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DESIGN AND CONSTRUCTION OF A TOOLBOX FOR MEASUREMENTS OF LIGHT AND TEMPERATURE

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ENGINEERING PHYSICS

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Design and construction of a toolbox for measurements Of light and temperature

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Supervisor

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By

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Aryan A. MUSTAFA

ABSTRACT

DESIGN AND CONSTRUCTION OF A TOOLBOX FOR MEASUREMENTS OF LIGHT AND TEMPERATURE

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M.Sc. Thesis in Engineering Physics
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In this study, a simple toolbox containing a digital lux meter and a digital thermometer has been constructed. Two different light sensors, a photo-resistor and a photo-transistor, and a well calibrated temperature sensor are used. Light sensors are calibrated against a reference photometer. The optical and thermal data are acquired by means of Arduino Uno and measurement results are printed on an LCD screen. In addition a Graphical User Interface using MATLAB has been developed to analyze and visualize the illumination and temperature data in desired time interval.

Key words: Arduino, MATLAB, LDR, TEMT6000, LM35, Lux meter.

ÖZET

IŞIK VE SICAKLIK ÖLÇÜMÜ IÇIN BIR ARAÇ KUTUSU

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Bu tezde, dijital lüxmetre ve termometre içeren bir araç kutusu geliştirimiştir. Çalışmada, foto direnç ve foto transistörden oluşan iki farklı ışık sensörü ve iyi kalibre edilmiş sıcaklık sensörü kullanılmıştır. Işık sensörleri referans bir fotometre baz alınarak kalibre edilmiştir. Optik ve sıcaklık verileri Arduino Uno ile toplanmış ve ölçüm sonuçları LCD ekrana yazdırılmıştır. Ayrıca, MATLAB programı kullanılarak aydınlatma ve sıcaklık verilerini istenilen zaman aralığında analiz eden ve uygun bir şekilde monitöre gösteren bir bir Grafik Arayüz programı da yazılmıştır.

Anahtar Kelimeler: Arduino, MATLAB, LDR, TEMT6000, LM35, Lux metre.

To my family

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LIST OF ABBREVIATIONS

LDR	Light Dependent Resistor
PH.T	Phototransistor (TEMT6000)
LM35	Temperature sensor
UV	Ultraviolet Light
IR	Infrared Light
E	Irradiance of the light source
I	Intensity of the light source
$\boldsymbol{I_o}$	Initial Intensity of the light source
d	Distance between irradiance and source
Ω	Solid angle,
sr	Steradian
λ	wavelength
Q	Radiant Energy
Q_λ	Spectral Radiant Energy
Φ	Radiant Flux

t	Time in Second
U	Radiant Energy Density
Φ_λ	Spectral Radiant Flux
Φ_e	Total Radiant Flux
dA	Differential Area
M	Radiant Exitance
E	Irradiance
M_λ	Spectral Radiant Exitance
E_λ	Spectral Irradiance
I_λ	Spectral Radiant Intensity
I_v	Luminous Intensity
I_e	Radiant Intensity
L	Radiance
U_v	Radiant Energy Density
E_v	Illuminance
L_v	Luminance
Φ_v	Luminous flux
Lm	Lunen
$V(\lambda)$	Standard Luminosity Function

lx	Lux
$V(\lambda)$	Spectral Luminous efficiency function
K_m	Luminous efficacy for photopic vision
cd	Candela
M_v	Luminous Exitance
$d\Phi_v$	Luminous Flux Leaving a Surface.
L_v	Luminance
θ	Angle
E_v	Illuminance
IDE	Integrated Development Environment
° C	Centigrade
° F	Fahrenheit
Testo	reference lux meter (TESTO 0635 0545)

CHAPTER 1

INTRODUCTION

Optics is a branch of Physics related to light and electromagnetic spectrum. Light measurements are very important in Optics and other engineering fields. Measurement of light intensity is a prime necessity in several occasions. The diversity of such needs make their way to various branches of physics and engineering as well as in media. For instance, in engineering, such kinds of measurements are needed to design optimum lighting conditions of a room. In photography, the light intensity measurements ensure good quality pictures for determining the right exposure [1].

In general, for the light intensity measurements characterized by the human eye, relatively expansive lux meters are used in laboratory experiments. In this study, we have designed and constructed a toolbox involving a digital lux meter and a thermometer. For the light measurements two cheap light sensors, a light dependent resistor (LDR) and a phototransistor (TEMT6000) are used. A well calibrated temperature sensor (LM35) is used for the temperature measurements. Both light and thermal data are collected by electronic board called Arduino Uno. The calibration of light sensors are performed by using a reference lux meter (TESTO 0635 0545). Finally the measurement results (the illumination in lux, the temperature in Celsius and associated errors) are displayed on a 4x20 LCD screen. In order to present the variation of input data in time and the measurement results on a computer's monitor, a graphical user interface program developed by MATLAB software is written as well.

The chapter organization of this thesis is as follows. Chapter 2 describes the theory related to this study. Chapter 3 introduces the apparatus used in the study. The calibration procedures of LDR and TEMT6000 are given in Chapter 4. The electronic data acquisition and the data analysis are described in Chapter 4. Finally a conclusion of the study is given in Chapter 5.

CHAPTER 2

THEORY

2.1 What is Light?

The light is simply a very small part of the electromagnetic spectrum, located between ultraviolet and infrared radiation. Light is defined as “the radiant energy that is capable of exciting the retina and producing a visual sensation.” Light, cannot be separately described in terms of radiant energy or of visual sensation, but is a combination of the two [2]. The visible portion of the electromagnetic spectrum extends from about 400 to about 700 nanometers (nm), as shown in Figure 2.1.

2.1.1 Light and optics

The Optics is a branch of science, mainly about light and vision. It also includes the study of other radiations very similar to light but not seen by the human eye. Light is a form of radiant energy. Radiant heat, radio waves, and X-rays are other forms of radiant energy. Light is sent out through space by luminous sources. Most of these are able to emit light because they are very hot [3].

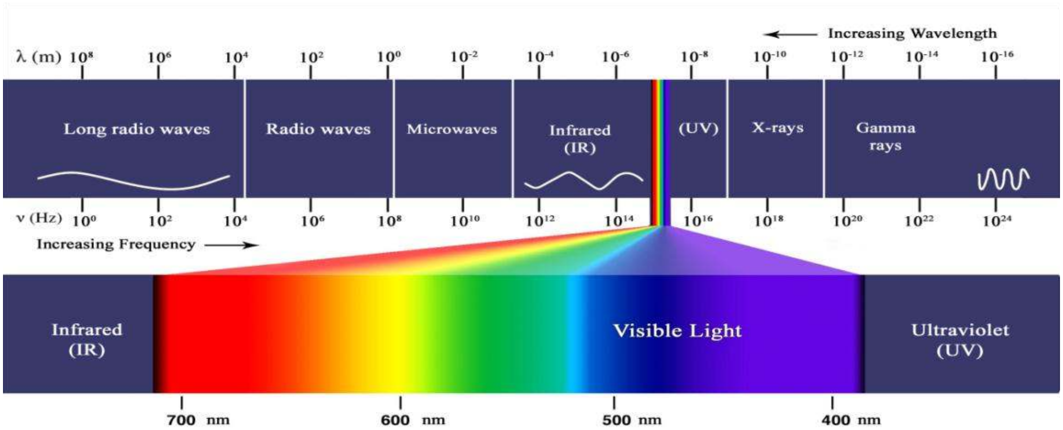


Figure 2.1 The electromagnetic spectrum.

2.1.2 Electromagnetic Wave Theory

Light is just one part of the various electromagnetic waves passing through the space. The electromagnetic spectrum covers a very much wider range, from radio waves with wavelengths of a meter or greater than a meter, down to x-rays with wavelengths of less than a nanometer. Optical radiation located between radio waves and x-rays on the spectrum, at x-ray and shorter wavelengths, electromagnetic radiation has a propensity. To be quite particle like in its demeanor, whereas toward the long wavelength end of the spectrum the demeanor is mostly wavelike. The visible part occupies an intermediate position, exhibiting both wave and particle properties in various degrees [4].

2.1.3 Ultraviolet Light (UV)

Ultraviolet (UV) radiation is a shape of electromagnetic radiation. The main source of UV radiation is the sun, although it can also come from man-made sources such as tanning beds and welding torches. In terms of energy, UV rays have more energy than visible light, but not as far as gamma rays. Ultraviolet (UV) radiation is divided into three wavelength ranges, as shown in Figure 2.2.

Types of UV Radiation classify UV radiation into three types UVA, UVB, and UVC. Some of them absorbs by ozone layers, but not all of these UV radiation [4].

UVA: Wavelength: 315-400 nm. Not absorbed by the ozone layer.

UVB: Wavelength: 280-315 nm. Mostly absorbed by the ozone layer, but some of them Arrive to the Earth’s surface.

UVC: Wavelength: 100-280 nm. Totally absorbed by the ozone stratum and atmosphere.

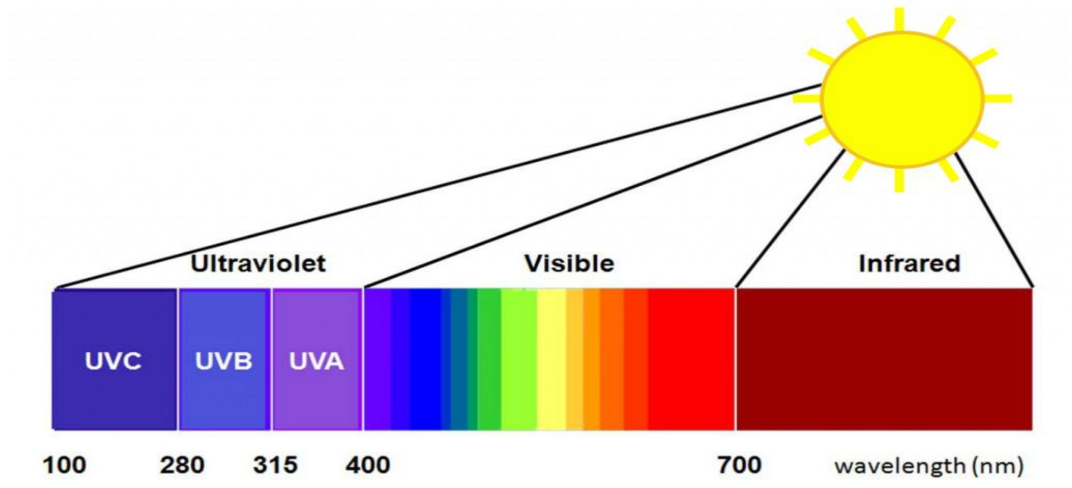


Figure 2.2 Type of Ultraviolet (UV) radiation.

2.1.4 Visible Light

The visible spectrum is a part of an electromagnetic spectrum that is visible to the human eye. An exemplary human eye will respond to wavelengths from about 400 to 700 (nm). As shown in Figure 2.3 [5].

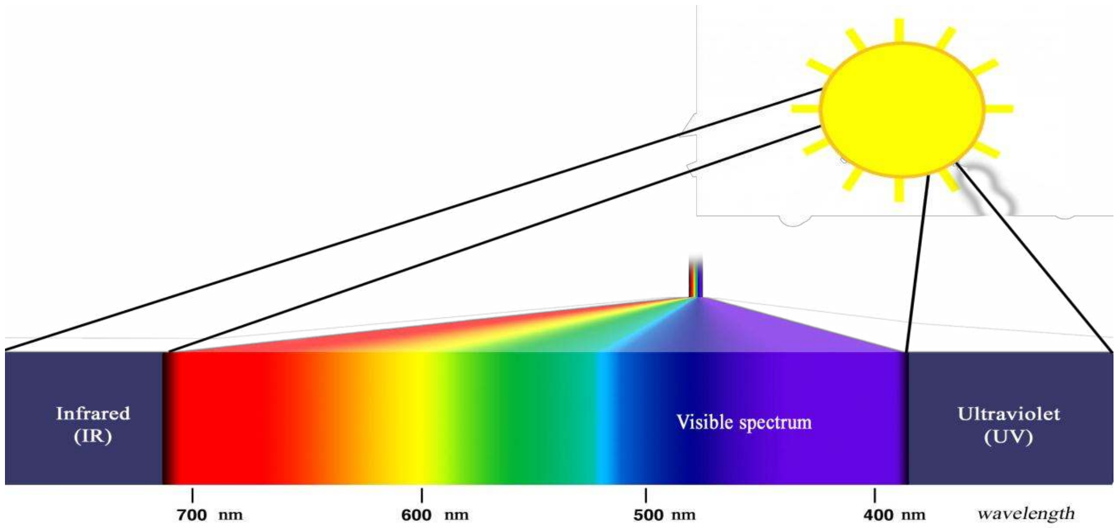


Figure 2.3 visible light in the electromagnetic spectrum.

However, the visible light does not contain to the all of the colors that the human eyes can be seen and distinguished. Unsaturated colors such as pink, or purple variations such as magenta and cyan, because they can be made only with a mix of multiple wavelengths [5].

