disorders that cause macular degeneration [16].

- Symptoms:

The disease typically causes vision loss during childhood or adolescence, although in some forms, vision loss may not be noticed until later in adulthood. It is rare for people with the disease to become completely blind. For most people vision loss progresses slowly over time to 20/200 or worse (Normal vision is 20/20) [16].

- Causes:

Mutations in a gene called ABCA4 are the most common cause of Stargardt disease. This gene makes a protein that normally clears away vitamin A by products inside photoreceptors. Cells that lack the ABCA4 protein cause accumulate of lipofuscin, central vision becomes impaired. The photoreceptors are died in Stargardt disease [16].

- Treatment & management:

Currently, there is no treatment for stargardt disease.

    - Some ophthalmologists promote patient to wear dark glasses and hats when out on bright light to reduce the buildup of lipofuscin.

CHAPTER FOUR

Project System Design

4.1 General Block Diagram
4.2 Surface Electrode Placement
4.3 Instrumentation Amplifier
4.4 High-Pass Filter
4.5 Low-Pass Filter
4.6 Non-Inverting Amplifier
4.7 Power Supply

4.1 General Block Diagram & System Design

In order to design portable EOG system, electrical components required. The next block diagram shows the component of the hardware system for horizontal movement for right eye as figure (4.1), the left eye has another block diagram in the same way for the right eye.

The electrode tools used for pick up ionic current from human body (eye) and convert it to electrical current. An INA used for picking up the component of the EOG signal and reduce the common mode voltage by CMRR.BPF then allow frequency from (0.1 to 30) Hz [1]. Eye movement have a very little signal (250-1000 μV) [1]. So use non-inverting amplifier to amplify the signal gain, the signal then connects with a computer.

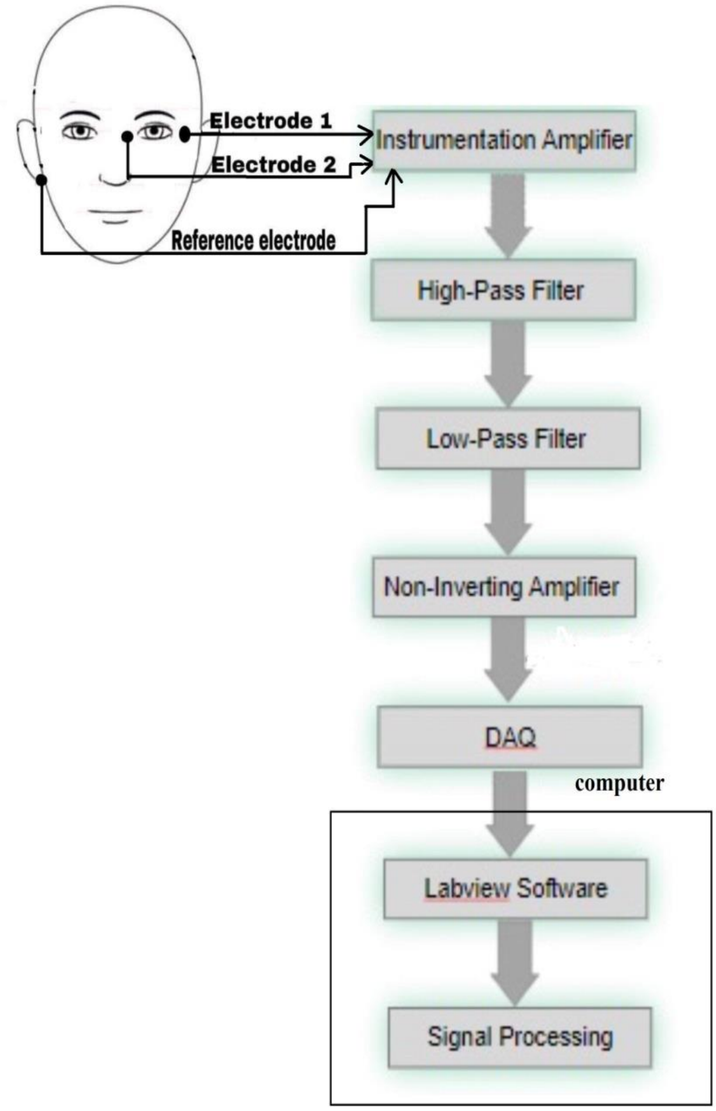

Figure (4.1): General Block diagram for EOG system.

4.2 Surface Electrode Placement

The eye has a standing electrical potential or charge across it, like a weak battery, with the front of the eye positive and the back negative. EOG signals were measured by placing nonpolarizable Silver-Silver Chloride (Ag/AgCl) skin electrodes on the region surrounding the eye, as they are low cost and easily available. The signals were recorded from horizontal channel. Horizontal electrodes were for detecting horizontal eye movements (left and right eye movement). The reference electrode is an electrode which has a stable and well-known electrode potential, and is needed in order to create a safety electrical path off and protect the amplifier.

4.3 Instrumentation Amplifier (INA)

The instrumentation amplifier circuit is used as a pre-amplifier show in figure (4.2) to acquire EOG signal from eyes through the non-invasive electrodes. Consist by 2 input from electrode which have been present as (electrode 1 and 2).

The AD620 will be used has the following properties:

- High common-mode rejection ratio
- High Input Impedance
- Low power consumption

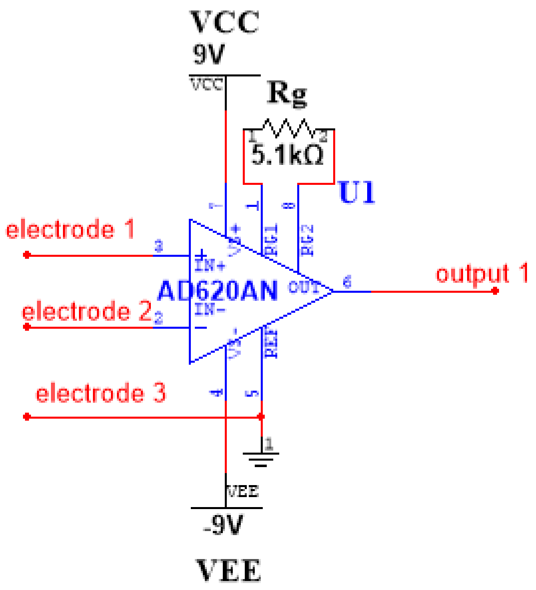

Figure (4.2): AD620 INA.

The gain of the pre-amplifier is preferred to be set 10, because of the weakness of the EOG signal & the initial amplification will reducing the effect of signal. Such as, skin muscle artifacts.

The gain of the pre-amplifier circuit can be expressed by the following Equation:

$$A = \frac{49.9k\Omega}{R_g} + 1 \qquad (4.1)$$

R_g: External resistance added to achieve a determined voltage gain.

A: INA voltage gain

pre-amplifier Calculations:

By Using Eq (4.1):

The value of R_g is:

$R_g = 5.54\ k\Omega$ according to resistor standard values we will choose $R_g = 5.1k\Omega$.

4.4 High-Pass Filter

The waveform of the signal from pre-amplifier still mix with noisy signal. So that need filter circuit to block the noisy signal for get better characteristic of the signal. HPF used to release the signal which have higher frequency than cut off (block the low frequency). In this project, make one stage of HPF which will block under 0.1 Hz of frequency. This circuit design in order to get the best signal result. A second order Butterworth High pass filter has been used in this project. HPF circuit show as figure (4.3).

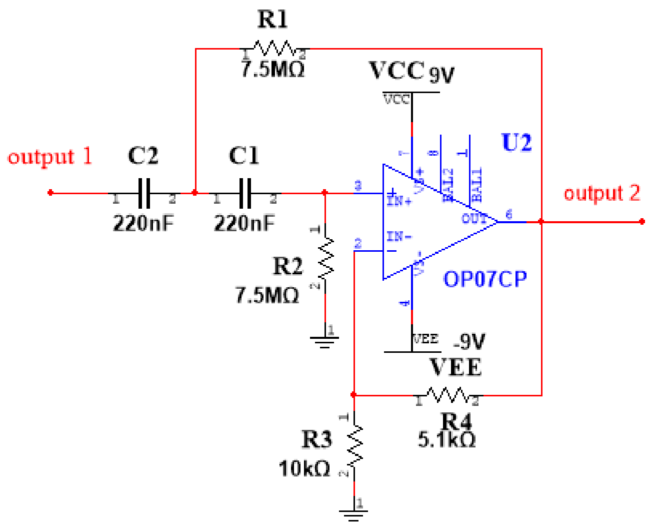

Figure (4.3): Second order HPF circuit

The Butterworth filter is a type of signal processing filter designed to have a frequency response as flat as possible in the band pass, (provide maximum band pass flatness), has no ripples.

From Butterworth Coefficient's Table, the value of Butterworth Coefficient's is:

a_1 = 1.4142

b_1 = 1.0000

$$f_c = \frac{\sqrt{b_1}}{2\pi * R * C} \quad (4.2)$$

$$A = 1 + \frac{R_4}{R_3} \quad (4.3)$$

Where f_c = 0.1 Hz, C = 220nF, b_1 =1.0000

$C_1 = C_2 = 220nF$

$$R_1 = \frac{b_1}{2\pi * f * c}$$

$$R_1 = \frac{1.0000}{2\pi * 0.1 * 220nF}$$

$R_1 = 7.2\ M\Omega$

According to Resistor Standard Values Table, the standard value we will choose

$R_1 = 7.5\ M\Omega$

$R_1 = R_2 = 7.5\ M\Omega$

Since the gain of this stage equal 1.51, by using Eq (4.3)

let R_3=10 $k\Omega$ so R_4 = 5.1 $k\Omega$.

The high pass filter is designed and tested got a cutoff frequency of 0.1 Hz. In this we have signal less than 0.1 Hz are attenuated and remaining signal are allowed to pass. Characteristic curve of HPF show as figure (4.4).

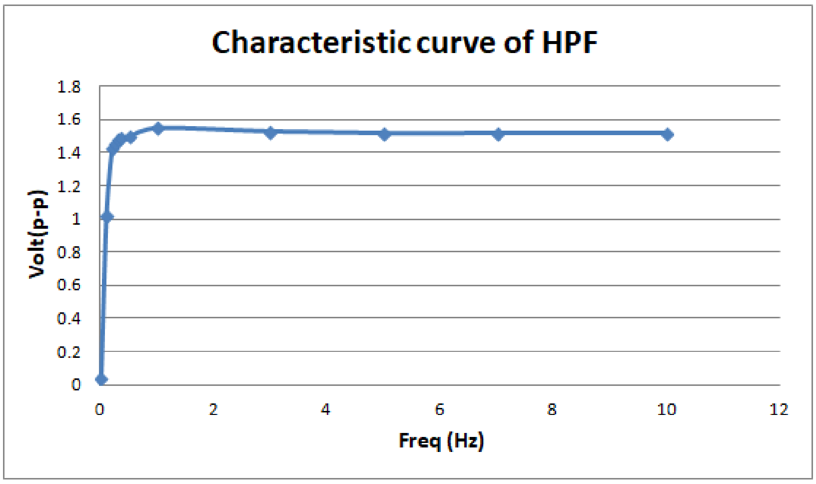

Figure (4.4): Characteristic curve of HPF.

4.5 Low-Pass Filter

LPF is the active filter which can release the signal which have lower frequency than cut off (block the high frequency). LPF in this project, make 1 stage and will block upper 30 Hz of frequency. A second order Butterworth low pass filter has been used in this project. It was used low-offset voltage operational amplifier (OP-07CP), low power consumption and dual power supply. We can simplify the filter design by choosing $R_7 = R_8$, and $C_3 = C_4$. value of resister R_3 can be compute with Equation, LPF circuit show as figure (4.5).