2.1.5 Spectral colors

Colors that can be produced by visible light, of a strait squad of wavelengths are known as a pure spectral color. The table (2.1) indicates the different color are in the approximation of the spectrum and in the wavelength, frequency and photon energy [6].

Table 2.1 Different color in the wavelength, frequency and photon energy

Color	Wavelength (nm)	Frequency (THZ)	Photon energy (ev)
violet	380 - 450	668 - 789	2.75 - 3.26
blue	450 - 495	606 - 668	2.50 - 2.75
green	495 - 570	526 - 606	2.17 - 2.50
yellow	570 - 590	508 - 526	2.10 - 2.17
orange	590 - 620	484 - 508	2.00 - 2.10
red	620 - 700	400 - 484	1.65 - 2.00

2.1.6 Infrared Light (IR)

Electromagnetic radiation at longer wavelength than the red end of visible light and shorter than microwaves, and the wavelength nearly between 0.7 and 100 microns. Almost none of the infrared portion of the electromagnetic spectrum can reach the surface of the Earth [7].

The infrared regions are classified as follows and as shown in Figure 2.4:

Near Infrared from 0.7 to 3 µm

Mid Infrared from 3 to 30 µm

Far Infrared from 30 to 100 µm

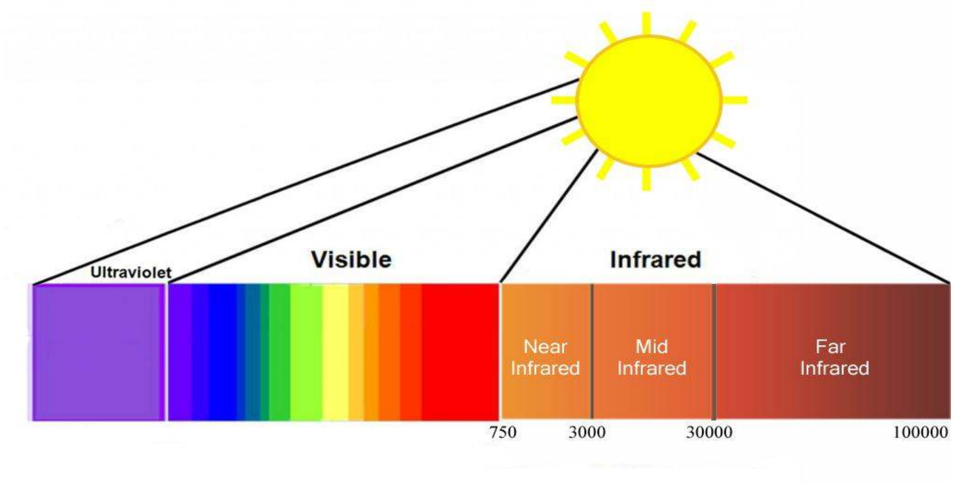


Figure 2.4 Types of Infrared (IR) radiation.

2.2 Basic Principles

2.2.1 The Inverse Square Law

The definition of inverse square law is the relationship between the irradiance from a source and distance. It states that the irradiance is equal to intensity per unit area varies in inverse proportion to the square of the distance. as shown in Figure 2.5 [4].

$$\boldsymbol{E} = \frac{\boldsymbol{I}}{\boldsymbol{d^2}} \tag{2.1}$$

E: irradiance of the light source

I: intensity of the light source

d: distance between irradiance and source

The inverse square law can be used only in cases where the light source approximates a point source. For Lambertian light sources a beneficial guideline to use for illuminance measurements is the five times rule.

The distance between the light source and the measurement point should be greater than five times in the radius of the source or largest dimension of the source for an accurate measurement. However, the five times rule does not work for a strongly directional light source [2].

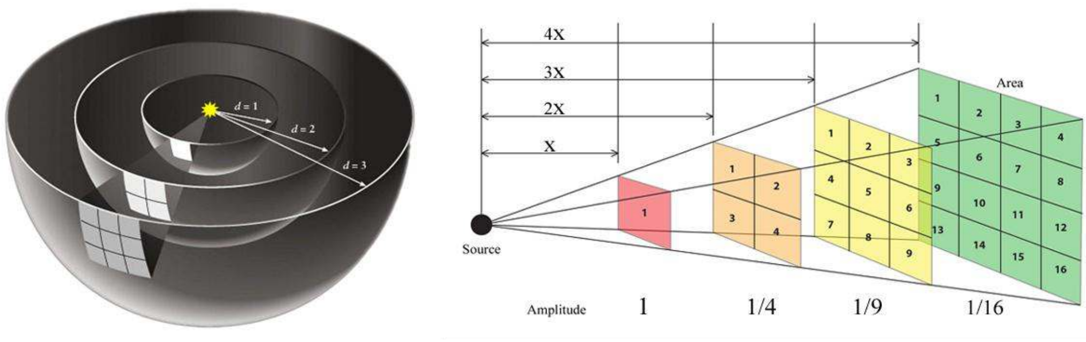


Figure 2.5 The inverse square law.

2.2.2 Lambertian Sources

To simplify some derivations, and important property, approximately exhibited by some sources and surfaces, is useful. Any surface, real or imaginary, whose radiance is independent of direction is said that to be a *Lambertian radiator*. As in the case of a source the surface can be self-luminous, or it can be a reflecting or transmitting one. If the radiance emanating from it is independent of the direction, this radiation is considered to be Lambertian. A Lambertian radiator can be thought of as a window onto an isotropic radiant flux field. Finite Lambertian radiators obey Lambert's cosine law [8].

2.2.3 Lambert's Cosine Law

The illuminance or irradiance falling on any surface varies as the cosine of the incident angle, θ. The perceived measurement area orthogonal to the incident flux is reduced at tilted angles, causing light to spread out over a wider area than it would if perpendicular to the measurement plane as shown in Figure 2.6 [1] .

It states that the irradiance falling on or leaving from any surface depends on the cosine of the light's or the observer's angle of incidence θ [9].

$$\boldsymbol{I} = \boldsymbol{I_o} * \boldsymbol{cos}(\theta) \qquad (2.2)$$

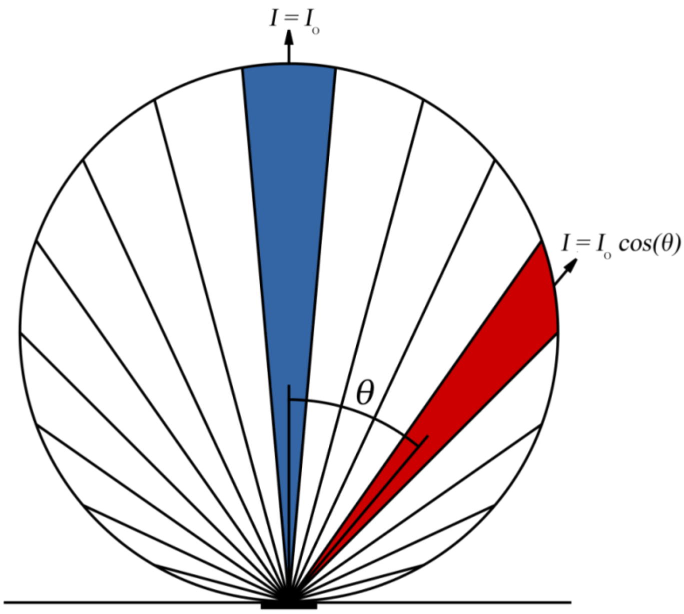


Figure 2.6 Lambert’s Cosine Law.

2.2.4 Lambertian surface

A Lambertian surface provides regular diffusion of the incident radiation such that its luminance or radiance from which it can be measured because is the same in all directions. Many diffuse surfaces are, in fact, Lambertian. If you sight this Light Measurement from an tilted angle, it should look as bright as it did when held perpendicular to your line of vision, The human eye is an ideal luminance, with its restricted solid viewing angle [10].

Figure 2.7 shows a surface radiating equally at 0° and at 60°. Since, by the cosine law, a radiance detector sees twice as much surface area in the same solid angle for the 60° case, the average incremental reflection must be half the magnitude of the reflection in the 0° case.

Figure 2.8 shows that a reflection from a diffuse Lambertian surface obeys the cosine law by distributing reflected energy in proportion to the cosine of the reflected angle.

Figure 2.7 Lambertian surface.

2.2.5 Solid Angle

The solid angle is the ratio of a portion of the area on the surface of a sphere to the square of the radius *r* of the sphere. This is illustrated in Figure 2.8a [11].

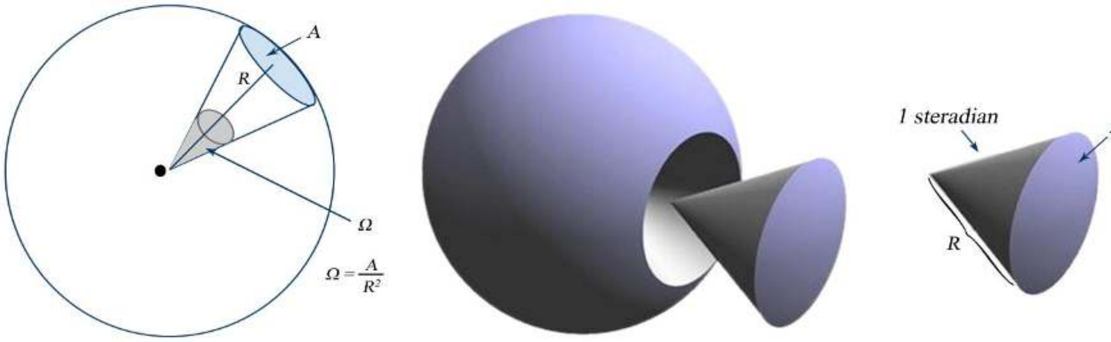
$$\Omega = \frac{A}{R^2} \qquad (2.3)$$

Ω: is solid angle,

The units for Ω and θ are steradians (sr) and radians R, respectively, although it should be noted that both of these measures of angle have no actual dimensions. Since the total surface area of a sphere is $4\pi R^2$, in one sphere the total solid angle is 4π sr [12].

$$\Omega = \frac{A}{R^2} = \frac{4\pi R^2}{R^2} = 4\pi\ sr \qquad (2.4)$$

Steradian (sr) is defined as "the solid angle confront at the centre of a sphere by an area on its surface numerically equal to the square of the radius." Figure 2.8b shows a cutaway figure of a sphere, with a cone-shaped solid angle measuring 1 steradian removed from a sphere. Figure 2.8c shows a view of the removed solid angle measuring 1 steradian. For example, a one-steradian section of a sphere that has a one meter radius subtends a surface area of one square meter [2].



(a) Steradian solid angle

(b) Steradian solid angle removed from a sphere.

(c) For a solid angle that measures 1 steradian, $A = R^2$.

Figure 2.8 Solid Angle

2.3 Basic Radiometric and Photometric Principles

Radiometry is that area of science measurement which himself with distribution of electromagnetic radiation being transferred from a source to a receiver.

In classical radiometry the Original concepts to describe quantities were based on two ideal entities, the perfect diffuser and the point source, with the receiver being that more readily available, the human eye of the observer. This region of radiometry, based on the receiver having the spectral response of human vision, is now called photometry [13].

2.4 Radiometry

The science of measuring light in any portion of the electromagnetic spectrum is called Radiometry. The term is usually limited to the measurement of visible light, infrared, and ultraviolet in practice using optical instruments.

There are two aspects of radiometry: practice and theory. The practice involves the scientific materials and instruments used in measuring light, including radiation thermocouples, photodiodes, charge-coupled devices, photosensitive dyes and emulsions, vacuum phototubes, and a plethora of others [14].

2.4.1 Radiant Energy

Light is radiant energy. Electromagnetic radiation transports energy through space. (Which can be considered both a wave and a particle, depending on how you measure it), energy is converted into some other form when light is absorbed by a physical object. For example, it heats a glass of water by a microwave oven, when its microwave radiation is absorbed by the water molecules. The radiant energy of the microwaves is converted into thermal energy (heat). Similarly, visible light causes an electric current to flow in a photographic light meter when its radiant energy is transferred to the electrons as kinetic energy [14].

Radiant energy is denoted as Q and is measured in Joules.

2.4.2 Spectral Radiant Energy

The definition of spectral radiant energy, which is the amount of radiant energy per unit wavelength interval at wavelength λ. It is defined as:

$$Q_\lambda = \frac{dQ}{d\lambda} \tag{2.5}$$

Spectral radiant energy is measured in joules per nanometer.

Sun is a broadband source emits electromagnetic radiation throughout most of the electromagnetic spectrum, which begin from radio waves to gamma rays. Most of its radiant energy is concentrated within the visible portion of the spectrum. A single-wavelength laser, on the other hand, is a monochromatic source; all of its radiant energy is emitted at one specific wavelength [14].

2.4.3 Radiant Flux

Radiant flux or power, is the flow rate of radiant energy, denoted as (Φ). It is measured in watts [2].

$$\Phi = \frac{dQ}{dt} \tag{2.6}$$

Φ: radiant flux in watt.

t: time in second.