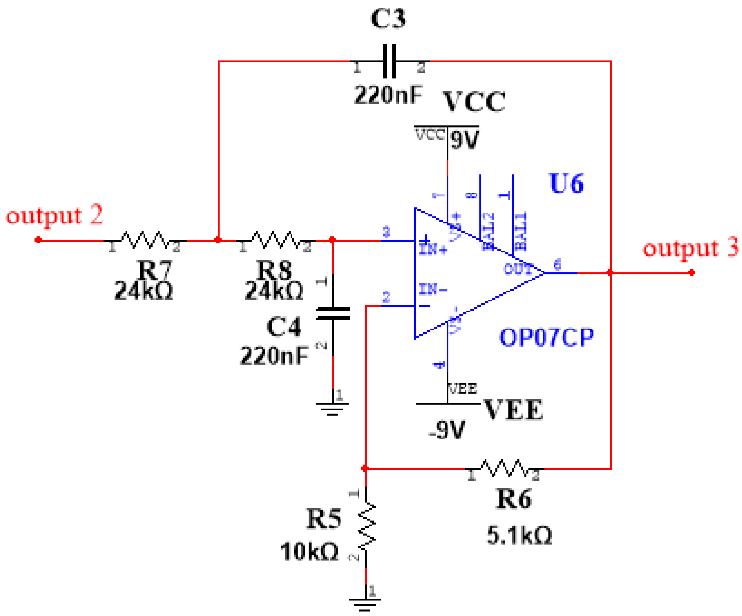

Figure (4.5): Second order LPF circuit.

From Butterworth Coefficient's Table, the value of Butterworth Coefficient's is:

a_2 = 1.4142

b_2 = 1.0000

$$A = 1 + \frac{R_6}{R_5} \quad (4.4)$$

Wheref_c = 30Hz, C = 220nF, b_2 =1.0000

$C_3 = C_4 = 220nF$

Use Eq (4.2):

$$R_7 = \frac{1}{2\pi * 30 * 220nF}$$

$R_7 = 24k\Omega$

$R_7 = R_8 = 24k\Omega$

Since the gain of this stage equal 1.51, by using Eq (4.4):

let R_5=10 $k\Omega$ so R_6 = 5.1 $k\Omega$.

The low pass filter is designed and tested got a cutoff frequency of 30Hz. In this we have signal more than 30Hz are attenuated and remaining signal are allowed to pass. Characteristic curve of LPF show as figure (4.6).

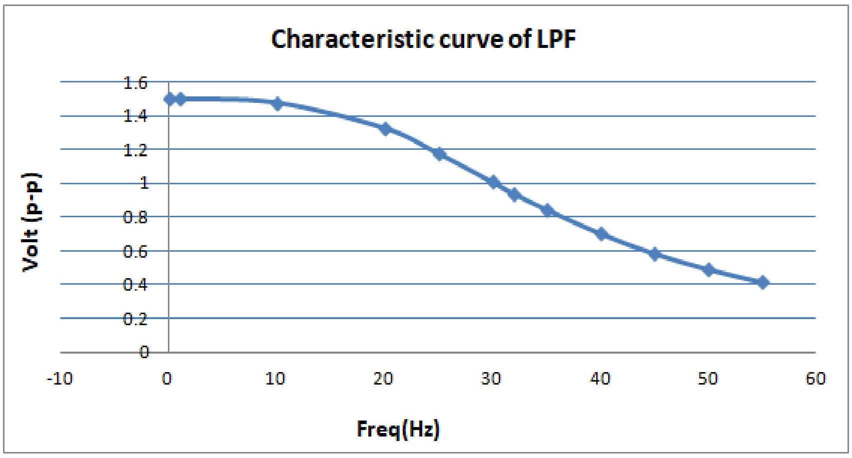

Figure (4.6): Characteristic curve of LPF.

4.6 Non-Inverting Amplifier

Eye movement have a very little signal, to make it readable by myDAQ need an amplifier circuit. To build an amplifier circuit need IC Op-Amp OP07 component to amplifying process, using a non-inverting amplifier to get the same signal with same phase. Non-Inverting Amplifier circuit we used for amplifier system show as figure (4.7).

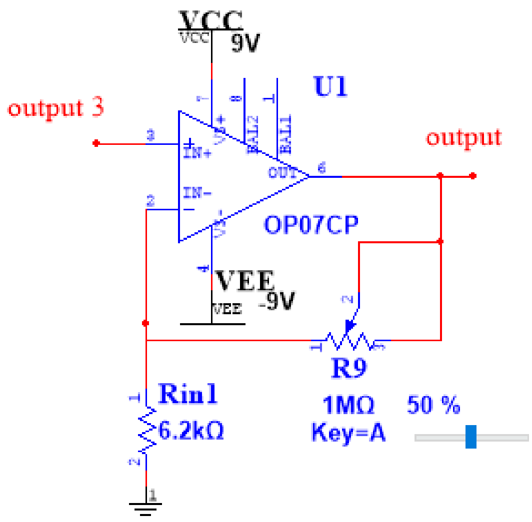

Figure (4.7): Non-inverting amplifier circuit.

In this stage, the gain is equal to 50.

$$A = 1+\frac{R_f}{R_{in}}$$

$$50= 1+\frac{R_f}{R_{in}}$$

$$\frac{R_f}{R_{in}} = 49$$

let R_{in}= 6.2 $k\Omega$.

R_f = 303.8 kΩ**,** According to Resistor Standard Values Table, the standard value we will choose

$R_f = 300\ k\Omega$, use a variable resistance R_f to have an adjustable gain.

4.7 Power Supply

To design this portable system, it needs to use two battery as a DC power supply with (+9) and (-9), has several characteristics such as, it is easy to use, more economical, light weight, and more safety.

CHAPTER FIVE

<u>Software Application (LabVIEW)</u>

5.1 Introduction
5.2 System Flow Chart
5.3 Signal Acquisition (DAQ)
5.4 Signal Processing (LabVIEW)

5.1 Introduction

LabVIEW, short for Laboratory Virtual Instrumentation Engineering Workbench [18].

LabVIEW graphical programming, practical applications in instrumentation and control, approach that helps you visualize every aspect of your application. It is used in the areas of data collection, control tool, information system tests including hardware configuration and measurement data. This visualization makes it simple to develop data analysis algorithms, and design custom engineering user interface.

It is relationships heavily on graphical interfaces (called Front Panel or front panels) and is a key loop in the development of its programs and files. It is called virtual instruments or short VI. VI consists of two elements:

- The front panel is the interactive user interface of a VI, so named because it simulates the front panel of a physical instrument. The front panel can contain knobs, push buttons, graphs, and many other controls (user inputs) and indicators (program outputs) [19].

- The block diagram is the VI's source code, you draw wires to connect the appropriate objects together to define the flow of data between them. Front panel objects have corresponding terminals on the block diagram so data can pass from the user to the program and back to the user [19].

- Why use Lab view:

    - Lab view easy to use
    - Faster development time.
    - Lab view appearance and operation simulate physical instruments. Such as, oscilloscope and multimeters.
    - There is a large library of drivers for data acquisition hardware and test instruments.
    - Lab view includes tools to help you analyze and present your data. Such as, filtering, curve fitting, calculus, statistics, graphs, charts and tables.
    - Graphical programming allows you to concentrate on the flow of data within your application, because it's simple does not obscure what the program is doing.

5.2 System Flow Chart

The function of LabVIEW in this project to measure and diagnosis of hereditary retinal diseases. Figure (5.1) describes the algorithm to measure and diagnosis hereditary retinal diseases.

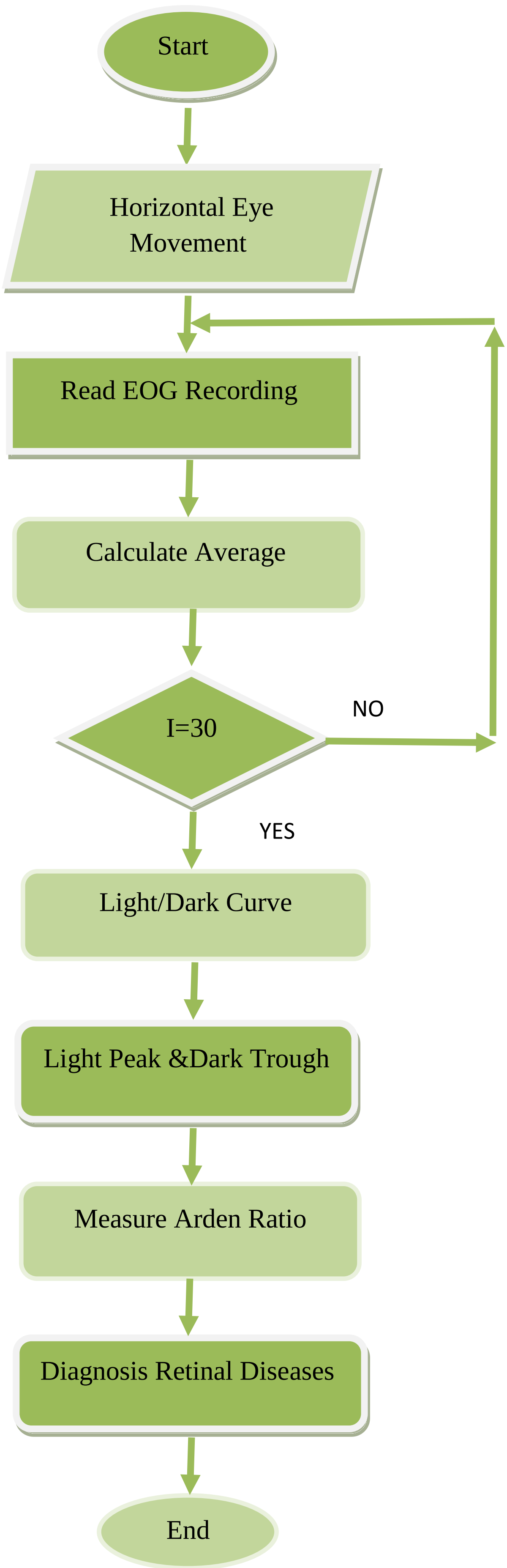

Figure (5.1): Flowchart of the implemented algorithm.

5.3 Signal Acquisition (DAQ)

EOG signal amplitude depends significantly on the position of the eyeballs relative to there are few conductive environments of the skull other contributing factors, so the myDAQ is very good to get up signal, myDAQ hardware acts as the interface between a computer and signals from the outside world. It primarily functions as a device that digitizes incoming analog signals so that a computer can explain them. Figure (5.2): show the National Instruments (NI) myDAQ are being use for signal acquisition.

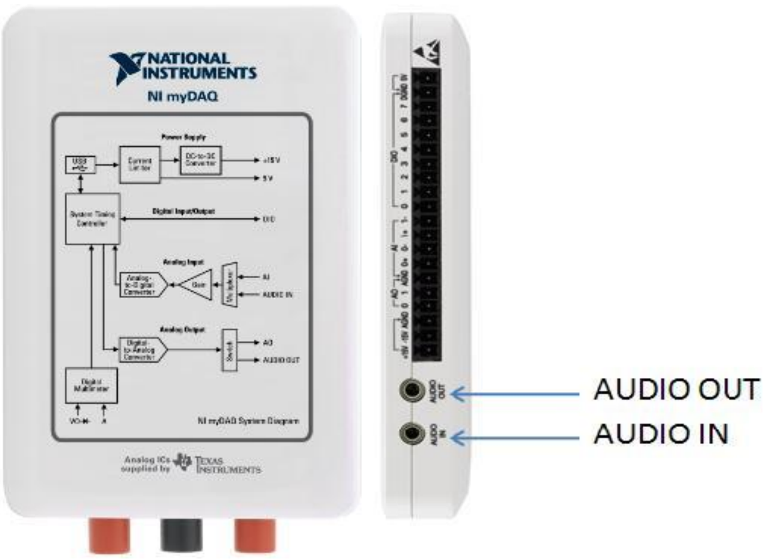

Figure (5.2): National Instruments (NI) myDAQ [20].