The fundamental concept in detector based radiometry is the measurement of radiant flux. Flux is the power, expressed in watts (joules per second), of the radiation incident on the detector. The measurement of flux, uniformity and beam size are unimportant factors, but detector uniformity is essential. Otherwise detector signal output would vary as the incident beam changes position or shape instead of remaining constant [13].

2.4.4 Spectral Radiant Flux

Spectral radiant flux is radiant flux per unit wavelength interval at wavelength λ. It is defined as:

$$\Phi_\lambda = \frac{d\Phi}{d\lambda} \quad (2.7)$$

and is measured in watts per nanometer [14].

When the radiation consists of a spread of wavelengths, the radiometric and the photometric terms may be functions of wavelength.

This dependence is noted by preceding the term with the word *spectral* and by using adding λ or the subscript λ in parentheses. For example, *spectral radian flux* is denoted Φ_λ. The total radiant flux is then determined by integration over the wavelength region of interest [15].

$$\Phi_e = \int_{\lambda_1}^{\lambda_2} \Phi_\lambda \, d\lambda \quad (2.8)$$

Φ_e: total radiant flux.

Φ_λ: spectral radiant flux

2.4.5 Radiant Flux Density

The radiant flux per unit area at a point on a surface is Radiant flux density, where the surface can be imaginary or real imaginary (i.e., a mathematical plane). There are two possible conditions.

The flux can also be departing the surface due to reflection or emission (see in Fig. 2.9a). The radiant flux density is then referred to as radiant exitance. As with irradiance, the flux above the surface can leave in any direction. The definition of radiant exitance is:

$$M = \frac{d\Phi}{dA} \tag{2.9}$$

where Φ: the radiant flux leaving the point.

dA: the differential area surrounding the point.

The flux can be arriving at the surface see in (Fig. 2.9b), in which case the radiant flux density is referred to as irradiance. The flux above the surface can arrives from any direction, as indicated by the rays. Irradiance is defined as:

$$E = \frac{d\Phi}{dA} \tag{2.10}$$

where Φ: the radiant flux arriving at the.

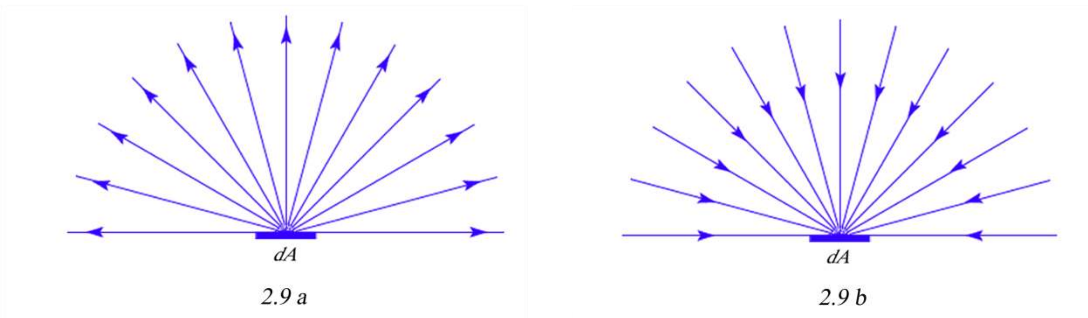


Figure 2.9 (a) Radiant exitance and (b) Irradiance

The importance of a "real or imaginary" surface cannot be exaggerated. It means that radiant flux density in anywhere in three-dimensional space can be measured. This includes on the surface of physical objects, in the space between them (e.g., in a vacuum or air), and inside transparent media such as glass and water. Radiant flux density is measured in watts per square meter [14].

2.4.6 Spectral Radiant Flux Density

Spectral radiant flux density is radiant flux per unit wavelength interval at wavelength λ. When the radiant flux is leaving the surface, it is called spectral radiant exitance, and is defined as:

$$M_\lambda = \frac{dM}{d\lambda} \tag{2.11}$$

When the radiant flux is arriving at the surface, it is called spectral irradiance, and is defined as:

$$E_\lambda = \frac{dE}{d\lambda} \tag{2.12}$$

Spectral radiant flux density is measured in watts per square meter per nanometer [14].

2.4.7 Irradiance

Irradiance is a measure of radiometric flux density, or flux per unit area. Irradiance is typically expressed in W/m^2 (watts per square meter).

2.4.8 Radiance

The radiance is the radiant flux emitted into unit solid angle per unit area of source in a given direction. Or the irradiance per unit solid angle. It is measured in $W/m^2/Sr$. If we consider an extended source comprising equally spaced point sources then

$$L_e = \frac{\Phi}{A\Omega} \tag{2.13}$$

Where (Φ) is the radiant flux of the source, which has an area A, and Ω is the solid angle, conjoined by the detector at the source [16].

2.4.9 Radiant Intensity

Radiant Intensity is a measure of radiometric power per unit solid angle incident on, passing through, or emerging from a point in space and propagating in a specified direction, measured in watts per steradian (W/Sr). The definition is:

$$I = \frac{d\phi}{dw} \tag{2.14}$$

where $d\Phi$ is an element of flux incident on or emerging from a point within element $d\omega$ of solid angle in the specified direction [14,17].

The representation of $d\omega$ in spherical coordinates is illustrated in Figure. 2.10

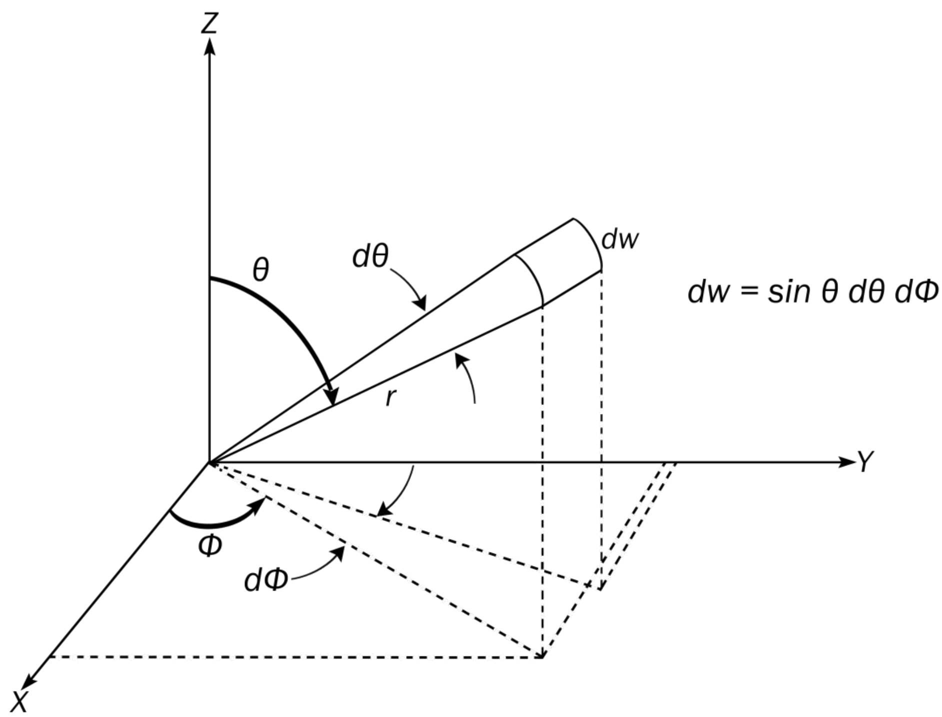


Figure. 2.10 : Element dw of solid angle in spherical coordinates.

2.4.10 Spectral Radiant Intensity

Spectral radiant intensity is radiant intensity per unit wavelength interval at wavelength λ. It is defined as:

$$I_\lambda = \frac{dI}{d\lambda} \quad (2.15)$$

and is measured in watts per steradian per nanometer.

2.5 Photometry

Photometry is the science of measuring visible light in units that are weighted according to the sensitivity of the human eye. Photometry is a subset of radiometry, and deals only with radiation in the visible part of the spectrum. Photometric quantities are defined in such a way that they amalgamate the variations in spectral sensitivity of the human eye over the visible spectrum, as a spectral weighting function built into their definition. These fields involve several accurate concepts, masked by a bewildering array of symbols and units [17, 18].

The purpose of photometry is to elucidate this idea as far as light is concerned and to introduce the physical parameters allowing us to quantify the visual observation of light sources and illuminated objects [19].

2.5.1 Luminous intensity

Luminous intensity is a fundamental photometric quantity, which has measured in candelas (cd, or lm/sr). Luminous intensity (I_v) is the fundamental SI quantity for photometry. The candela is the fundamental unit from which all other photometric units are derived. By definition a candela is the luminous intensity in a given direction emitted by monochromatic source.

Luminous intensity is a property of source, defined by the quantity of luminous flux uniformly distributed within a given angle in a certain direction, For nearly monochromatic sources, such as light emitting diodes, measurement of luminous flux can easily be performed by using a detector with constant luminous responsivity with a fixed aperture, calculating the solid angle from separation distance between source and aperture. For wide wavelength sources, however lack of a detector with constant luminous response over the entire range of wavelengths makes lamp standards more practical [13].

The luminous intensity for monochromatic light of a particular wavelength λ is given by

$$I_v = 683 \cdot V(\lambda) \cdot I_e \qquad (2.16)$$

where

I_v: is the luminous intensity in candelas (cd),

I_e :is the radiant intensity in watts per steradian (W/sr),

$V(\lambda)$: is the standard luminosity function.

If more than one wavelength is present (as is usually the case), one must sum or integrate over the spectrum of wavelengths present to get the luminous intensity:

$$I_v = 683 \int_0^{\infty} V(\lambda) \cdot \frac{dI_e(\lambda)}{d\lambda} \cdot d\lambda \qquad (2.17)$$

How to measure the brightness of light, it’s a one of the most difficult concepts to understanding. This is difficult because the human eye is more sensitive to some colors (frequencies) than others, thus realization some colors to be brighter than they in fact are. The human eye is more sensitive to the colors in the middle of the spectrum of human visibility (greens and yellows) than those at the limit of the spectrum of human visibility (reds and blues). In the figure (2.11) is a graphic exemplification of the relative intensities of the spectrum [20].

Lux (lx) is known as a unit of luminous flux. It is equal to one lumen per square meter and Lux values related directly to consider the brightness in the distance, environment, and orientation. One lumen is the true visible irradiance of a source, it is equivalent to one candela per three dimensional angle measured, or one candela per steradian. Essentially, it is the output of one common candle. More precisely, candela is specified as "a source that emits monochromatic radiation of frequency 540 x 10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian." A foot-candle is an alternative measure of illumination primarily used in the United States; one foot-candle is equivalent one lumen per square foot and approximately 10.76 lx [15].

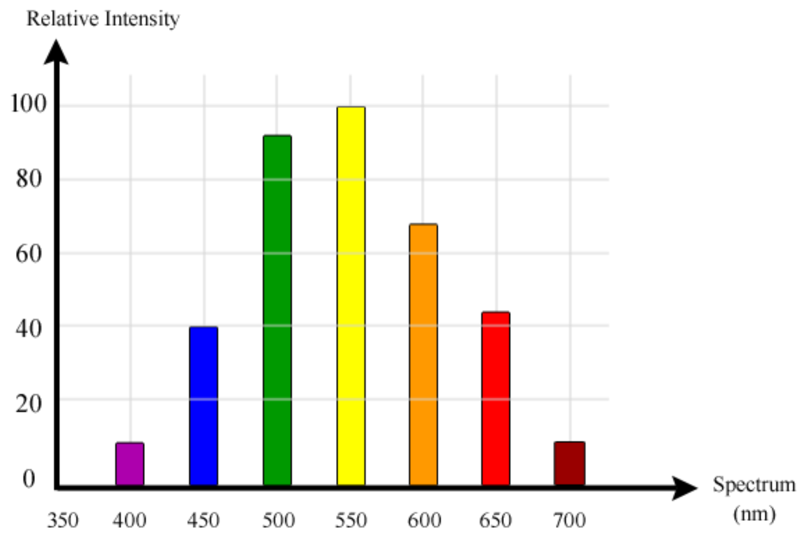


Figure 2.11 is a graphic exemplification of the relative intensities of the spectrum.

2.5.2 Luminous Flux

The effectiveness of a sample of radiant flux in evoking the sensation of brightness does not depends only on the quantity of radiant flux in the sample but also on how the flux is distributed among the various wave lengths the sample may contain, Figure: 2.12 shows that the brightness sensation evoked by the given quantity of radiant flux of wavelength 555 nm, for example, is greater than that evoked by the same quantity of radiant flux of wavelength 600 nm or 500 nm. With the aid of the standard relative luminosity curve, any sample of radiant flux can be evaluated with respect to its brightness-producing capacity. Radiant flux, evaluated with respect to its capacity to evoke the sensation of brightness, is called luminous flux [21].

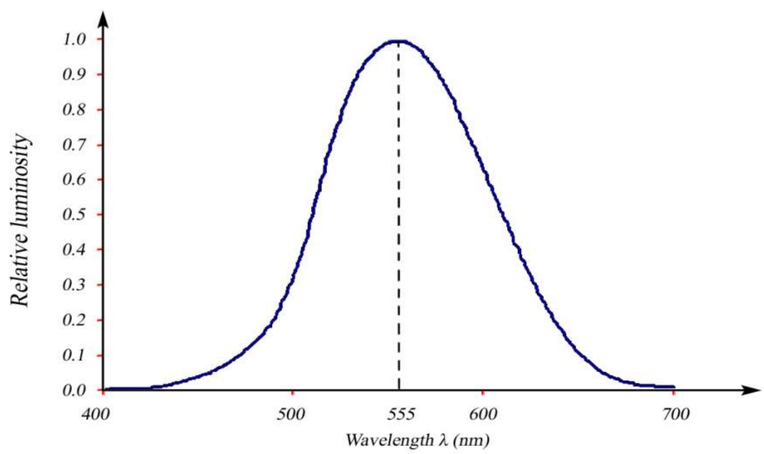


Figure: 2.12 Relative luminosity curve for the standard observer.

The photometric equivalent of radiant power is luminous flux , and the unit that is equivalent to the watt is the lumen . Luminous flux is spectral radiant flux weighted by the appropriate eye response function . The definition of luminous flux for the photopic CIE Standard Observer is:

$$\Phi_v = K_m \int \Phi_\lambda \, V(\lambda) d\lambda \qquad (2.18)$$

Where

$V(\lambda)$: is the spectral luminous efficiency function.

K_m: is the luminous efficacy for photopic vision .

The SI unit of luminous flux (Φ_v) is the lunen (lm). One lumen is defined as the luminous flux of light produced by a light source that emits one candela of luminous intensity over a solid angle of one steradian. The spectral luminous efficiency is defined near the maximum, λ_m= 555 nm, of the photopic ef ficiency function to be approximately 683 lm W^{-1} [11].

2.5.3 Luminous exitance

Luminous exitance (M_v) is the density of luminous flux leaving a surface at a point, as shown in the equation below [22].

$$M_v = \frac{d\Phi_v}{dA} \qquad (2.19)$$

$d\Phi_v$: meaning the luminous flux leaving a surface.

2.5.4 Luminance

Luminance (L_v) is the photometric equivalent of radiance. Luminance is the luminous flux per unit area per unit solid angle. The luminous flux from element of a surface surrounding at a given point, emitted into a small solid angle containing the given direction, per unit area of the element projected to that given direction on a plane is perpendicular. It is defined as:

$$L_v = \frac{d\Phi_v}{d\Omega\, dA \cos\theta} \tag{2.20}$$

where

$d\Phi_v$: is the luminous flux emitted (transmitted or reflected) by an elementary beam passing through the given point.

$d\Omega$: the solid angle.

θ: is the angle between the normal to that section and the direction of the beam.

d*A:* is the area of a section of that beam.

A units have been used for luminance is candela per square meter (cd/m^2), or lumens per square meter per steradians (lumen/m^2/sr) [11].

Luminance is often used to characterize reflection or emission from flat, diffuse surface. The luminance explains how much luminous power will be detected by an human eye looking at the surface from a particular angle of view. Thus luminance is an indicator of how bright the surface will appear. In this case, the solid angle of interest is the solid angle subtended by the eye's pupil. In the videos industry the luminance is used to characterize the brightness of displays. For example a typical computer display emits luminance between 50 and 300 cd/m^2 [23].

2.5.5 Illuminance

Illuminance (E_v): When luminous hits a surface we say that the surface is illuminated. This familiar concept is well defined quantitatively as follows. At any point of the surface we builds a small area dA and allow $d\Phi_v$ represent the luminous flux incident on this area. The Illuminance E_v at the point is defined as the ratio of $d\Phi_v$ to dA.

$$E_v = \frac{d\Phi_v}{dA} \tag{2.21}$$

Where $d\Phi_v$: is the luminous flux emitted (transmitted or reflected) by an elementary beam passing through the given point.

dA*:* is the area of a section of that beam.

That is the luminous flux incident per unit area is known as illuminance, and is expressed in (lumens/m^2) or (lumens/ft^2). One lumen/m^2 is called a lux, and one lumens/ft^2 is called a footcandle. In the surface of finite area A if the Illuminance is the same at all points and if Φ_v the total luminous flux incident on the surface is the above equation is becomes [21]:

$$E_v = \frac{\Phi_v}{A} \tag{2.22}$$

The figure (2.13) is clarifies the three units of illuminance mentioned above. (S) is a point source uniformly distributed in the all direction have intensity 1 candle or 1 lumen/steradian. Therefore the luminous flux emersion from the source within a solid angle of 1 steradian is 1 lumen. If a spherical surface of radius 1 m is build concentric with the source, the area cut out of this surface by the unit solid angle is 1 m^2. Hence the illuminance on this surface is 1 lumen/m^2 or 1 lux. The area out of a spherical surface is 1 ft^2 in a radius 1 ft. This area also intercepts 1 illuminance and the lumen on it is 1 lumen/ft^2 or 1 footcandle. Similarly, the illuminance on a surface area of 1 cm^2, at a distance or radius of 1 cm from the source, is 1 lumen/cm^2. In the table (2.2) shows some of typical values of illuminance [21].

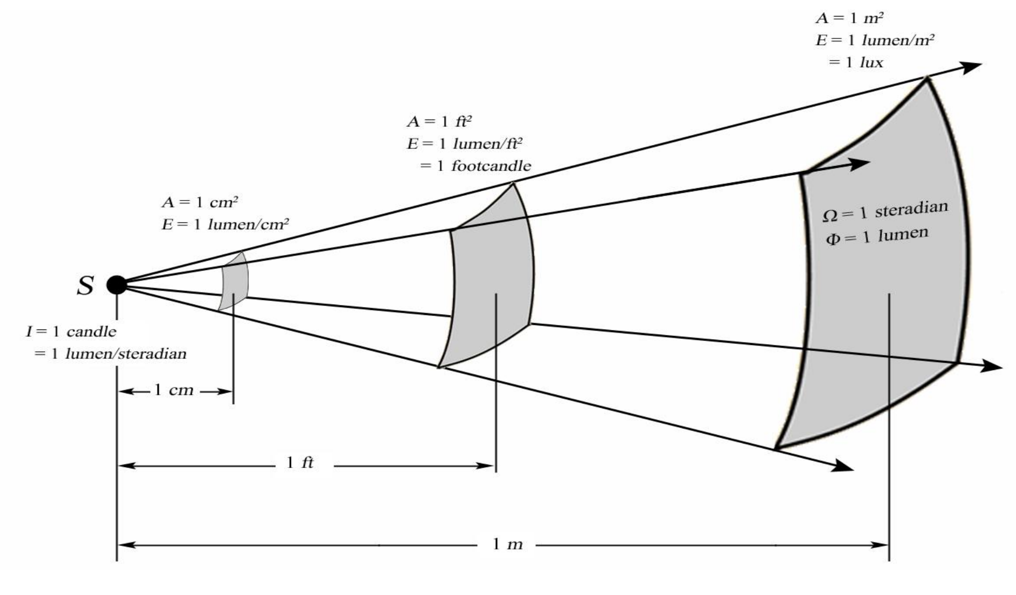


Figure: 2.13 Diagram illustrating the three units of illuminance.

Table 2.2 Typical values of illuminance.

Illuminance (representative values)	Illuminance (representative values)	
	Lumens/m² *(lux)*	*Lumens/ft²* *(footcandles)*
Sunlight plus skylight (maximum)	100,000	10,000
Sunlight plus skylight (dull day)	1,000	100
Interiors - daylight	200	20
Interiors - artificial ligt	100	10
Full moonlight	0.2	0.02

2.5.6 Illuminance produced by a point source.

Let in the Fig. 2.14 dA be an surface element whose normal makes in angle (θ) with point source (S) in the distance (r). Let (I) be the intensity of the source in the direction of the element dA. The solid angle subtended by dA at the source is [21].

$$d\Omega = \frac{dA\, cos\theta}{r^2} \tag{2.23}$$

and since by definition the-intensity $\mathrm{I} = \frac{\mathrm{d}\Phi}{\mathrm{d}\Omega}$, the flux dΦ in the solid angle dΩ is

$$d\Phi = I\, d\Omega = \frac{I\, dA\, cos\theta}{r^2} \tag{2.24}$$

And all of this flux is incident on the area dA, and hence the illuminance of *dA* is

$$E = \frac{d\Phi}{dA} = \frac{I\, cos\theta}{r^2} \tag{2.25}$$

the illuminance of an element of surface witch illuminated by a point source is inversely proportional to the square of the distance of the element from the source and directly proportional to the intensity of the point source and the cosine of the angle between the normal to the element of surface and the line joining the element and the source.

When a surface element is illuminated by more than one source the total illuminance is the arithmetic sum of the illuminances produced by the individual sources [21].

2.5.7 Radiometric and Photometric Quantities

The table (2.3) summarizes radiometric quantities, symbols, and units (in the left columns) and the corresponding photometric quantities, symbols, and units (to the right columns). The symbol for a photometric quantity is just the symbol for the corresponding radiometric quantity, with the addition of the subscript v (for *visual*) [4].

Table 2.3 Radiometric and photometric quantities and units.

Radiometric			Photometric		
Quantity	Symbol	Units	Quantity	Symbol	Units
Wavelength	λ	nanometer (nm)	Wavelength	λ	nanometer (nm)
Radiant energy	Q	watt-seconds (W-s)	Luminous energy	Q_v	lumen-seconds (lm-s)
Radiant energy density	U	watt-seconds/m^3 (Ws/m^3)	Luminous energy density	U_v	lumen-seconds/m^3(lm-s/m^3)
Radiant flux(power)	Φ	watts (W)	Luminous flux(power)	Φ_v	lumens (lm)
Irradiance	E	watts/m^2 (W/m^2)	illuminance	E_v	lux (lx; lm/m^2)
Radiance	L	watts/m^2/steradian($W/m^2/sr$)	Luminance	L_v	lumens/m^2/steradian (lm/m2/sr)
Radiant intensity	I	watts/steradian (W/sr)	Luminous intensity	I_v	candela (cd; lm/sr)

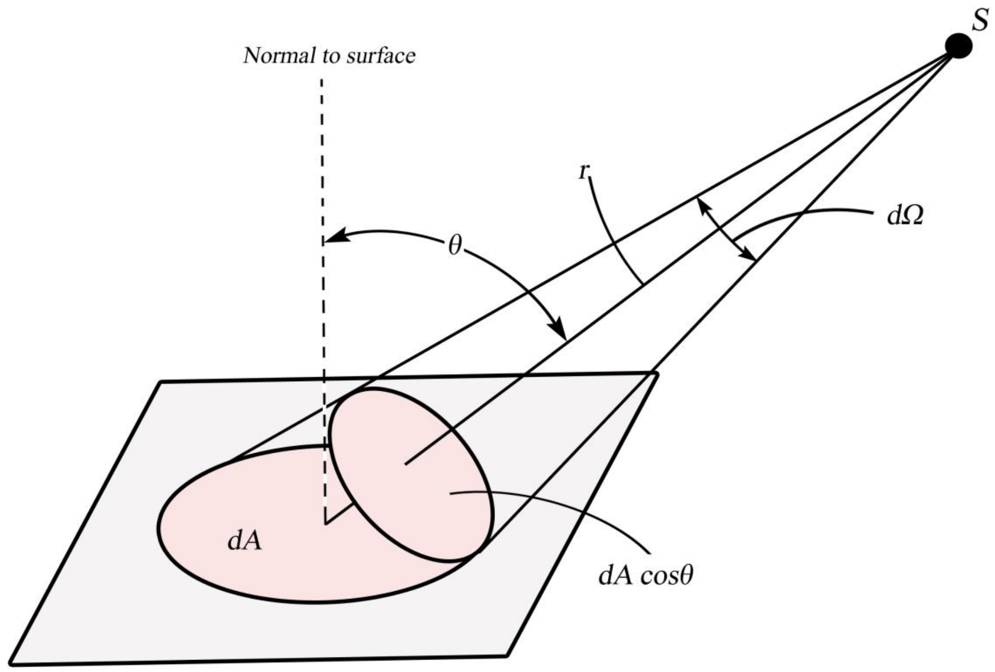


Figure: 2.14 Illuminance of an element of surface by a point source.

2.5.8 The photometer

A rough comparison of the intensities of two point sources may be made by looking at them, but when quantitative measurements must be made the sources are compared indirectly by means of the illuminance they produce on a screen. A device for doing this is called a photometer and it is explained, in principle, in Fig. 2.15. One side of the screen (S) is illuminated only by the point source P_1, and the other sides illuminated only by the point source P_2. The position of the screen can be adjusted along the line joining P_1 and P_2 Even the judges observers on both faces of the screen to be equally illuminated. The distances d_1 and d_2 are then measured, and from equation (25), It's received this equation (26).

$$E = \frac{I_1}{{d_1}^2} = \frac{I_2}{{d_2}^2} \quad or \quad \frac{I_1}{I_2} = \frac{{d_1}^2}{{d_2}^2} \qquad (2.26)$$

where I_1 and I_2 are the intensities of the point sources in the direction of the screen. If the intensity of either point sources is known, that the other can be computed [21].