Signal acquisition (DAQ) is the process of measuring an electrical or physical phenomenon such as voltage, current, temperature, pressure, or sound with a compute. For this process create VI that acquires data (DAQ assistant) show as figure (5.3), signal acquisition for the two eyes use two channel show as figure (5.4).

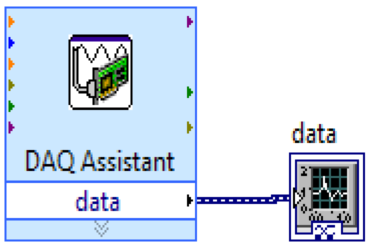

Figure (5.3): VI DAQ Assistant.

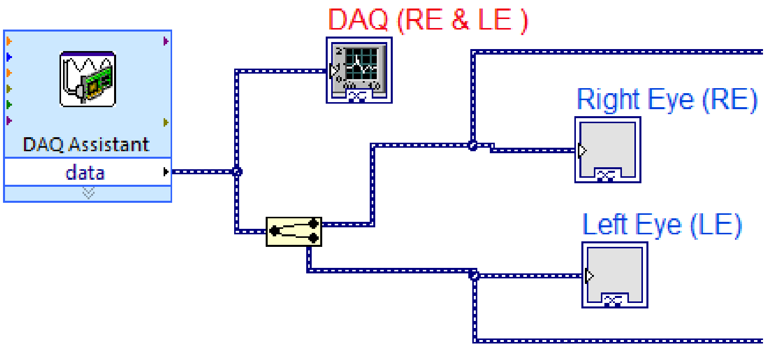

Figure (5.4): Signal acquisition for the two eyes.

5.4 Signal Processing (LabVIEW)

The next step of acquisition the EOG signal is signal processing. This to make sure that the quality of signal is extracted and at the same time the unwanted parts of EOG signal are removed, because there are three types of eye movements can be recognized in the EOG signal: saccades, fixations, and blinks. The first one is the most important in recordings. A fixation is when the eye is stationary, it happened between saccades. Blinks are no need in the recording, and to remove muscles artifacts. The steps of signal processing for two eyes are show as below:

- Take the signal recording in every one minute along 30 minutes (light & dark adaption), use for loop for make the loop working (signal processing) for signal taken at one-minute for two eyes. Figure (5.5): timed loop.

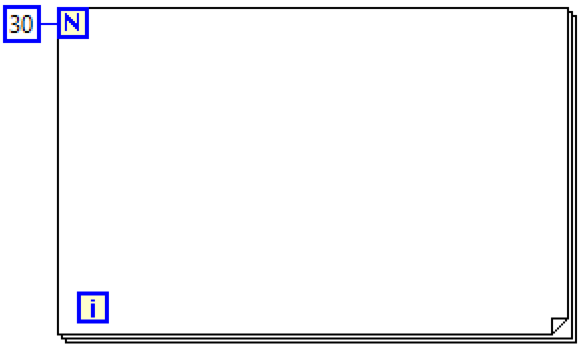

Figure (5.5): For Loop.

– Calculate the average of the amplitude saccades in each one minute. Figure (5.6): show Express VI (Statistics) produces arithmetic mean (average).

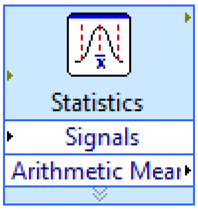

Figure (5.6): This Express VI produces arithmetic mean (average).

– Storing the value of average along 30 minutes in array and export it to excel file. Figure (5.7): show Array for storing averages values.

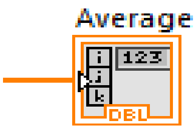

Figure (5.7): Array for storing averages values.

– Converting the file excel to text file for reading the values.

– Read the excel file for Plot the average amplitude of the EOG in volt on graph representing the 30 minutes of the test (Light/ Dark Curve Smoothing). It shown as figure (5.8).

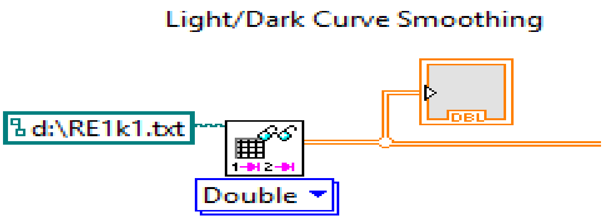

Figure (5.8): Read the excel file for Plot the average amplitude of the EOG (Light/Dark Curve Smoothing).

–

– For make best curve fitting use Express VI (Curve Fitting) produces best fit (Arden Ratio Curve), which is ignore any points known to be incorrect show as figure (5.9).

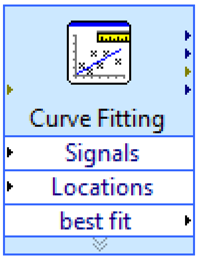

Figure (5.9): This Express VI produces best fit**.**

– Take the peak and trough of the underlying curve, not maximum and minimum recorded values, use Express VI (Statistics) produces Maximum & Minimum show as figure (5.10). Then Calculate the Arden Ratio this is the ratio between Maximum (peak) & Minimum (trough), by doing Sub VI block diagram, show as figure (5.11). The process of diagnosing retinal diseases done by make Sub VI block diagram, show as Figure (5.12).

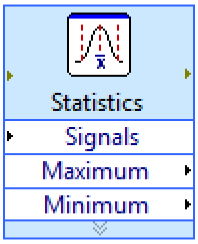

Figure (5.10): This Express VI produces Maximum & Minimum.

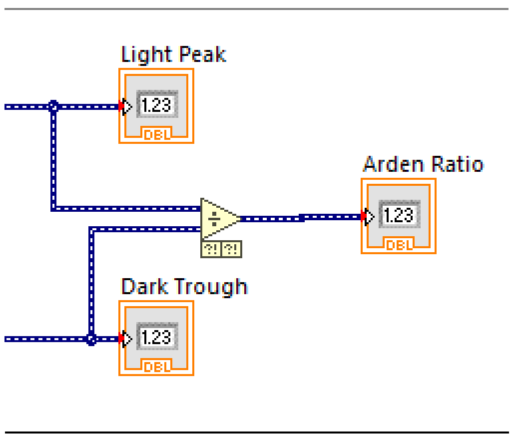

Figure (5.11): SubVI Block Diagram for Calculate the Arden Ratio.

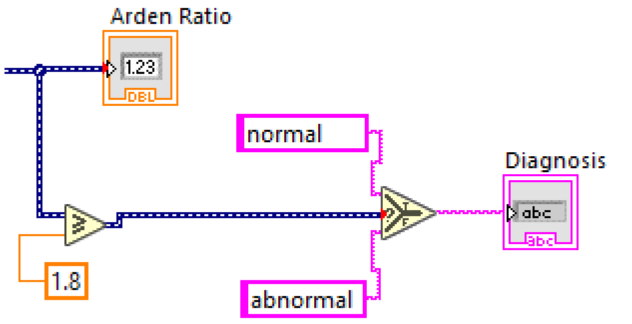

Figure (5.12): Sub VI Block Diagram for Diagnosis of retinal disease.

CHAPTER SIX

<u>Project Implementation & Result</u>

6.1 Electrode Placement
6.2 Project Implementation
6.3 Results
6.4 Challenges
6.5 Conclusion

6.1 Electrode Placement

In the system used five electrodes for detecting horizontal eye movements, which are fixed on the inner and outer end of the eyes, as shown in figure (6.1).

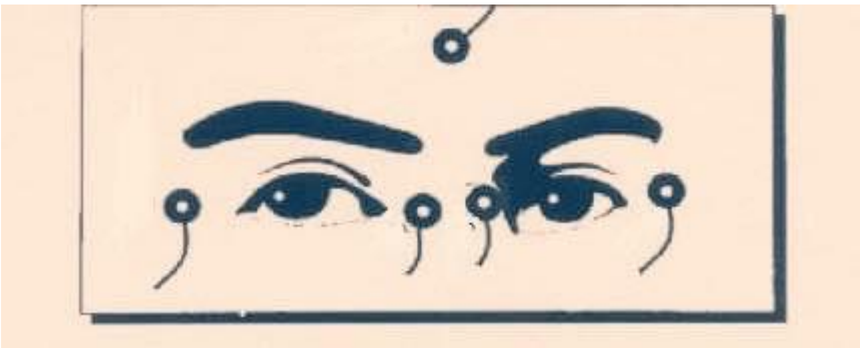

Figure (6.1): Electrodes position.

6.2 Project Implementation

Practical implementation of the project has been done in the second semester, and the implementation started by implementing each individual subsystem. After completing this implementation, the components of the system are connected together to accomplish the final project as one unit, as shown in figure (6.2).

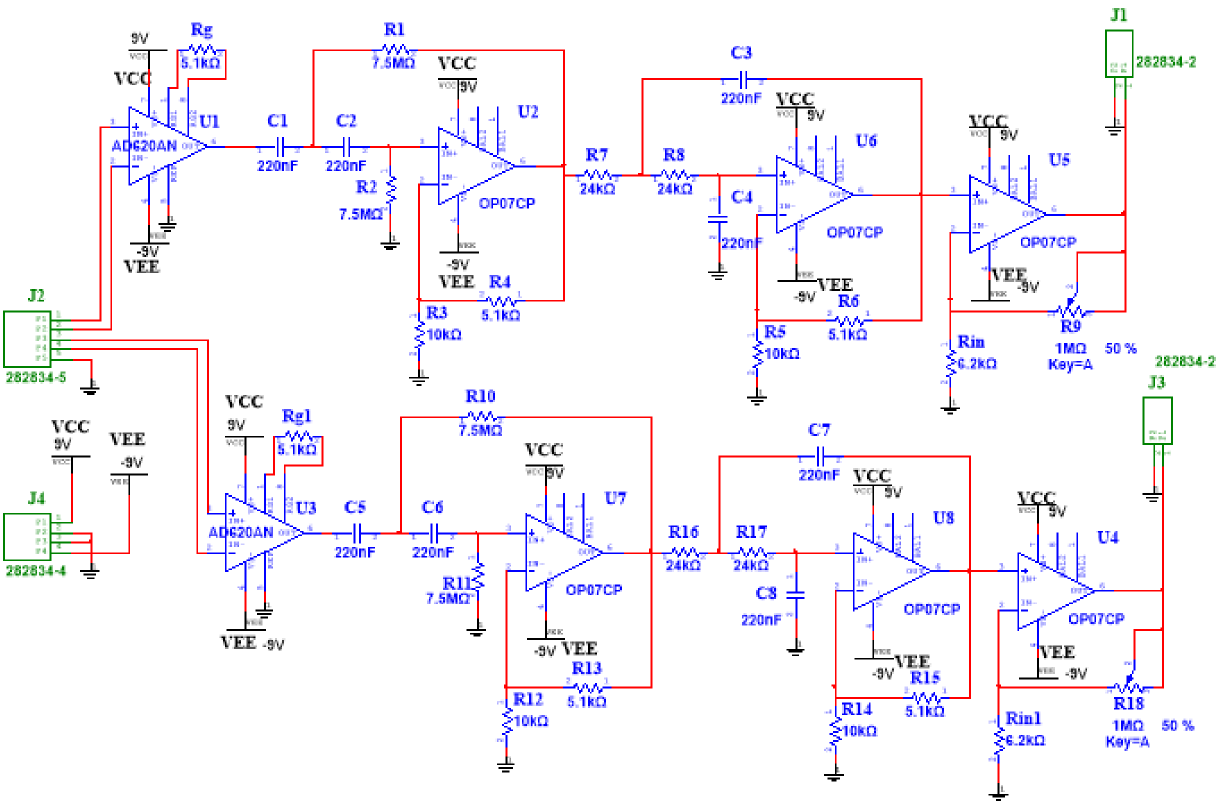

Figure (6.2): Final Project.