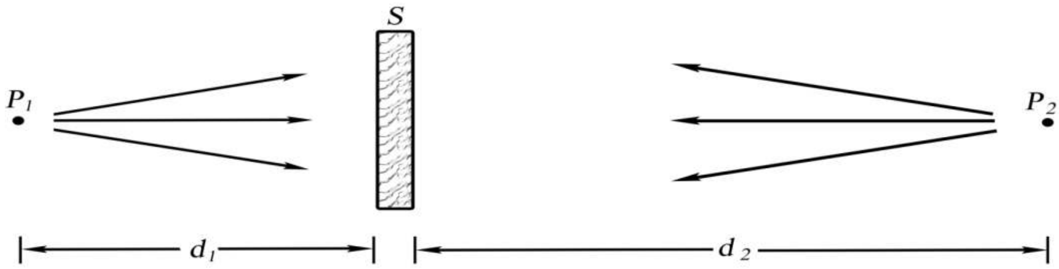


Figure: 2.15 Principle of the photomrter.

The intensity of the unknown source in other directions may be found by rotating it and making measurements at different azimuths. Remembering that in any direction the intensity is the number of lumens per steradian in that direction, it will be seen that from a knowledge of the intensity in a number of directions about the source the total flux emitted by the source can be found. In practice, the simple screen (S) of Fig. 2.15 is replaced by a more complicated device called a Lummer-Brodhun photometer head, Which allows both sides of the screen to be viewed simultaneously. The construction of this device is illustrated in Fig. 2.16. The screen (S) is a sheet of magnesium oxide or plaster of Paries. Diffusely reflected light from either side of the screen is reflected by the right-angle prisms A and B to the photometer "cube" C, which consists of two right-angle prisms, the hypotenuse of one being ground away over a portion of its area. Light incident on the area in contact is transmitted, so that the center of the field of view receives only light reflected from the right side of the screen (S). The outer portion of the field receives light from the left side of S, totally reflected by the left prism at regions where the two prisms are not in contact. When the photometer is adjusted for a balance the entire field appears uniformly bright. To compensate for any differences in the reflecting characteristics of the faces of the screen (S) the photometer head is rotated through 180 , thus interchanging the faces of the screen, and another setting made. Averaging the two very nearly eliminates any error due to dissimilarity of the faces [21].

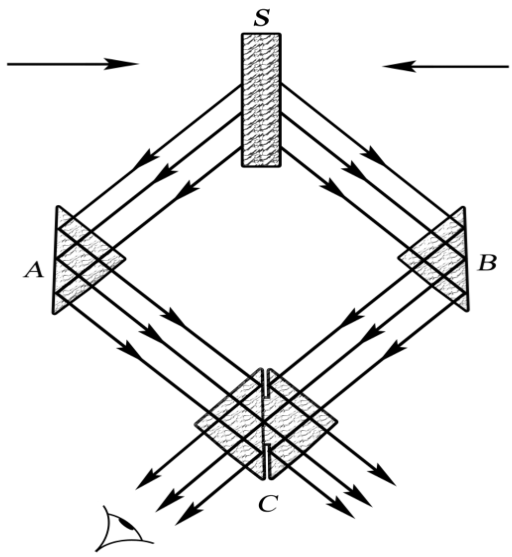


Figure: 2.16 Lummer-Brodhun photometer.

2.5.9 Heterochromatic photometry.

heterochromatic photometry is the process of comparing two light beams of different color. If both parts of a photometric field are not of the same color it is very difficult to decide when the two appear equally bright. One method makes use of the flicker photometer, in which the field is illuminated alternately by light from the two sources. As the frequency of the alternations is increased from a small value, it is found that at a particular frequency the color difference disappears because of persistence of vision, while a brightness flicker remains unless both sides of the photometer screen are equally illuminated. The setting of the photometer head is then made by noting the position at which the brightness flicker disappears [21].

2.5.10 Spectrophotometry.

Spectrophotometry is one method of heterochromatic photometry in which the two beams to be compared are first dispersed in to spectra and then compared throughout the spectrum step-by-step. At each setting both parts of the field are then illuminated by monochromatic light. Spectrophotometric methods find their chief application in the determination of the transmittance and reflectance of colored materials. If the material is transparent its spectral transmittance, the percentage of incident light transmitted at each wave length, is obtained by dividing the light beam from a single source into two parts, sending one part around the sample and the other part through the sample, and then comparing the two beams wavelength by wavelength. In the opaques material the spectral reflectance is found by comparing at each wave length, the quantity of light reflected from a sample with that reflected from a diffusely reflecting white surface [21].

CHAPTER 3

MATERIAL

3.1 What is Arduino?

Arduino is an open-source platform used for building and construction of electronics projects. Arduino consists of both a physical programmable circuit board (often referred to as a microcontroller) and a piece of software, or IDE (Integrated Development Environment) that runs on your computer, used to write and upload computer code to the physical board. Became very popular Arduino platform with people just starting out with electronics, and for good reason. Unlike most of the previous programmable circuit boards, the Arduino does not need a separate piece of hardware (called a programmer) in order to load new code onto the board, you can simply use a USB cable. Additionally, the Arduino uses a simplified version of C ++, which makes it easier to learn the program. Finally, Arduino provides standard form factor that breaks the functions of micro-controller unit in the package and more easily [24].

3.1.1 History of Arduino

It was in the year 2005 that was born the first ever Arduinos board in the classroom for the Interactive Design Institute in Ivrea, Italy. It was in the Interactive Design Institute that a hardware thesis was contributed for a wiring design by a Colombian student named Hernando Barragan. The title of the thesis was ("Arduino – The Revolution of Open Hardware"). Looked a little different from the usual thesis but none of them did not imagine that it would carve a niche in the field of electronics. A team of five developers, as shown in the figure 3.1, have made to this thesis, and when it was full of new wire platform, and they worked to make it much lighter, and less expensive, and is available to the open source community [25-27].

Figure 3.1 The Arduino core team (from left hand side)

David Cuartielles, Gianluca Martino, Tom Igoe, David Mellis, and Massimo Banzi

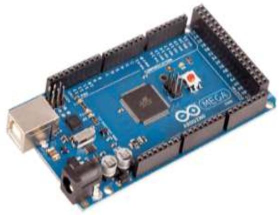
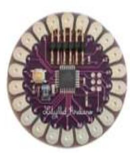
3.1.2 List (type) of Arduino boards

A reference to past and present Arduino boards, and where different from the Arduino base feature set, compatibility, features, and licensing details are included in. Many versions of the official Arduino hardware have been commercially produced to date, and in the table (4) shown features, licensing details and image [28].

3.1.3 Arduino UNO

The Arduino Uno is a microcontroller board based on the ATmega328P. We like it mainly because of its extensive support network and its versatility. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a USB connection, a 16 MHz ceramic resonator, an ICSP header, a power jack,and a reset button. It contains everything needed to support the microcontroller; simply to get started connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery. The Arduino Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip, and the Arduino Uno boards as shown in the figure 3.2. The name of (UNO) it means (One) in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduino, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform.

Table 3.1 List (type) of Arduino boards.

Name	Describtion	Image
Arduino UNO	There have been many revisions of the USB Arduino board, including the Extreme, NG, and Diecimila. This is the latest revision of the basic Arduino USB board.	
Arduino MEGA	A larger, more powerful Arduino board. Has extra digital pins, PWM pins, analog inputs, serial ports, etc. The version of the Mega released with the Uno, this version features the Atmega2560, which has twice the memory.	
Arduino Fio	An Arduino intended for use as a wireless node. Has a header for an XBee radio, a connector for a LiPo battery, and a battery charging circuit.	
Arduino LilyPad	A stripped-down, circular Arduino board designed for stitching into clothing and other fabric/flexible applications. Needs an additional adapter to communicate with a computer.	
Arduino Nano	The Arduino Nano is an all-in-one, compact design for use in breadboards.	
Arduino Leonardo	The Leonardo uses the Atmega32U4 processor, which has a USB controller built-in, eliminating one chip as compared to previous Arduinos.	
Arduino Ethernet	Based on the same WIZnet W5100 chip as the Arduino Ethernet Shield. A serial interface is provided for programming, but no USB interface. Late versions of this board support Power over Ethernet (PoE).	
Arduino Due	The first Arduino board based on an ARM Processor. Features 2 channel 12-bit DAC, 84Mhz clock frequency, 32-bit architecture, 512KB Flash and 96KB SRAM.	

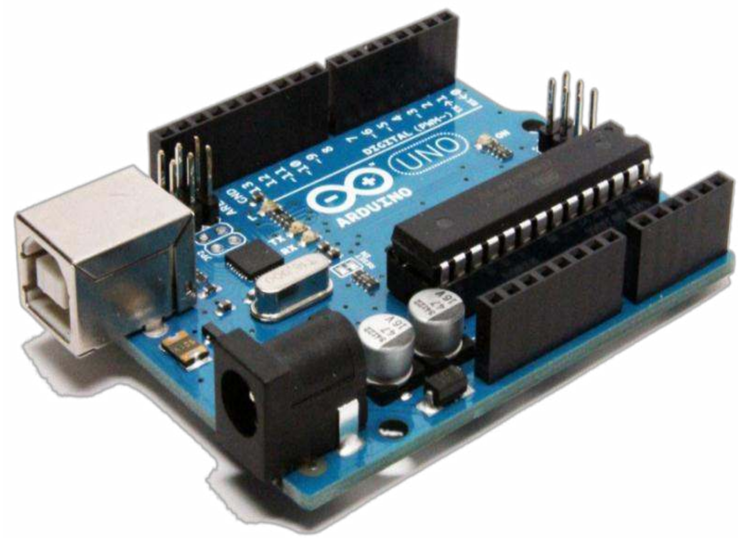


Figure 3.2 The Arduino Uno boards.

In the table (5) as shown a technical specifications of Arduino UNO [29].

Table 3.2 Specifications of Arduino UNO.

Microcontroller	ATmega328
Operating Voltage	5V
Supply Voltage (recommended)	7-2V
Maximum supply voltage	20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

3.1.4 ATmega328P Microcontroller

The ATmega 328P is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture, as shown the face diagram in the figure 3.3(a) and block diagram in the figure 3.3(b). By executing powerful instructions in a single clock cycle, the ATmega 328P achieves through puts approaching 1 MIPS per MHz allowing the system designee to optimize power consumption versus processing speed [30].

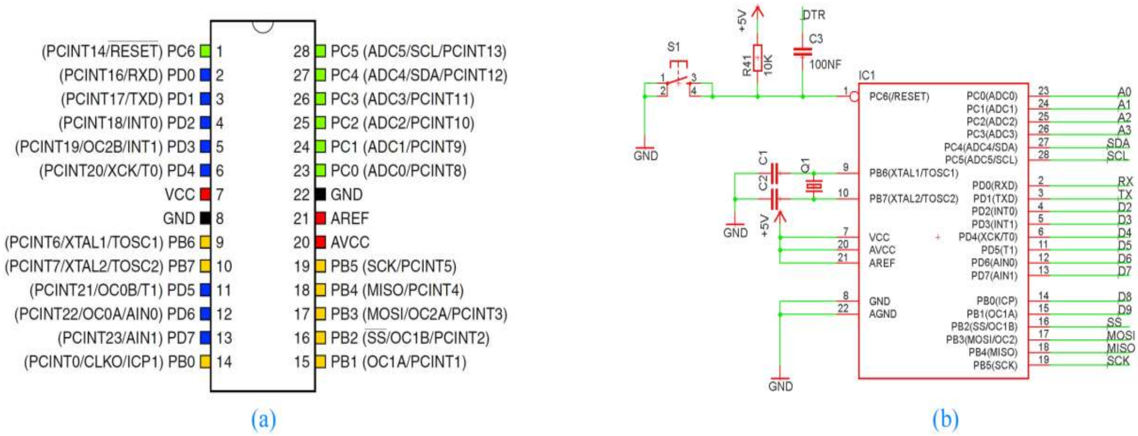


Figure 3.3 (a) The ATmega 328P face diagram and (b) the block diagram

3.1.5 Arduino software

Software programs, called sketches, are generated on a computer using the Arduino (IDE). The (IDE) enables you to write and code editing and converting this code to understand the instructions Arduino hardware. The IDE also conveys those instructions to the Arduino Board (a process called uploading). There are a variety of official boards that you can use with the Arduino software and a wide range of Arduino-compatible boards produced by members of the community. Also the Arduino softwares we can be used with Windows, Linux, and Mac system [31]. Sketches: The visible text of an Arduino software program is called a Sketch, As shown in the figure (3.4). But the Sketch becomes alive when you upload it to your Arduino.

Every Arduino Software Sketch has two main parts:

- SETUP - Runs Once at the beginning.
- LOOP - Runs over and over again, forever[32].

In the case of the Arduino the language is C. The IDE enables you to write a computer program, which is a set of step-by-step instructions that you then upload to the Arduino. Then your Arduino will carry out those instructions and interact with the world outside. In the Arduino world, programs are known as 'Sketches'. The Arduino hardware and software are both Open Source, which means the code, the schematics, design, etc. are all open for anyone to take freely and do what they like with it [33].

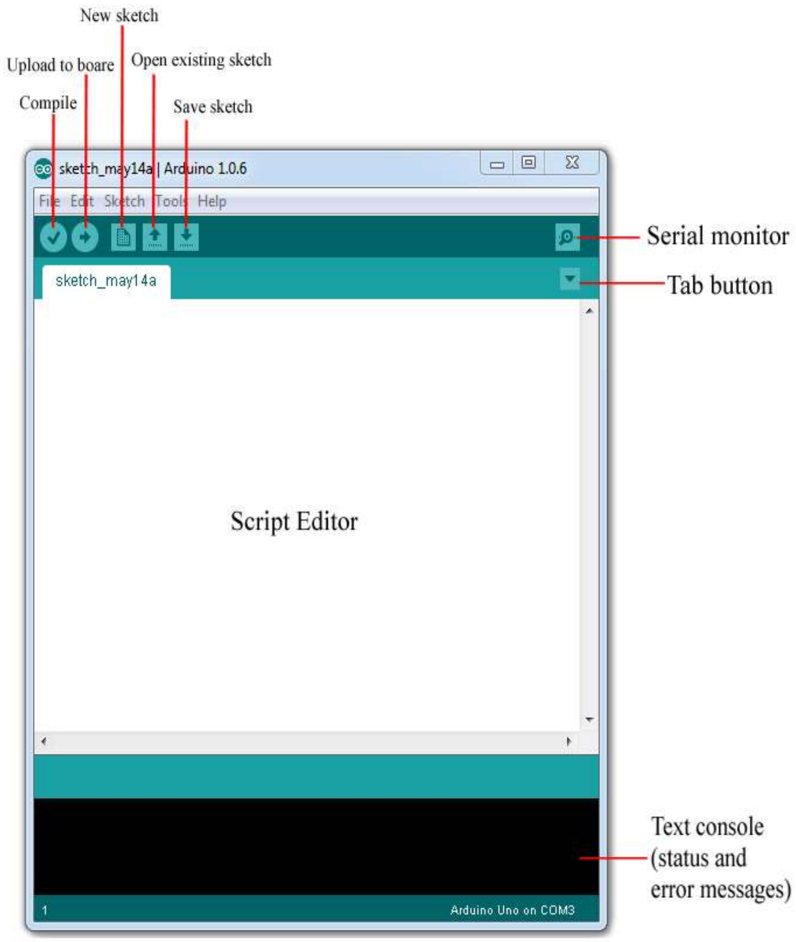


Figure 3.4 The Arduino Software (sketches).

Also in the figure (3.5) shows that the very simple example code for turns on an LED for one second, and then turns off for one second, repeatedly.

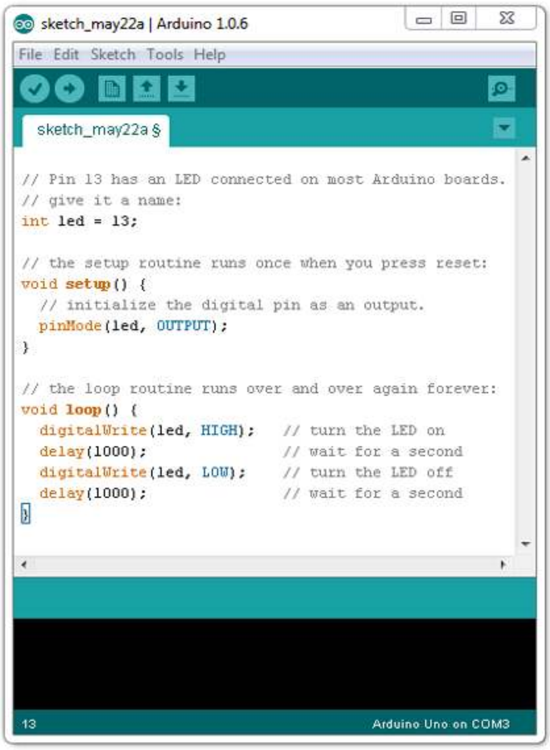


Figure 3.5 The simple example code for Arduino Software (sketches) .

3.2 MATLAB Software

Matlab is a high-level language and interactive environment for numerical computation, visualization, and programming. Matlab, which stands for MATrix LABoratory, is a state-of-the-art mathematical software package that is used extensively in both academia and industry.

We can analyze data, develop algorithms, and create models and applications. The language, tools, and builtin math functions enable you to explore multiple approaches and reach a solution faster than with spreadsheets or traditional programming languages, such as Java or C/C++. We can use MATLAB for a range of applications, including communications and signal processing, test and measurement, image and video processing, control systems, computational finance, and computational biology. More than a million engineers and scientists in industry and academia use MATLAB, the language of technical computing [34].

Features of MATLAB:

• High-level language for numerical computation, visualization, and application development

• Interactive environment for iterative exploration, design, and problem solving

• Mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, numerical integration, and solving ordinary differential equations

• Built-in graphics for visualizing data and tools for creating custom plots

• Development tools for improving code quality and maintainability and maximizing performance

• Tools for building applications with custom graphical interfaces

• Functions for integrating Matlab based algorithms with external applications and languages such as C, Java, .NET, and Microsoft Excel[34]. Also we are shows that the MATLAB software face in the figure (3.6).

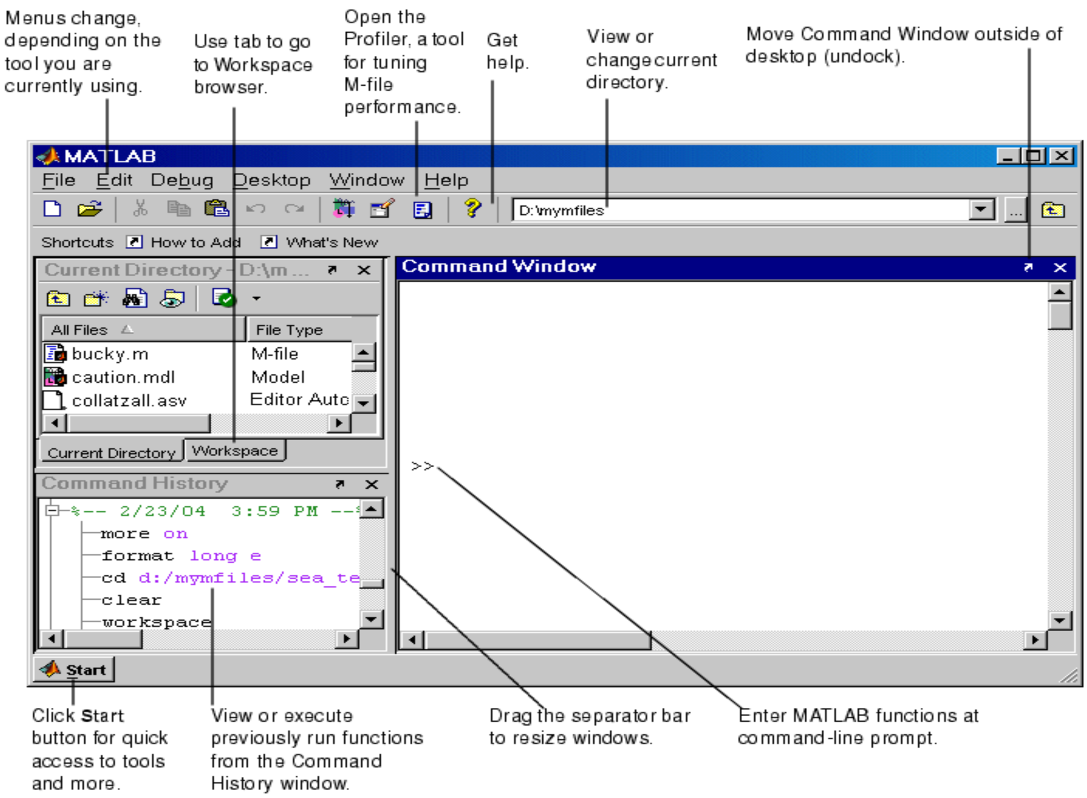


Figure 3.6 The MATLAB software faces.

In this study we have used the MATLAB software for the purpose of collection and plotting the data from Arduino Uno.

3.3 Light dependent resistor (LDR)

The light dependent resistor (LDR) is a sensor (photoconductor, photocell, or photoresistor), and is a light-controlled variable resistor. The resistance of a photoresistor decreases with increasing incident light intensity. This kind of sensor is commonly used in light sensor circuits in open areas, to control street lamps and light- and dark-activated switching circuits [35].

LDR's are made of semiconductors as light sensitive materials, on an isolating base, as shown in the figure (3.7). The most common semiconductors used in this system are cadmium sulphide, lead sulphide, germanium, silicon and gallium arsenide [36].

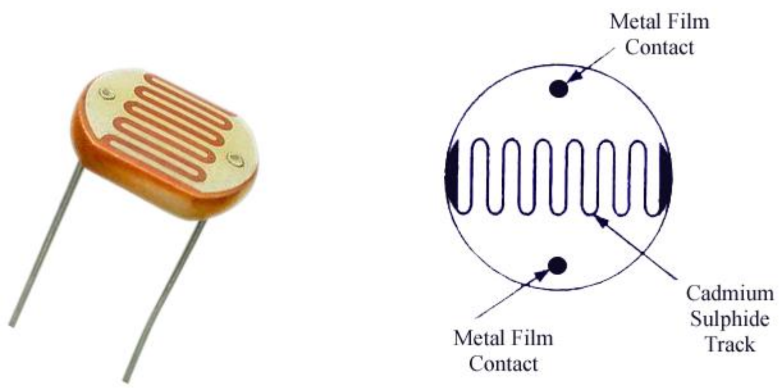


Figure 3.7 The light dependent resistor (LDR).

Light dependent resistors are a vital component in any electric circuit which is to be turned on and off automatically according to the level of ambient light - for example, solar powered garden lights, and night security lighting. To understand how an LDR works, it is first necessary to understand that an electrical current consists of the movement of electrons within a material.

Good conductors have a large number of free electrons that can drift in a given direction under the action of a potential difference. Insulators with a high resistance have very few free electrons, and therefore it is hard to make them move and hence a current to flow.

An LDR is made of semiconductor material with a high resistance. It has a high resistance because there are very few electrons that are free and able to move - the vast majority of the electrons are locked into the crystal lattice and unable to move. Therefore in this state there is a high LDR resistance. As light falls on the semiconductor, the light photons are absorbed by the semiconductor lattice and some of their energy is transferred to the electrons. This gives some of them sufficient energy to break free from the crystal lattice so that they can then conduct electricity. This results in a lowering of the resistance of the semiconductor and hence the overall LDR resistance. The process is progressive, and as more light shines on the LDR semiconductor, so more electrons are released to conduct electricity and the resistance falls further [37].

3.4 The TEMT6000 Ambient Light Sensor

TEMT6000 is a silicon NPN epitaxial planar phototransistor in a miniature transparent mold for surface mounting onto a printed circuit board. The device is sensitive to the visible spectrum, as shown in the figure (3.8). The main features is an adapted to human eye responsivity, and it is sensitive to visible range in the spectrum. The ambient light sensor have a many application such as control of display backlight dimming in LCD displays and keypad backlighting of mobile devices and in industrial on/off-lighting operation [38].

• Automotive sensors

• Mobile phones

• Notebook computers

• Cameras

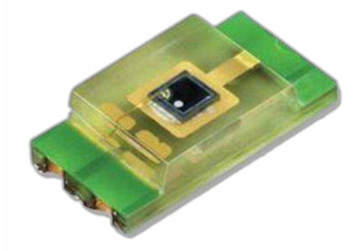


Figure 3.8 The TEMT6000 Ambient Light Sensor

3.5 The LM35 Temperature Sensor

The LM35 series are precision integrated-circuit temperature devices with an output voltage linearly- proportional to the Centigrade temperature, as shown in the figure (3.9). The LM35 device has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from the output to obtain convenient Centigrade scaling. The LM35 device does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾°C Over a full −55°C to 150°C temperature range. Lower cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air. [39].

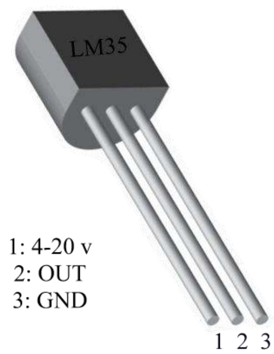


Figure 3.9 The LM35 Temperature Sensor

The main features of LM35 is

Calibrated directly in ° Celsius (Centigrade)
Linear + 10.0 mV/°C scale factor
0.5°C accuracy guaranteeable (at +25°C)
Rated for full −55° to +150°C range
Suitable for remote applications
Low cost due to wafer-level trimming
Operates from 4 to 30 volts
Less than 60 µA current drain

CHAPTER 4

METHODS AND RESULTS

4.1 Calibration methods

The definition of calibration is a test during which known values of measurand are applied to the transducer and corresponding output readings are recorded under specified conditions. The definition involves the capability to regulate the device to zero and to set the desired span. An interpretation of the definition would say that a calibration is a comparison of measuring equipment against a standard instrument of higher accuracy to detect, correlate, rectify, adjust and document the accuracy of the instrument being compared. Typically, calibration of an instrument is checked at several points throughout the calibration range of the instrument. The definition of calibration range is a region between the limits within which a quantity is measured, transmitted or received, expressed by stating the lower and upper range values. The limits are defined by the zero and span values. The zero value is the lower end of the range. Span is defined as the algebraic difference between the upper and lower range values [40].