6.3 Results

The results of the project were in several stages as follows:

6.3.1 EOG Test

During execution the EOG-system, it has been tested output signal for horizontal eye movements in many cases for controlling the saccadic eyes movement of the eyes by LabVIEW software the following figures depicts these output signals.

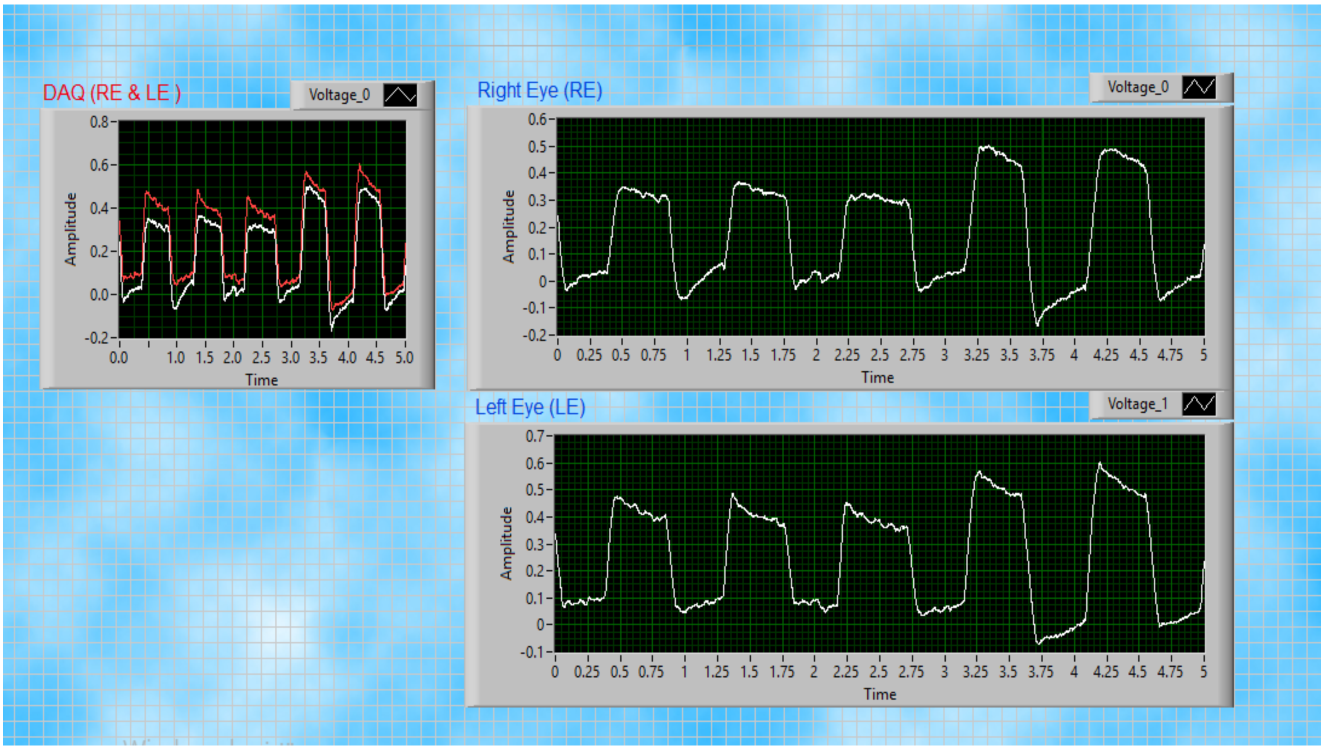

Figure (6.3): EOG signal by horizontal movement of the eyes (Saccadic eye movement).

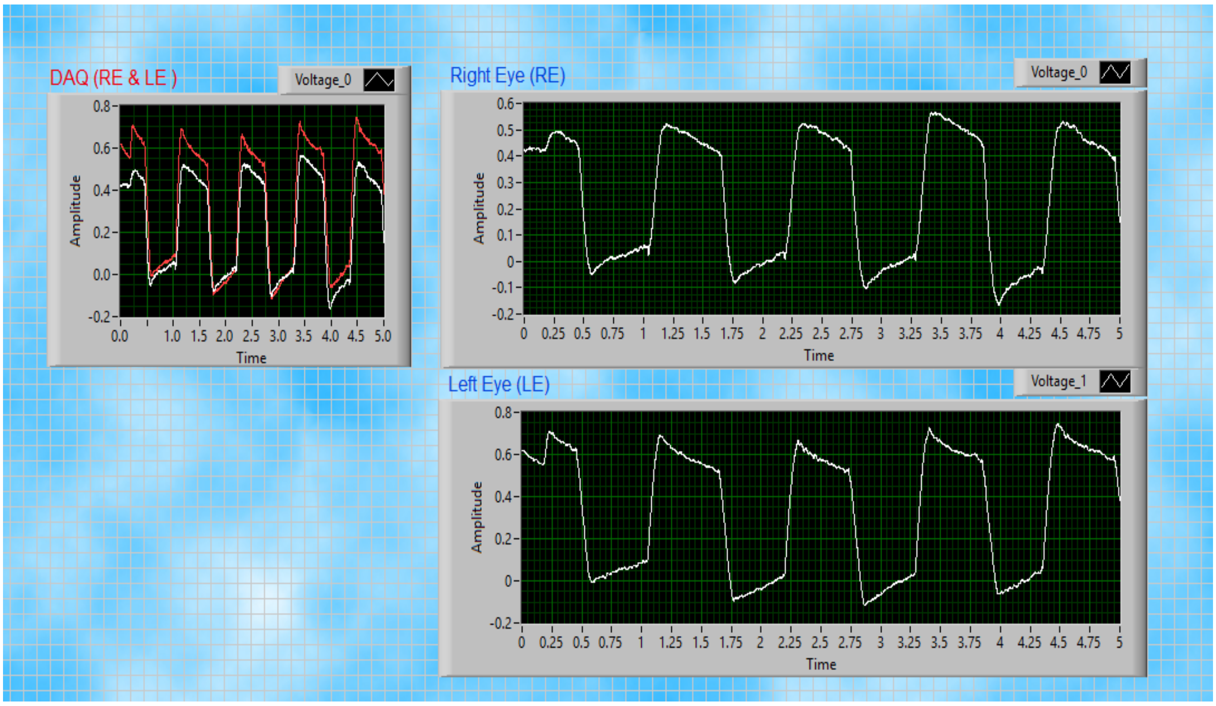

Figure (6.4): EOG signal by horizontal movement of the eyes (Saccadic eye movement).

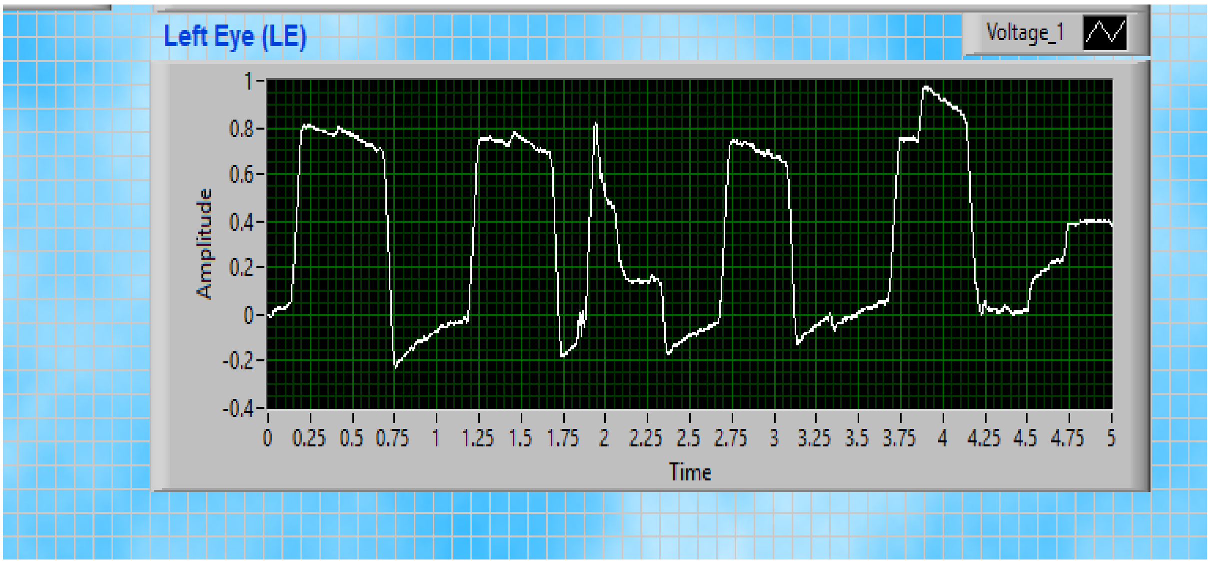

Figure (6.5): Saccadic eye movement with a blink artifact.

6.3.2 Arden Ratio Measurement & Diagnosis

The first step is to calculate the average of saccadic eye movements during one minute along 30 minutes. Table (6.1) show the averages during first EOG test for right and left eye for case (1). Then plot the averages values at smoothing curve for two eyes for (case (1) & case(2)), shown as figure (6.6) and (6.7), then use best fit to get the Arden Ratio curve for two eyes, shown as figure (6.8) and (6.9), to take the light peak and Dark trough then divide these two values to have Arden ratio and compare it with ratio to have the correct diagnosis and display it, shown as figure (6.10) and (6.11).

Table (6.1): Table of averages during EOG test for right and left eye (Case (1)).

Minutes	Averages (RE)	Averages (LE)
1	0.209275	0.109346
2	0.212548	0.081765
3	0.216117	0.153263
4	0.251105	0.133901
5	0.204684	0.154706
6	0.205097	0.163894
7	0.238372	0.158891
8	0.261683	0.157664
9	0.20347	0.15451
10	0.208572	0.151833
11	0.191435	0.166209
12	0.185556	0.172274
13	0.12193	0.171934
14	0.244641	0.139466
15	0.227833	0.16548
16	0.18622	0.155615
17	0.260554	0.120072
18	0.218743	0.139925
19	0.193573	0.148502
20	0.22768	0.166561
21	0.270142	0.156044
22	0.301937	0.147436
23	0.235261	0.177823
24	0.240371	0.159587
25	0.252239	0.167925
26	0.219986	0.217342
27	0.188434	0.179889
28	0.217868	0.165737
29	0.203409	0.175183
30	0.213192	0.158753

- Plot the averages values at smoothing curve for two cases:

Case (1)

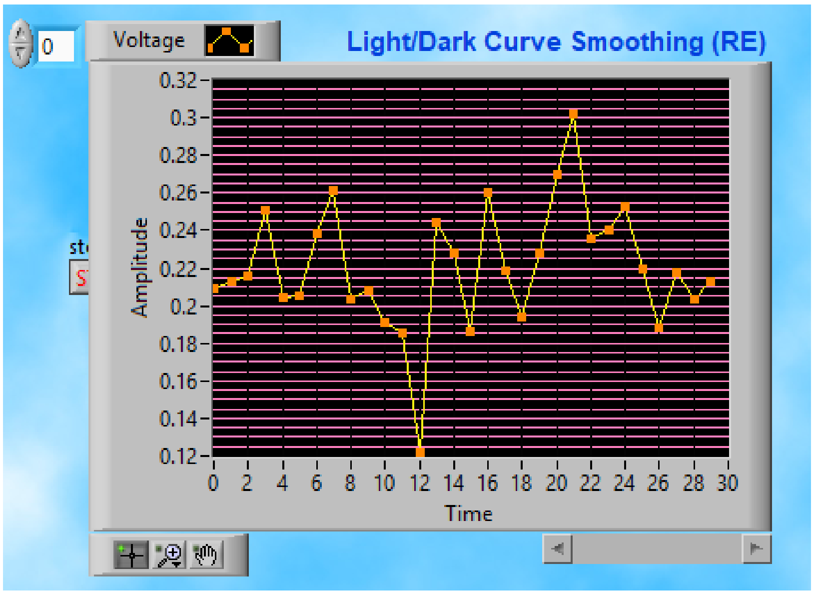

Figure (6.6): Smoothing recordings defines the dark trough and light peak amplitudes from which to calculate the Arden Ratio (Case1(RE)).