4.2 Procedure of calibration

In this project the light intensity has been measured by wiring a phototransistor TEMT6000 and a light dependent resistor (LDR) with an Arduino Uno as it displayed values on the liquid crystal displays, which has a 20 character and 4 lines blue background displays. By using a variable light source and an external reference photometer (or Lux meter) like Testo Lux meter, the sensor output can still be calibrated. The photometer and LDR with phototransistor TEMT6000 are placed equidistant in front of the light source like a white compact fluorescent lamp. After that new data is collected as function of distance for both light sensors. The results are shown in Tables (4.1) and (4.2). Note that for a fixed distance it is also found that the input light intensity data fluctuates in time as shown in figure (4.1) and (4.2). As a result we compute the time average of the light intensity over a predefined time interval. This results in more stable results.

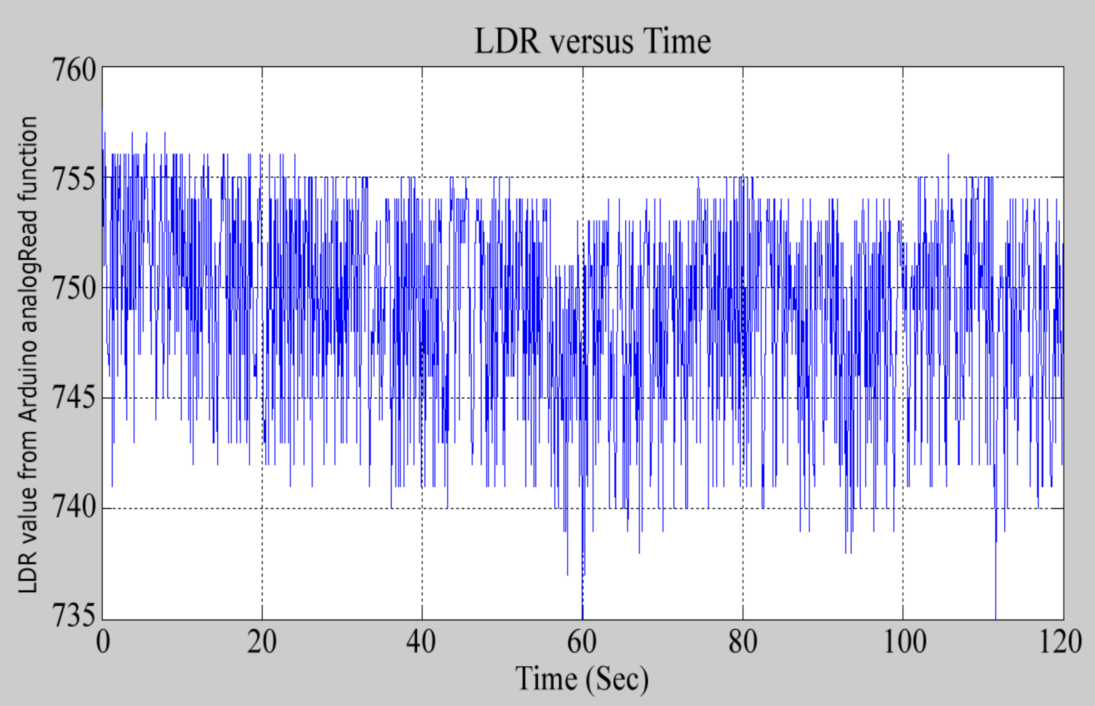


Figure 4.1 The fluctuations of LDR.

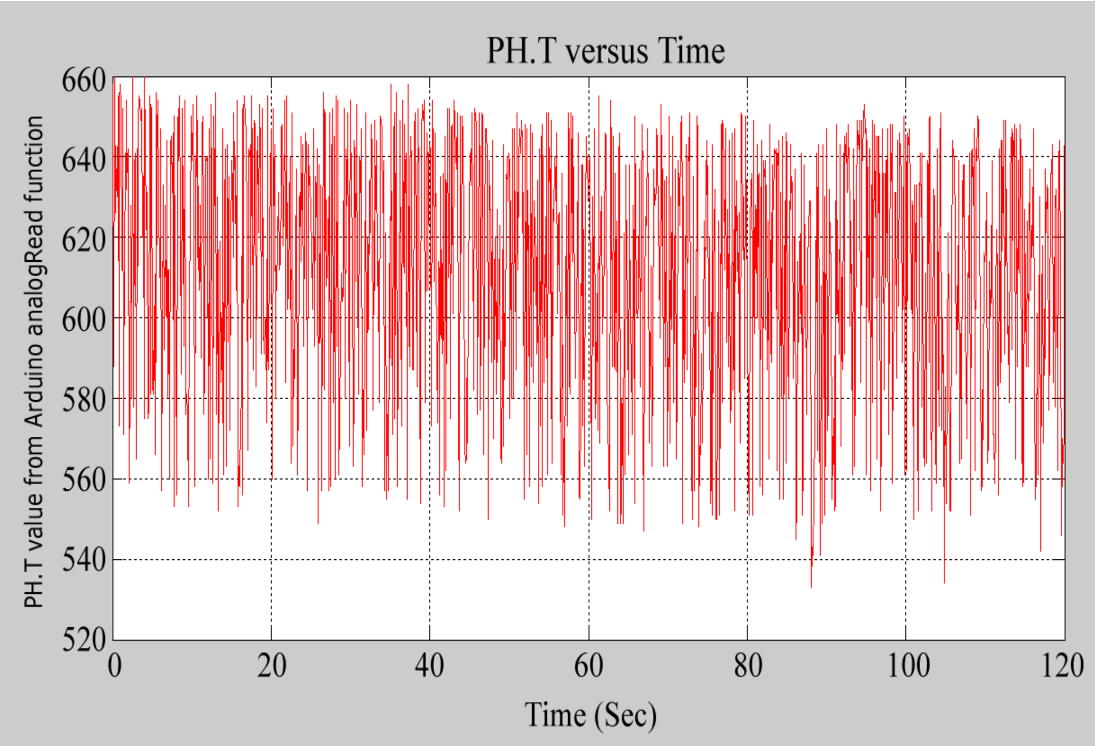


Figure 4.2 The fluctuations of phototransistor TEMT6000.

Table 4.1 LDR data from Arduino and corresponding calibrated values taken from the original Testo lux meter by increasing the distance.

Distance (cm)	**E_x (LDR) (Arduino)**	**E_y (calibrated) in (Lux)**
15	743	6195
20	682	3900
25	630	2766
30	583	2072
35	542	1634
40	504	1315
45	468	1070
50	437	899
55	409	768
60	383	663
65	361	579
70	340	509
75	320	454
80	300	408
85	288	370
90	272	339
95	253	300
100	240	273
105	229	252
110	216	230
115	205	211
120	194	194
125	186	182
130	179	171
135	172	160
140	163	149
145	157	140
150	150	130
155	143	124
160	138	115
165	133	109
170	128	103
175	123	96
180	114	90

Table 4.2 PHT data from Arduino and corresponding calibrated values taken from the original Testo lux meter by increasing the distance.

Distance (cm)	E_x (PH.T) in (Arduino)	E_y (calibrated) in (Lux)
15	787	6195
20	541	3900
25	400	2766
30	308	2072
35	249	1634
40	203	1315
45	168	1070
50	143	899
55	123	768
60	107	663
65	95	579
70	83	509
75	74	454
80	66	408
85	60	370
90	56	339
95	49	300
100	46	273
105	42	252
110	39	230
115	36	211
120	33	194
125	31	182
130	30	171
135	28	160
140	26	149
145	24	140
150	23	130
155	22	124
160	21	115
165	20	109
170	19	103
175	18	96
180	17	90

4.3 Curve fitting

Curve fitting is the process of constructing a mathematical function, or a curve, that has the best fit to a series of data points, probably subject to constraints where an exact fit to the data is required. Curve fitting can involve either interpolation, or smoothing, in which a smooth function is constructed that approximately fits the data [41,42].

In MATLAB, the Curve Fitting Toolbox is a collection of M-file and graphical user interfaces (GUIs) functions built on the MATLAB technical computing environment. Curve Fitting Toolbox provides an app and functions for fitting curves and surfaces to data. The toolbox lets us perform exploratory data analysis post-process and pre-process data, compare candidate models, and remove outliers[43].

4.3.1 The Data Fitting Procedure for LDR

For (LDR), the data in table (4.1) is used and the fitting results is shown in figure (4.3). There are two types of numerical fit results displayed in the Fitting GUI: goodness of fit statistics and confidence intervals on the fitted coefficients. The goodness of fit statistics helps you to determine how well the curve fits the data. The confidence intervals on the coefficients determine their accuracy. The fitting object display includes the model, the fitted coefficients, and the confidence bounds for the fitted coefficients. As follows:

General model Exp1:

$$f(x) = a * e^{(b*x)} \tag{4.1}$$

Coefficients (with 95% confidence bounds):

a = 50.91, confidence bounds: (45.82, 56)

b = 0.006425, confidence bounds: (0.006279, 0.006572)

goodness of fitting is:

R-square = 0.9977

Also from the confidence bounds of each fitted coefficients (a and b) in the equation (4.1), we are found a value of uncertainty parameter (σ_a and σ_b), because each of fitted coefficients have an uncertainty parameter, the value takes from confidence bounds, takes as follows equations:

$$\sigma_a = \frac{(56-50.91)}{2} = 2.545 \longrightarrow \sigma_a{}^2 = 6.477$$

$\sigma_b = \frac{(0.006572 - 0.006425)}{2} = 7.349 * 10^{-5} \Longrightarrow \sigma_b{}^2 = 5.4007 * 10^{-9}$

$$\sigma_{f(x)} = \sqrt{\left(\frac{\partial f(x)}{\partial a} * \sigma_a\right)^2 + \left(\frac{\partial f(x)}{\partial b} * \sigma_b\right)^2} \quad (4.2)$$

$$\sigma_{f(x)} = \sqrt{\left(e^{2bx} * \sigma_a{}^2\right) + \left(a^2 * x^2 * \sigma_b{}^2 * e^{2bx}\right)}$$

$$\sigma_{f(x)} = \sqrt{\left(6.477 + 1.399 * 10^{-5} * x^2\right) * e^{2bx}}$$

Finally, the light illumination in lux and associated error with (95% CL) can be found from:

$$E(x) = a * e^{(b*x)} \pm 2 * \sigma_{f(x)} \quad (4.3)$$

4.3.2 The Data Fitting Procedure for PH.T

For (PH.T), the data in table (4.2) is used and the fitting results is shown in figure (4.5). The fitting object display includes the model, the fitted coefficients, and the confidence bounds for the fitted coefficients. As follows:

General model:

$$f(x) = p * x^2 + q * x \quad (4.4)$$

Coefficients (with 95% confidence bounds):

p = 0.002464, confidence bounds: (0.002399, 0.002529)

q = 5.923, confidence bounds: (5.883, 5.962)

goodness of fitting is:

R-square = 0.9999

Also from the confidence bounds of each fitted coefficients (p and q) in the equation (4.4), we are found a value of uncertainty parameter (σ_p and σ_q), because each of fitted coefficients have an uncertainty parameter, the value takes from confidence bounds, takes as follows equations:

$\sigma_p = \frac{(0.002529 - 0.002464)}{2} = 3.249 * 10^{-5} \Longrightarrow \sigma_p{}^2 = 1.0556 * 10^{-9}$

$\sigma_q = \frac{(5.962 - 5.923)}{2} = 0.0195 \Longrightarrow \sigma_q{}^2 = 3.8025 * 10^{-4}$

$$\sigma_{f(x)} = \sqrt{\left(\frac{\partial f(x)}{\partial p} * \sigma_p\right)^2 + \left(\frac{\partial f(x)}{\partial q} * \sigma_q\right)^2} \tag{4.5}$$

$$\sigma_{f(x)} = \sqrt{(x^2 * \sigma_p)^2 + (x * \sigma_q)^2}$$

$$\sigma_{f(x)} = \sqrt{(1.0556 * 10^{-9} * x^4) + (3.8025 * 10^{-4} * x^2)}$$

Finally, the light illumination in lux and associated error with (95% CL) can be found from:

$$E(x) = p * x^2 + q * x \pm 2 * \sigma_{f(x)} \tag{4.6}$$

The figure (4.4) and (4.6) as shows how light intensity decreases as the lamp is moved away from the each lux meter LDR and PHT respectively. The same data is also obtained by using the calibrator (Testo Lux meter) as shows in the figure (4.7). As we expected, the light intensity is proportional to $1/(\text{distance})^2$, which is not really sudden since it depends upon the area of the beam of light falling on the all sensor. In figures (4.8) and (4.9), illumination outputs (from LDR, from PHT and from calibrator) are plotted together with linear and logarithmic scales respectively. All measurement results are in good agreement.