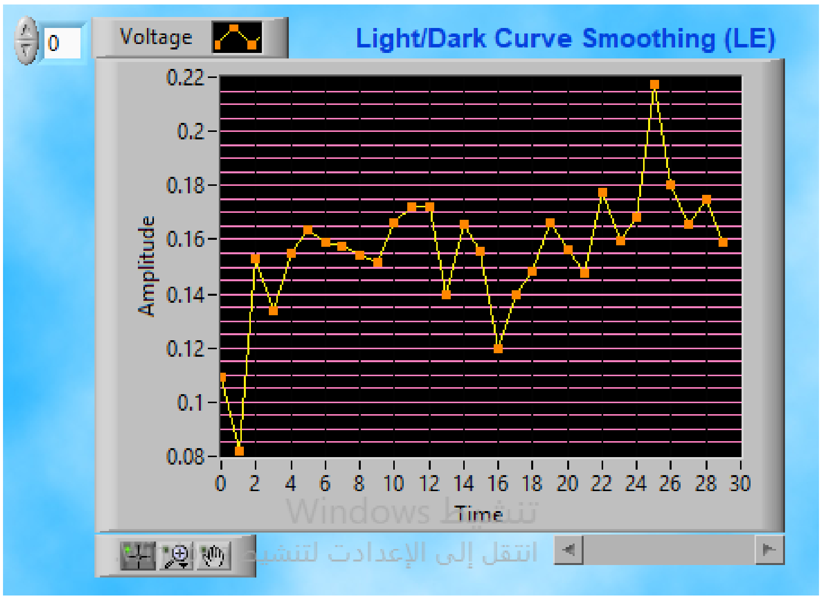

Figure (6.7): Smoothing recordings defines the dark trough and light peak amplitudes from which to calculate the Arden Ratio (Case1(LE)).

Case (2)

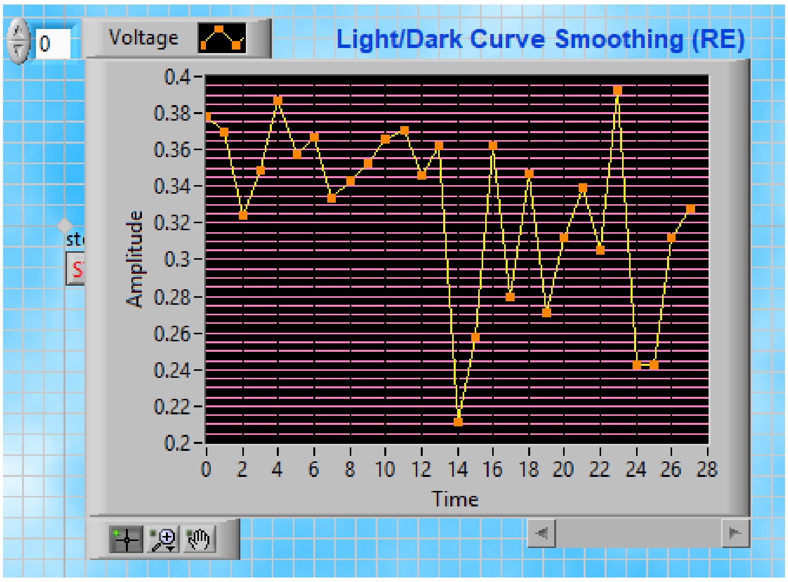

Figure (6.8): Smoothing recordings defines the dark trough and light peak amplitudes from which to calculate the Arden Ratio (case2 (for right eye)).

- Use best fit to get the Arden Ratio curve for two cases:

Case (1)

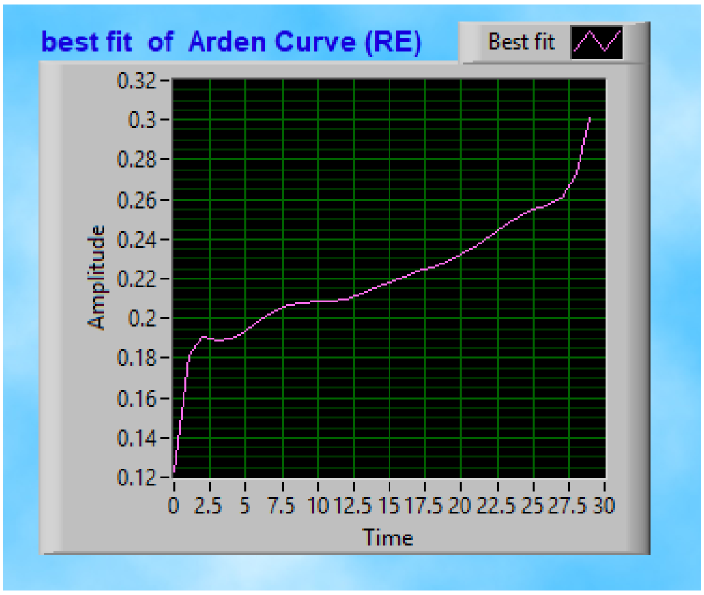

Figure (6.9): Arden Curve (Case1(RE)).

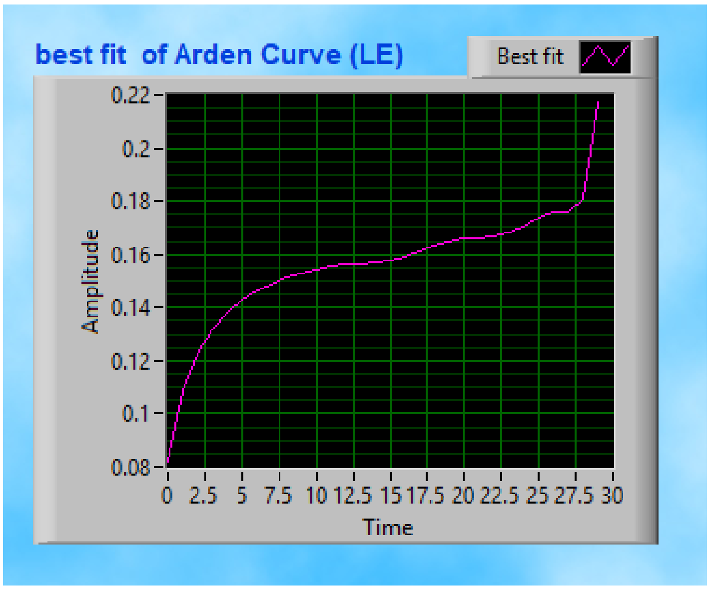

Figure (6.10): Arden Curve (Case1 (LE)).

Case (2)

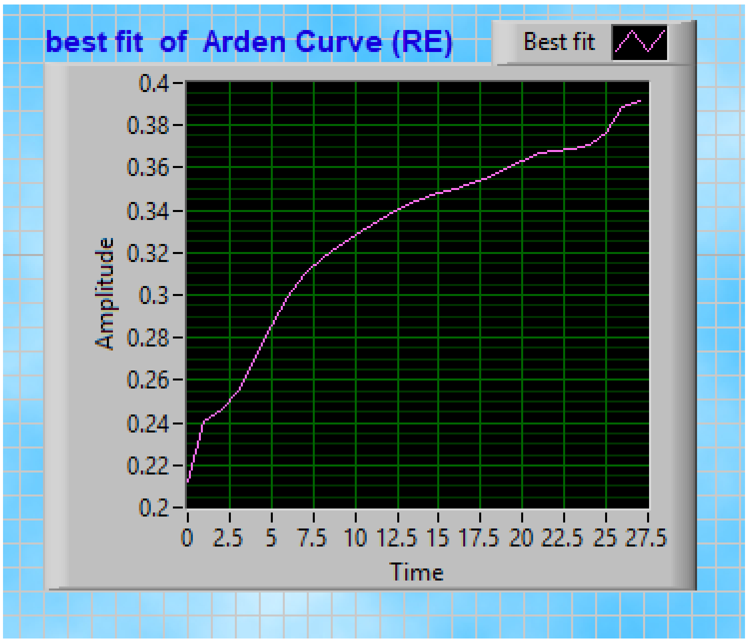

Figure (6.11): Arden Curve (case2 (RE)).

- Take the light peak and Dark trough from the Arden curve for two cases in LabVIEW software then divide these two values to have Arden ratio and compare it with normal ratio (1.8) to have the correct diagnosis and display it.

Case (1)

Figure (6.12): Measure Arden ratio and diagnosis for normal patient (RE).

Figure (6.13): Measure Arden ratio and diagnosis for normal person (LE).

Case (2)

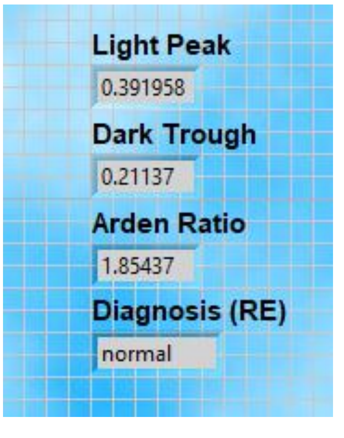

Figure (6.14): Measure Arden ratio and diagnosis (case2 (RE)).

- The result diagnosis of two cases, shown as figure (6.3):

Table (6.2): Table of result diagnosis of two cases.

Case	Diagnosis (RE)	Diagnosis (LE)
1	Normal	Normal
2	Normal	---------

6.4 Challenges

During the project implementation the system, some challenge was faced, such as:

- Some of the system components are expensive like EOG electrodes.
- Not all of the required component for the project are available in the Palestinian market.

6.5 Conclusion

Design and Implementation EOG-system for diagnosis hereditary retinal diseases.

The portable EOG-system is useful to do its aims that represents in measure Arden Ratio and diagnosis of genetic retinal diseases by comparing the result with Arden ratio to provide the following purposes:

- The project helps ophthalmologists to provide correct diagnosis for hereditary retinal diseases that affect the eyes, which is important for give the best treatment for the patient.
- The device also has light weight, so it can be used easily and everywhere.
- This system combined between efficiency and efficiency, since it uses LabVIEW software which increase the power of diagnosis method.

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<u>Appendix A</u>

<u>Data Sheet for Basic Component</u>

Low Cost Low Power Instrumentation Amplifier

AD620

FEATURES

Easy to use
- **Gain set with one external resistor**
  - **(Gain range 1 to 10,000)**
- **Wide power supply range (±2.3 V to ±18 V)**
- **Higher performance than 3 op amp IA designs**
- **Available in 8-lead DIP and SOIC packaging**
- **Low power, 1.3 mA max supply current**

Excellent dc performance (B grade)
- **50 µV max, input offset voltage**
- **0.6 µV/°C max, input offset drift**
- **1.0 nA max, input bias current**
- **100 dB min common-mode rejection ratio (G = 10)**

Low noise
- **9 nV/√Hz @ 1 kHz, input voltage noise**
- **0.28 µV p-p noise (0.1 Hz to 10 Hz)**

Excellent ac specifications
- **120 kHz bandwidth (G = 100)**
- **15 µs settling time to 0.01%**

APPLICATIONS

Weigh scales
ECG and medical instrumentation
Transducer interface
Data acquisition systems
Industrial process controls
Battery-powered and portable equipment

Table 1. Next Generation Upgrades for AD620

Part	Comment
AD8221	Better specs at lower price
AD8222	Dual channel or differential out
AD8226	Low power, wide input range
AD8220	JFET input
AD8228	Best gain accuracy
AD8295	+2 precision op amps or differential out
AD8429	Ultra low noise

CONNECTION DIAGRAM

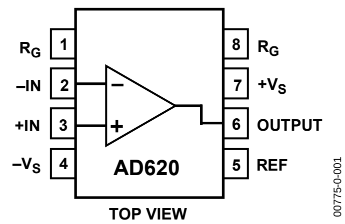

Figure 1. 8-Lead PDIP (N), CERDIP (Q), and SOIC (R) Packages

PRODUCT DESCRIPTION

The AD620 is a low cost, high accuracy instrumentation amplifier that requires only one external resistor to set gains of 1 to 10,000. Furthermore, the AD620 features 8-lead SOIC and DIP packaging that is smaller than discrete designs and offers lower power (only 1.3 mA max supply current), making it a good fit for battery-powered, portable (or remote) applications.

The AD620, with its high accuracy of 40 ppm maximum nonlinearity, low offset voltage of 50 µV max, and offset drift of 0.6 µV/°C max, is ideal for use in precision data acquisition systems, such as weigh scales and transducer interfaces. Furthermore, the low noise, low input bias current, and low power of the AD620 make it well suited for medical applications, such as ECG and noninvasive blood pressure monitors.

The low input bias current of 1.0 nA max is made possible with the use of Superβeta processing in the input stage. The AD620 works well as a preamplifier due to its low input voltage noise of 9 nV/√Hz at 1 kHz, 0.28 µV p-p in the 0.1 Hz to 10 Hz band, and 0.1 pA/√Hz input current noise. Also, the AD620 is well suited for multiplexed applications with its settling time of 15 µs to 0.01%, and its cost is low enough to enable designs with one in-amp per channel.

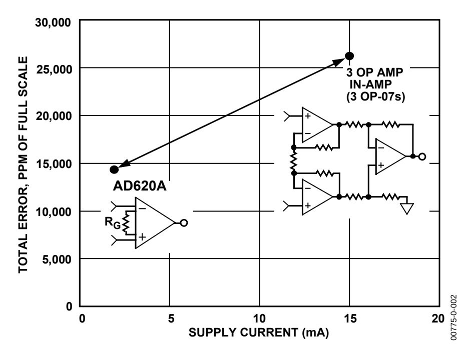

Figure 2. Three Op Amp IA Designs vs. AD620

Rev. H

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SPECIFICATIONS

Typical @ 25°C, V_S = ±15 V, and R_L = 2 kΩ, unless otherwise noted.

Table 2.

Parameter	Conditions	AD620A			AD620B			AD620S[1]			
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Unit
GAIN	G = 1 + (49.4 kΩ/R_G)										
Gain Range		1		10,000	1		10,000	1		10,000	
Gain Error[2]	V_{OUT} = ±10 V										
G = 1			0.03	0.10		0.01	0.02		0.03	0.10	%
G = 10			0.15	0.30		0.10	0.15		0.15	0.30	%
G = 100			0.15	0.30		0.10	0.15		0.15	0.30	%
G = 1000			0.40	0.70		0.35	0.50		0.40	0.70	%
Nonlinearity	V_{OUT} = −10 V to +10 V										
G = 1–1000	R_L = 10 kΩ		10	40		10	40		10	40	ppm
G = 1–100	R_L = 2 kΩ		10	95		10	95		10	95	ppm
Gain vs. Temperature											
	G = 1			10			10			10	ppm/°C
	Gain >1[2]			−50			−50			−50	ppm/°C
VOLTAGE OFFSET	(Total RTI Error = V_{OSI} + V_{OSO}/G)										
Input Offset, V_{OSI}	V_S = ±5 V to ± 15 V		30	125		15	50		30	125	µV
Overtemperature	V_S = ±5 V to ± 15 V			185			85			225	µV
Average TC	V_S = ±5 V to ± 15 V		0.3	1.0		0.1	0.6		0.3	1.0	µV/°C
Output Offset, V_{OSO}	V_S = ±15 V		400	1000		200	500		400	1000	µV
	V_S = ± 5 V			1500			750			1500	µV
Overtemperature	V_S = ±5 V to ± 15 V			2000			1000			2000	µV
Average TC	V_S = ±5 V to ± 15 V		5.0	15		2.5	7.0		5.0	15	µV/°C
Offset Referred to the Input vs. Supply (PSR)	V_S = ±2.3 V to ±18 V										
G = 1		80	100		80	100		80	100		dB
G = 10		95	120		100	120		95	120		dB
G = 100		110	140		120	140		110	140		dB
G = 1000		110	140		120	140		110	140		dB
INPUT CURRENT											
Input Bias Current			0.5	2.0		0.5	1.0		0.5	2	nA
Overtemperature				2.5			1.5			4	nA
Average TC			3.0			3.0			8.0		pA/°C
Input Offset Current			0.3	1.0		0.3	0.5		0.3	1.0	nA
Overtemperature				1.5			0.75			2.0	nA
Average TC			1.5			1.5			8.0		pA/°C
INPUT											
Input Impedance											
Differential			10‖2			10‖2			10‖2		GΩ_pF
Common-Mode			10‖2			10‖2			10‖2		GΩ_pF
Input Voltage Range[3]	V_S = ±2.3 V to ±5 V	$-V_S + 1.9$		$+V_S - 1.2$	$-V_S + 1.9$		$+V_S - 1.2$	$-V_S + 1.9$		$+V_S - 1.2$	V
Overtemperature		$-V_S + 2.1$		$+V_S - 1.3$	$-V_S + 2.1$		$+V_S - 1.3$	$-V_S + 2.1$		$+V_S - 1.3$	V
	V_S = ± 5 V to ±18 V	$-V_S + 1.9$		$+V_S - 1.4$	$-V_S + 1.9$		$+V_S - 1.4$	$-V_S + 1.9$		$+V_S - 1.4$	V
Overtemperature		$-V_S + 2.1$		$+V_S - 1.4$	$-V_S + 2.1$		$+V_S + 2.1$	$-V_S + 2.3$		$+V_S - 1.4$	V

Parameter	Conditions	AD620A Min	AD620A Typ	AD620A Max	AD620B Min	AD620B Typ	AD620B Max	AD620S[1] Min	AD620S[1] Typ	AD620S[1] Max	Unit
Common-Mode Rejection											
Ratio DC to 60 Hz with											
1 kΩ Source Imbalance	V_{CM} = 0 V to ± 10 V										
G = 1		73	90		80	90		73	90		dB
G = 10		93	110		100	110		93	110		dB
G = 100		110	130		120	130		110	130		dB
G = 1000		110	130		120	130		110	130		dB
OUTPUT											
Output Swing	R_L = 10 kΩ										
	V_S = ±2.3 V to ± 5 V	$-V_S$ + 1.1		$+V_S$ − 1.2	$-V_S$ + 1.1		$+V_S$ − 1.2	$-V_S$ + 1.1		$+V_S$ − 1.2	V
Overtemperature		$-V_S$ + 1.4		$+V_S$ − 1.3	$-V_S$ + 1.4		$+V_S$ − 1.3	$-V_S$ + 1.6		$+V_S$ − 1.3	V
	V_S = ±5 V to ± 18 V	$-V_S$ + 1.2		$+V_S$ − 1.4	$-V_S$ + 1.2		$+V_S$ − 1.4	$-V_S$ + 1.2		$+V_S$ − 1.4	V
Overtemperature		$-V_S$ + 1.6		$+V_S$ − 1.5	$-V_S$ + 1.6		$+V_S$ − 1.5	$-V_S$ + 2.3		$+V_S$ − 1.5	V
Short Circuit Current			±18			±18			±18		mA
DYNAMIC RESPONSE											
Small Signal −3 dB Bandwidth											
G = 1			1000			1000			1000		kHz
G = 10			800			800			800		kHz
G = 100			120			120			120		kHz
G = 1000			12			12			12		kHz
Slew Rate		0.75	1.2		0.75	1.2		0.75	1.2		V/μs
Settling Time to 0.01%	10 V Step										
G = 1–100			15			15			15		μs
G = 1000			150			150			150		μs
NOISE											
Voltage Noise, 1 kHz	$Total\ RTI\ Noise = \sqrt{(e^2_{ni}) + (e_{no}/G)^2}$										
Input, Voltage Noise, e_{ni}			9	13		9	13		9	13	nV/√Hz
Output, Voltage Noise, e_{no}			72	100		72	100		72	100	nV/√Hz
RTI, 0.1 Hz to 10 Hz											
G = 1			3.0			3.0	6.0		3.0	6.0	μV p-p
G = 10			0.55			0.55	0.8		0.55	0.8	μV p-p
G = 100–1000			0.28			0.28	0.4		0.28	0.4	μV p-p
Current Noise	f = 1 kHz		100			100			100		fA/√Hz
0.1 Hz to 10 Hz			10			10			10		pA p-p
REFERENCE INPUT											
R_{IN}			20			20			20		kΩ
I_{IN}	V_{IN+}, V_{REF} = 0		50	60		50	60		50	60	μA
Voltage Range		$-V_S$ + 1.6		$+V_S$ − 1.6	$-V_S$ + 1.6		$+V_S$ − 1.6	$-V_S$ + 1.6		$+V_S$ − 1.6	V
Gain to Output		1 ± 0.0001			1 ± 0.0001			1 ± 0.0001			
POWER SUPPLY											
Operating Range[4]		±2.3		±18	±2.3		±18	±2.3		±18	V
Quiescent Current	V_S = ±2.3 V to ±18 V		0.9	1.3		0.9	1.3		0.9	1.3	mA
Overtemperature			1.1	1.6		1.1	1.6		1.1	1.6	mA
TEMPERATURE RANGE											
For Specified Performance		−40 to +85			−40 to +85			−55 to +125			°C

[1] See Analog Devices military data sheet for 883B tested specifications.
[2] Does not include effects of external resistor R_G.
[3] One input grounded. G = 1.
[4] This is defined as the same supply range that is used to specify PSR.

ABSOLUTE MAXIMUM RATINGS

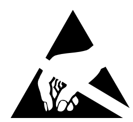
Table 3.

Parameter	Rating
Supply Voltage	±18 V
Internal Power Dissipation[1]	650 mW
Input Voltage (Common-Mode)	$\pm V_S$
Differential Input Voltage	25 V
Output Short-Circuit Duration	Indefinite
Storage Temperature Range (Q)	−65°C to +150°C
Storage Temperature Range (N, R)	−65°C to +125°C
Operating Temperature Range	
AD620 (A, B)	−40°C to +85°C
AD620 (S)	−55°C to +125°C
Lead Temperature Range	
(Soldering 10 seconds)	300°C

[1] Specification is for device in free air:
8-Lead Plastic Package: θ_{JA} = 95°C
8-Lead CERDIP Package: θ_{JA} = 110°C
8-Lead SOIC Package: θ_{JA} = 155°C

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other condition s above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ESD CAUTION



ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

Ultralow Offset Voltage Operational Amplifier

FEATURES

Low V_{OS}: 75 µV maximum
Low V_{OS} drift: 1.3 µV/°C maximum
Ultrastable vs. time: 1.5 µV per month maximum
Low noise: 0.6 µV p-p maximum
Wide input voltage range: ±14 V typical
Wide supply voltage range: ±3 V to ±18 V
125°C temperature-tested dice

APPLICATIONS

Wireless base station control circuits
Optical network control circuits
Instrumentation
Sensors and controls
- **Thermocouples**
- **Resistor thermal detectors (RTDs)**
- **Strain bridges**
- **Shunt current measurements**

Precision filters

GENERAL DESCRIPTION

The OP07 has very low input offset voltage (75 µV maximum for OP07E) that is obtained by trimming at the wafer stage. These low offset voltages generally eliminate any need for external nulling. The OP07 also features low input bias current (±4 nA for the OP07E) and high open-loop gain (200 V/mV for the OP07E). The low offset and high open-loop gain make the OP07 particularly useful for high gain instrumentation applications.

PIN CONFIGURATION

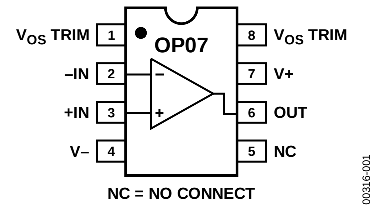


Figure 1.

The wide input voltage range of ±13 V minimum combined with a high CMRR of 106 dB (OP07E) and high input impedance provide high accuracy in the noninverting circuit configuration. Excellent linearity and gain accuracy can be maintained even at high closed-loop gains. Stability of offsets and gain with time or variations in temperature is excellent. The accuracy and stability of the OP07, even at high gain, combined with the freedom from external nulling have made the OP07 an industry standard for instrumentation applications.

The OP07 is available in two standard performance grades. The OP07E is specified for operation over the 0°C to 70°C range, and the OP07C is specified over the −40°C to +85°C temperature range.

The OP07 is available in epoxy 8-lead PDIP and 8-lead narrow SOIC packages. For CERDIP and TO-99 packages and standard microcircuit drawing (SMD) versions, see the OP77.

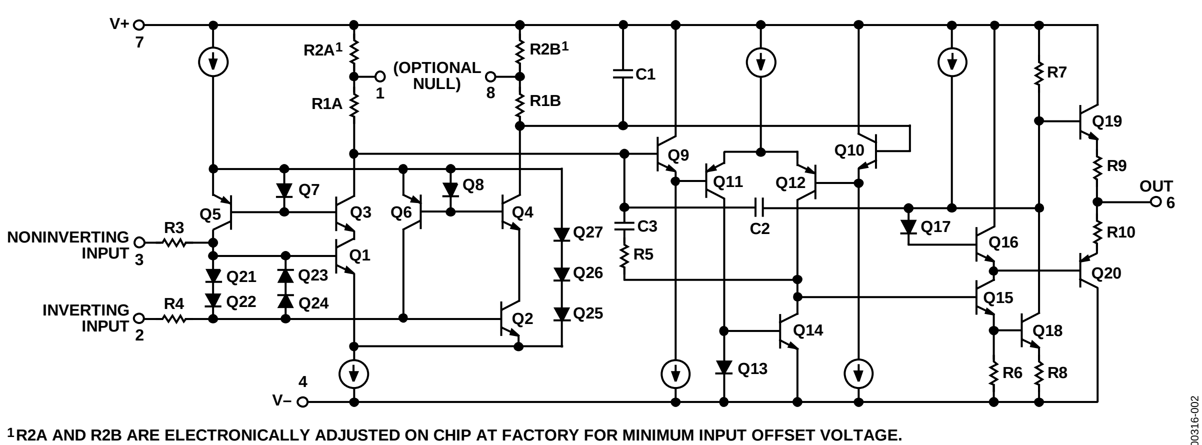


Figure 2. Simplified Schematic

Rev. G

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SPECIFICATIONS

OP07E ELECTRICAL CHARACTERISTICS

V_S = ±15 V, unless otherwise noted.

Table 1.

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
INPUT CHARACTERISTICS						
T_A = 25°C						
Input Offset Voltage[1]	V_{OS}			30	75	µV
Long-Term V_{OS} Stability[2]	V_{OS}/Time			0.3	1.5	µV/Month
Input Offset Current	I_{OS}			0.5	3.8	nA
Input Bias Current	I_B			±1.2	±4.0	nA
Input Noise Voltage	e_n p-p	0.1 Hz to 10 Hz[3]		0.35	0.6	µV p-p
Input Noise Voltage Density	e_n	f_O = 10 Hz		10.3	18.0	nV/√Hz
		f_O = 100 Hz[3]		10.0	13.0	nV/√Hz
		f_O = 1 kHz		9.6	11.0	nV/√Hz
Input Noise Current	I_n p-p			14	30	pA p-p
Input Noise Current Density	I_n	f_O = 10 Hz		0.32	0.80	pA/√Hz
		f_O = 100 Hz[3]		0.14	0.23	pA/√Hz
		f_O = 1 kHz		0.12	0.17	pA/√Hz
Input Resistance, Differential Mode[4]	R_{IN}		15	50		MΩ
Input Resistance, Common Mode	R_{INCM}			160		GΩ
Input Voltage Range	IVR		±13	±14		V
Common-Mode Rejection Ratio	CMRR	V_{CM} = ±13 V	106	123		dB
Power Supply Rejection Ratio	PSRR	V_S = ±3 V to ±18 V		5	20	µV/V
Large Signal Voltage Gain	A_{VO}	R_L ≥ 2 kΩ, V_O = ±10 V	200	500		V/mV
		R_L ≥ 500 Ω, V_O = ±0.5 V, V_S = ±3 V[4]	150	400		V/mV
0°C ≤ T_A ≤ 70°C						
Input Offset Voltage[1]	V_{OS}			45	130	µV
Voltage Drift Without External Trim[4]	TCV_{OS}			0.3	1.3	µV/°C
Voltage Drift with External Trim[3]	TCV_{OSN}	R_P = 20 kΩ		0.3	1.3	µV/°C
Input Offset Current	I_{OS}			0.9	5.3	nA
Input Offset Current Drift	TCI_{OS}			8	35	pA/°C
Input Bias Current	I_B			±1.5	±5.5	nA
Input Bias Current Drift	TCI_B			13	35	pA/°C
Input Voltage Range	IVR		±13	±13.5		V
Common-Mode Rejection Ratio	CMRR	V_{CM} = ±13 V	103	123		dB
Power Supply Rejection Ratio	PSRR	V_S = ±3 V to ±18 V		7	32	µV/V
Large Signal Voltage Gain	A_{VO}	R_L ≥ 2 kΩ, V_O = ±10 V	180	450		V/mV
OUTPUT CHARACTERISTICS						
T_A = 25°C						
Output Voltage Swing	V_O	R_L ≥ 10 kΩ	±12.5	±13.0		V
		R_L ≥ 2 kΩ	±12.0	±12.8		V
		R_L ≥ 1 kΩ	±10.5	±12.0		V
0°C ≤ T_A ≤ 70°C						
Output Voltage Swing	V_O	R_L ≥ 2 kΩ	±12	±12.6		V

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
DYNAMIC PERFORMANCE						
T_A = 25°C						
Slew Rate	SR	R_L ≥ 2 kΩ[3]	0.1	0.3		V/µs
Closed-Loop Bandwidth	BW	A_{VOL} = 1[5]	0.4	0.6		MHz
Open-Loop Output Resistance	R_O	V_O = 0, I_O = 0		60		Ω
Power Consumption	P_d	V_S = ±15 V, No load		75	120	mW
		V_S = ±3 V, No load		4	6	mW
Offset Adjustment Range		R_P = 20 kΩ		±4		mV

[1] Input offset voltage measurements are performed by automated test equipment approximately 0.5 seconds after application of power.
[2] Long-term input offset voltage stability refers to the averaged trend time of V_{OS} vs. the time over extended periods after the first 30 days of operation. Excluding the initial hour of operation, changes in V_{OS} during the first 30 operating days are typically 2.5 µV. Refer to the Typical Performance Characteristics section. Parameter is sample tested.
[3] Sample tested.
[4] Guaranteed by design.
[5] Guaranteed but not tested.

OP07C ELECTRICAL CHARACTERISTICS

V_S = ±15 V, unless otherwise noted.

Table 2.

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
INPUT CHARACTERISTICS						
T_A = 25°C						
Input Offset Voltage[1]	V_{OS}			60	150	µV
Long-Term V_{OS} Stability[2]	V_{OS}/Time			0.4	2.0	µV/Month
Input Offset Current	I_{OS}			0.8	6.0	nA
Input Bias Current	I_B			±1.8	±7.0	nA
Input Noise Voltage	e_n p-p	0.1 Hz to 10 Hz[3]		0.38	0.65	µV p-p
Input Noise Voltage Density	e_n	f_O = 10 Hz		10.5	20.0	nV/√Hz
		f_O = 100 Hz[3]		10.2	13.5	nV/√Hz
		f_O = 1 kHz		9.8	11.5	nV/√Hz
Input Noise Current	I_n p-p			15	35	pA p-p
Input Noise Current Density	I_n	f_O = 10 Hz		0.35	0.90	pA/√Hz
		f_O = 100 Hz[3]		0.15	0.27	pA/√Hz
		f_O = 1 kHz		0.13	0.18	pA/√Hz
Input Resistance, Differential Mode[4]	R_{IN}		8	33		MΩ
Input Resistance, Common Mode	R_{INCM}			120		GΩ
Input Voltage Range	IVR		±13	±14		V
Common-Mode Rejection Ratio	CMRR	V_{CM} = ±13 V	100	120		dB
Power Supply Rejection Ratio	PSRR	V_S = ±3 V to ±18 V		7	32	µV/V
Large Signal Voltage Gain	A_{VO}	R_L ≥ 2 kΩ, V_O = ±10 V	120	400		V/mV
		R_L ≥ 500 Ω, V_O = ±0.5 V, V_S = ±3 V[4]	100	400		V/mV
−40°C ≤ T_A ≤ +85°C						
Input Offset Voltage[1]	V_{OS}			85	250	µV
Voltage Drift Without External Trim[4]	TCV_{OS}			0.5	1.8	µV/°C
Voltage Drift with External Trim[3]	TCV_{OSN}	R_P = 20 kΩ		0.4	1.6	µV/°C
Input Offset Current	I_{OS}			1.6	8.0	nA
Input Offset Current Drift	TCI_{OS}			12	50	pA/°C
Input Bias Current	I_B			±2.2	±9.0	nA
Input Bias Current Drift	TCI_B			18	50	pA/°C
Input Voltage Range	IVR		±13	±13.5		V
Common-Mode Rejection Ratio	CMRR	V_{CM} = ±13 V	97	120		dB
Power Supply Rejection Ratio	PSRR	V_S = ±3 V to ±18 V		10	51	µV/V
Large Signal Voltage Gain	A_{VO}	R_L ≥ 2 kΩ, V_O = ±10 V	100	400		V/mV

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
OUTPUT CHARACTERISTICS						
T_A = 25°C						
Output Voltage Swing	V_O	R_L ≥ 10 kΩ	±12.0	±13.0		V
		R_L ≥ 2 kΩ	±11.5	±12.8		V
		R_L ≥ 1 kΩ		±12.0		V
−40°C ≤ T_A ≤ +85°C						
Output Voltage Swing	V_O	R_L ≥ 2 kΩ	±12	±12.6		V
DYNAMIC PERFORMANCE						
T_A = 25°C						
Slew Rate	SR	R_L ≥ 2 kΩ[3]	0.1	0.3		V/μs
Closed-Loop Bandwidth	BW	A_{VOL} = 1[5]	0.4	0.6		MHz
Open-Loop Output Resistance	R_O	V_O = 0, I_O = 0		60		Ω
Power Consumption	P_d	V_S = ±15 V, No load		80	150	mW
		V_S = ±3 V, No load		4	8	mW
Offset Adjustment Range		R_P = 20 kΩ		±4		mV

[1] Input offset voltage measurements are performed by automated test equipment approximately 0.5 seconds after application of power.
[2] Long-term input offset voltage stability refers to the averaged trend time of V_{OS} vs. the time over extended periods after the first 30 days of operation. Excluding the initial hour of operation, changes in V_{OS} during the first 30 operating days are typically 2.5 μV. Refer to the Typical Performance Characteristics section. Parameter is sample tested.
[3] Sample tested.
[4] Guaranteed by design.
[5] Guaranteed but not tested.

ABSOLUTE MAXIMUM RATINGS

Table 3.

Parameter	Ratings
Supply Voltage (V_S)	±22 V
Input Voltage[1]	±22 V
Differential Input Voltage	±30 V
Output Short-Circuit Duration	Indefinite
Storage Temperature Range	
S and P Packages	−65°C to +125°C
Operating Temperature Range	
OP07E	0°C to 70°C
OP07C	−40°C to +85°C
Junction Temperature	150°C
Lead Temperature, Soldering (60 sec)	300°C

[1] For supply voltages less than ±22 V, the absolute maximum input voltage is equal to the supply voltage.

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

THERMAL RESISTANCE

θ_{JA} is specified for the worst-case conditions, that is, a device soldered in a circuit board for surface-mount packages.

Table 4. Thermal Resistance

Package Type	θ_{JA}	θ_{JC}	Unit
8-Lead PDIP (P-Suffix)	103	43	°C/W
8-Lead SOIC_N (S-Suffix)	158	43	°C/W

ESD CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although this product features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

Butterworth Coefficients

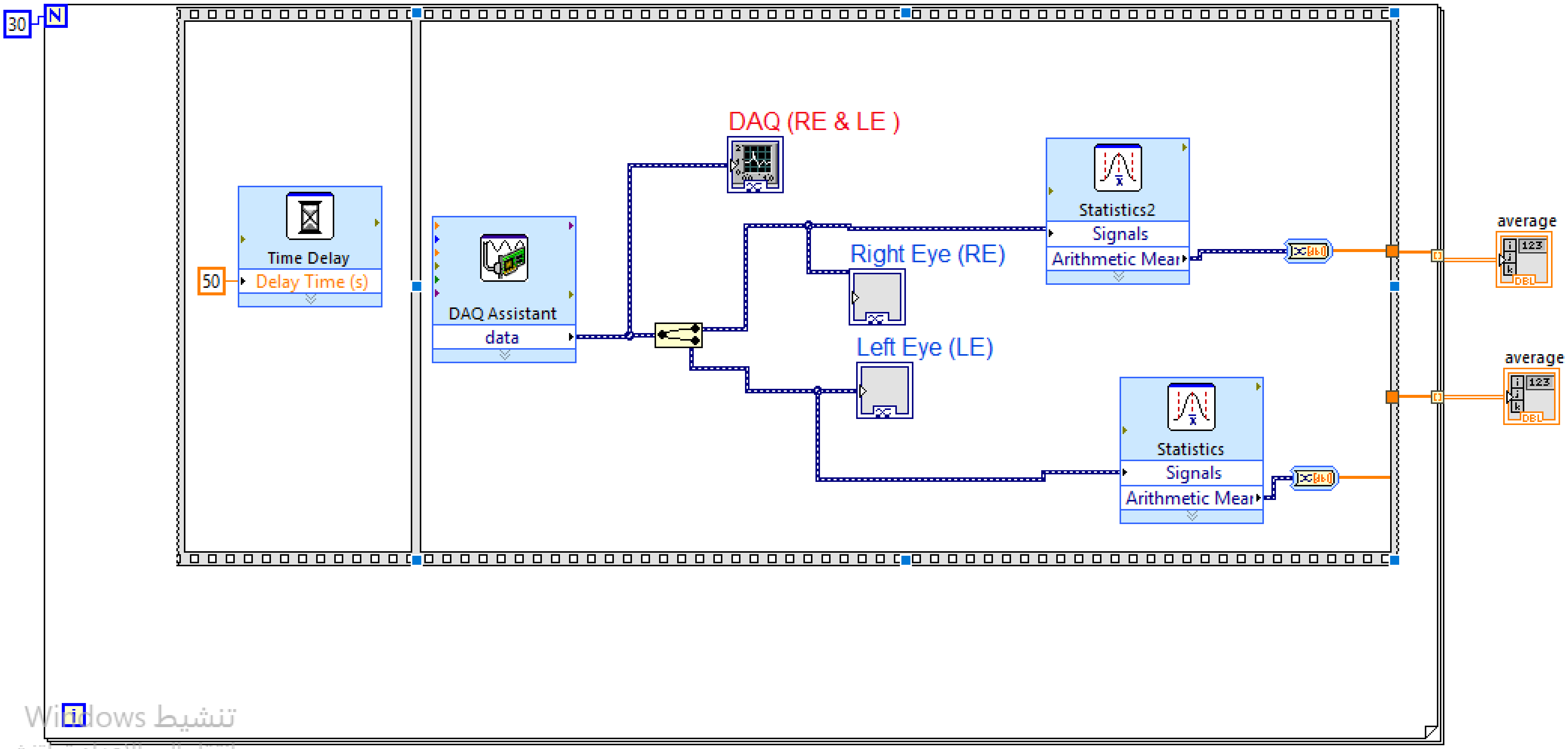
n	i	a_i	b_i	$k_i = f_{Ci} / f_C$	Q_i
1	1	1.0000	0.0000	1.000	—
2	1	1.4142	1.0000	1.000	0.71
3	1	1.0000	0.0000	1.000	—
	2	1.0000	1.0000	1.272	1.00
4	1	1.8478	1.0000	0.719	0.54
	2	0.7654	1.0000	1.390	1.31
5	1	1.0000	0.0000	1.000	—
	2	1.6180	1.0000	0.859	0.62
	3	0.6180	1.0000	1.448	1.62

Standard Resistor Values (±5%)						
1.0	10	100	1.0K	10K	100K	1.0M
1.1	11	110	1.1K	11K	110K	1.1M
1.2	12	120	1.2K	12K	120K	1.2M
1.3	13	130	1.3K	13K	130K	1.3M
1.5	15	150	1.5K	15K	150K	1.5M
1.6	16	160	1.6K	16K	160K	1.6M
1.8	18	180	1.8K	18K	180K	1.8M
2.0	20	200	2.0K	20K	200K	2.0M
2.2	22	220	2.2K	22K	220K	2.2M
2.4	24	240	2.4K	24K	240K	2.4M
2.7	27	270	2.7K	27K	270K	2.7M
3.0	30	300	3.0K	30K	300K	3.0M
3.3	33	330	3.3K	33K	330K	3.3M
3.6	36	360	3.6K	36K	360K	3.6M
3.9	39	390	3.9K	39K	390K	3.9M
4.3	43	430	4.3K	43K	430K	4.3M
4.7	47	470	4.7K	47K	470K	4.7M
5.1	51	510	5.1K	51K	510K	5.1M
5.6	56	560	5.6K	56K	560K	5.6M
6.2	62	620	6.2K	62K	620K	6.2M
6.8	68	680	6.8K	68K	680K	6.8M
7.5	75	750	7.5K	75K	750K	7.5M
8.2	82	820	8.2K	82K	820K	8.2M
9.1	91	910	9.1K	91K	910K	9.1M

Appendix B

Software Code (LabVIEW)

A. Block Diagram (Signal Acquisition)
B. Block Diagram Arden Ratio Measurement & Diagnosis



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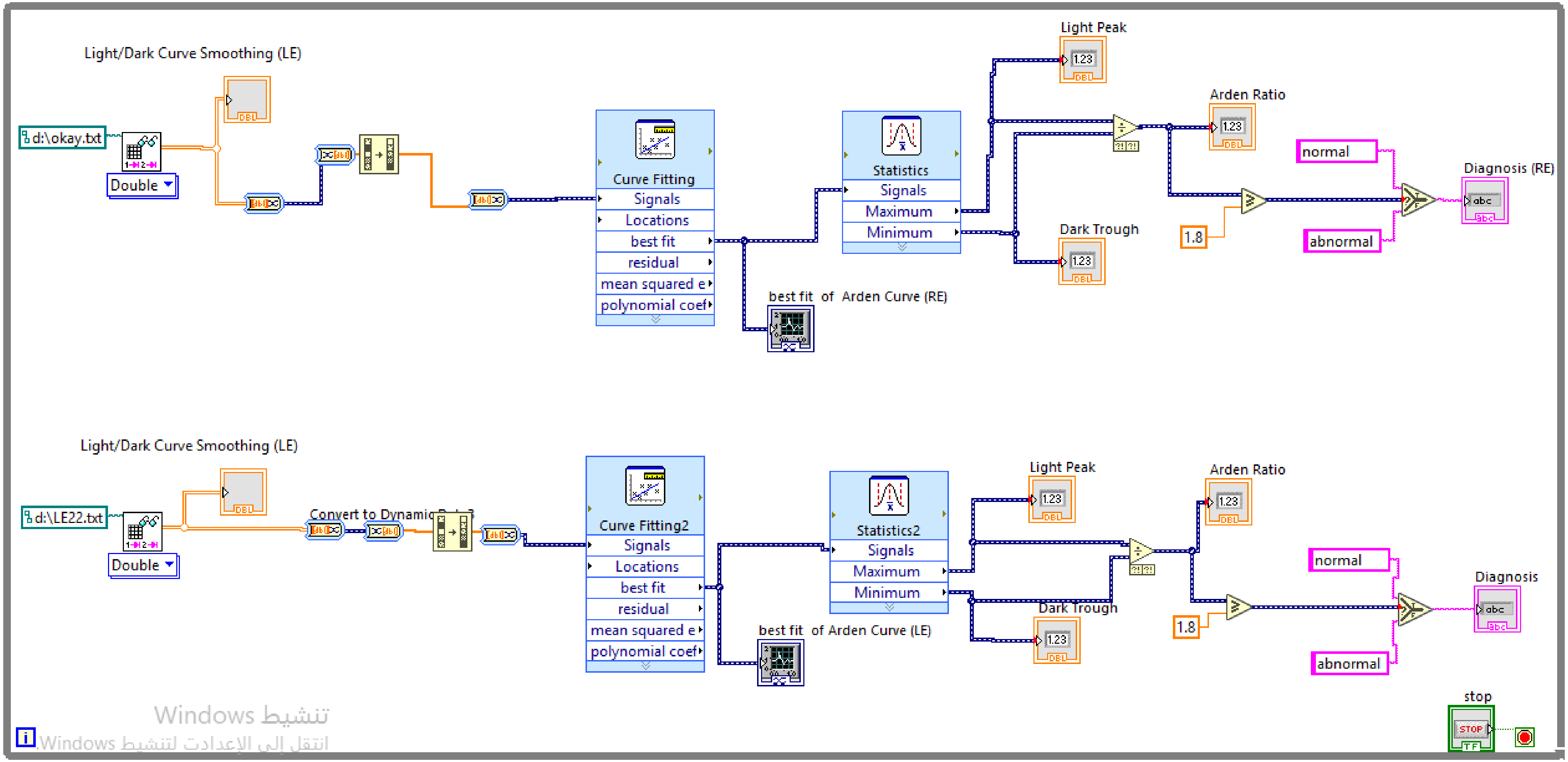
N
50
Time Delay
Delay Time (s)
DAQ Assistant
data
DAQ (RE & LE)
Right Eye (RE)
Left Eye (LE)
Statistics2
Signals
Arithmetic Mean
Statistics
Signals
Arithmetic Mean
average
average



Light/Dark Curve Smoothing (LE)
d:\okay.txt
Double
Curve Fitting
Signals
Locations
best fit
residual
mean squared e
polynomial coef
best fit of Arden Curve (RE)
Statistics
Signals
Maximum
Minimum
Light Peak
Dark Trough
Arden Ratio
1.8
normal
abnormal
Diagnosis (RE)
Light/Dark Curve Smoothing (LE)
d:\LE22.txt
Double
Curve Fitting2
Signals
Locations
best fit
residual
mean squared e
polynomial coef
best fit of Arden Curve (LE)
Statistics2
Signals
Maximum
Minimum
Light Peak
Dark Trough
Arden Ratio
1.8
normal
abnormal
Diagnosis
stop