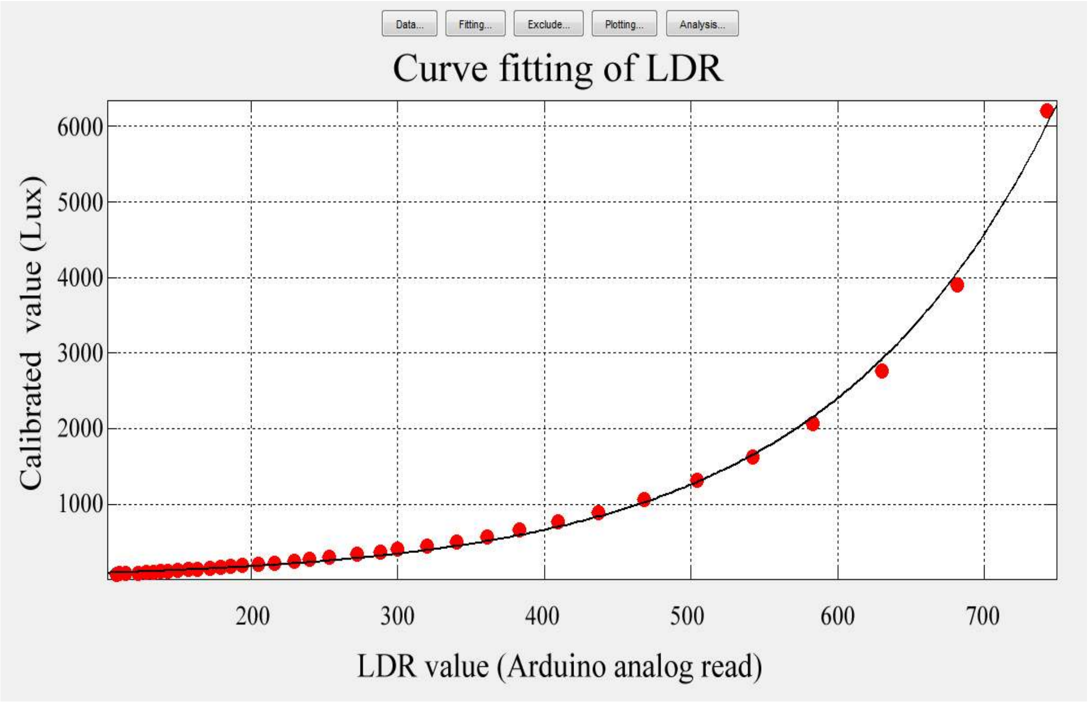


Figure 4.3 The Data Fitting of LDR.

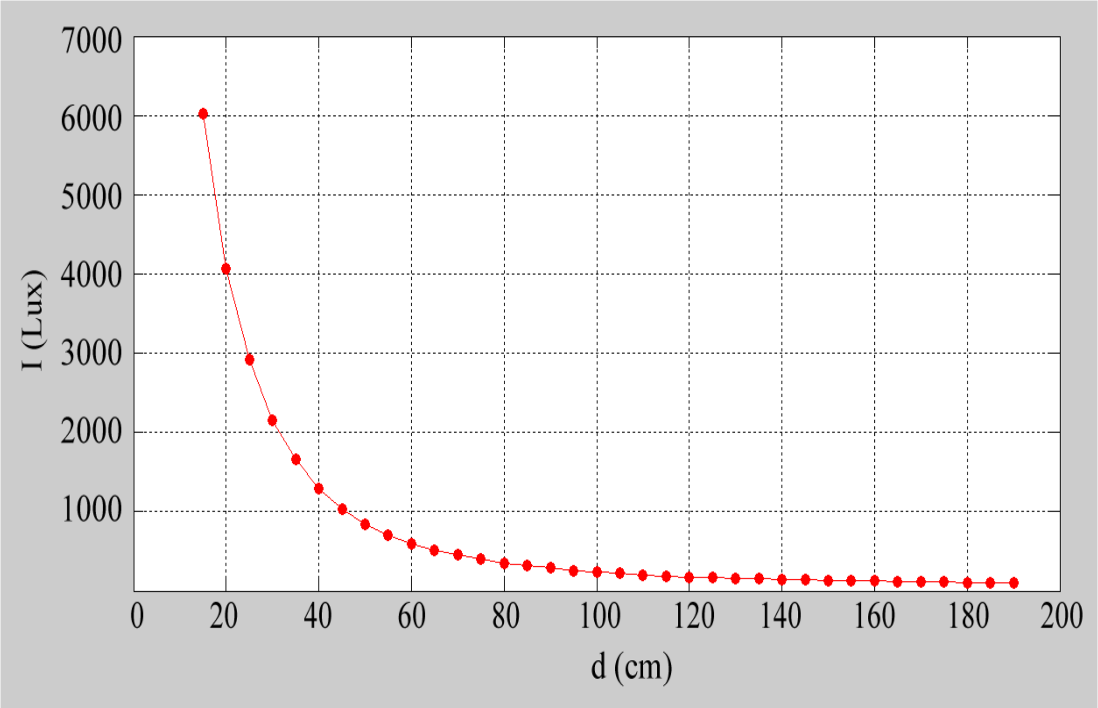


Figure 4.4 E in lux vs distance for LDR

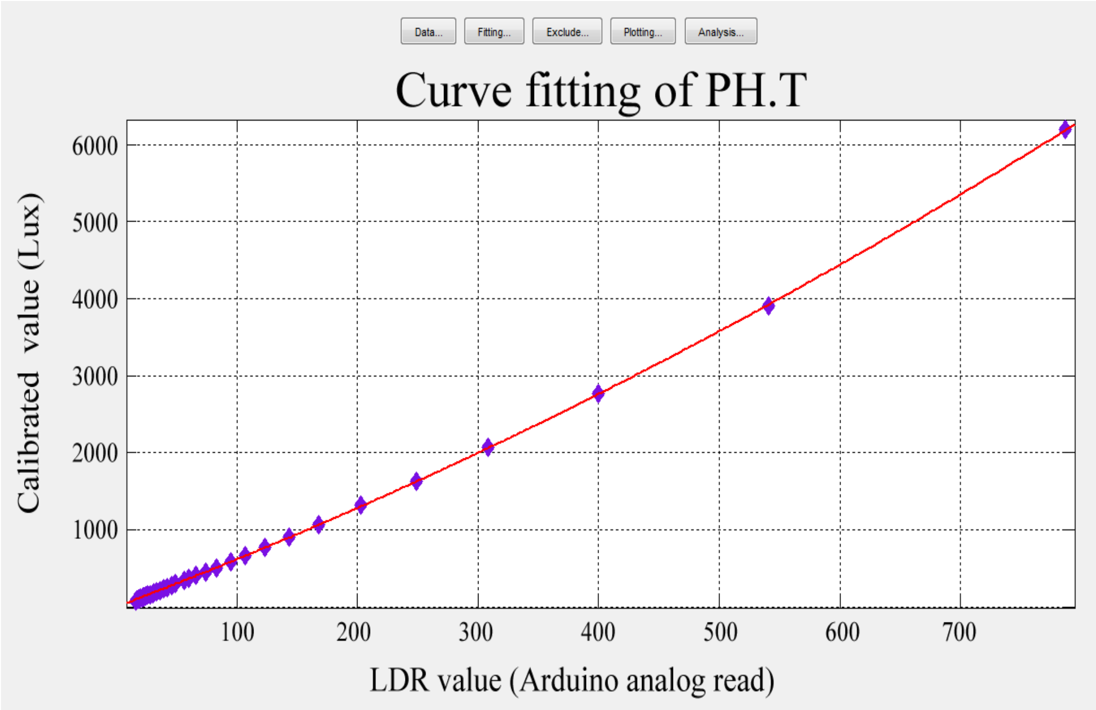


Figure 4.5 PHT fitting result

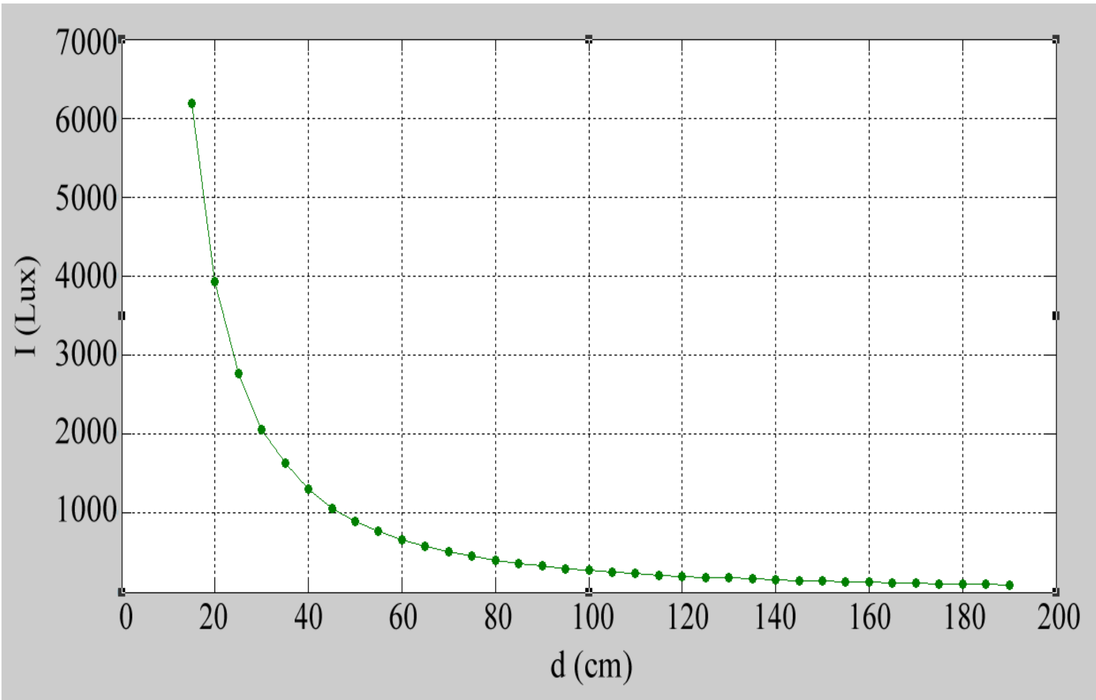


Figure 4.6 E in lux vs distance for PHT

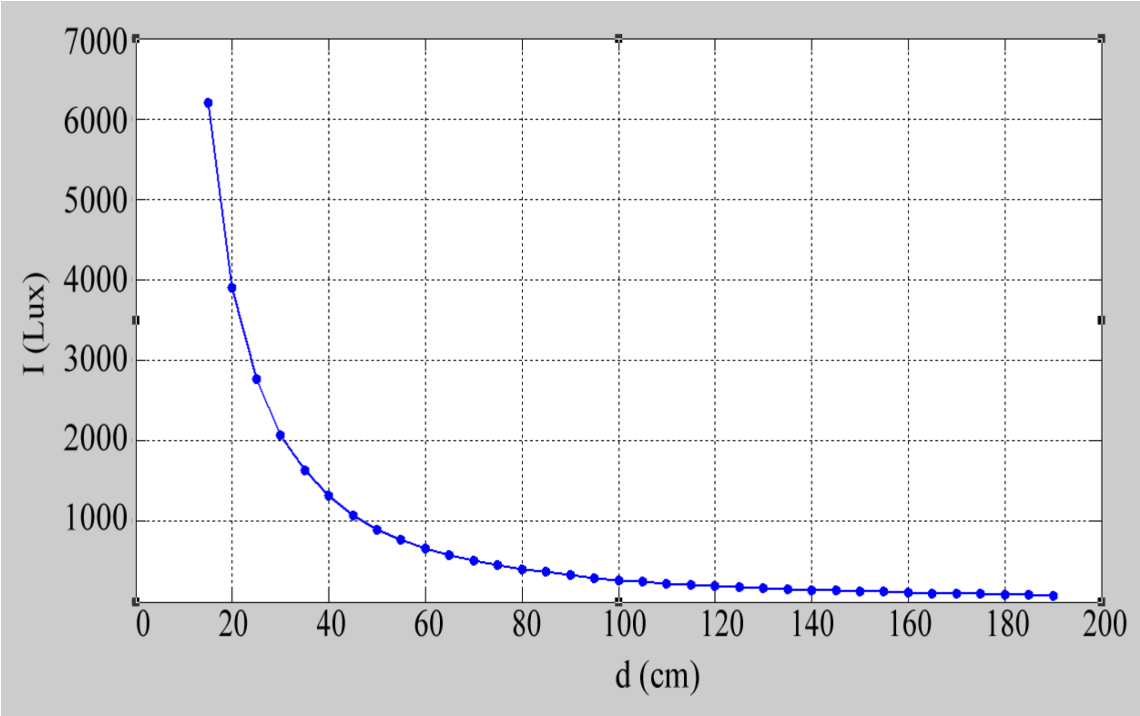


Figure 4.7 E in lux vs distance for our calibrator

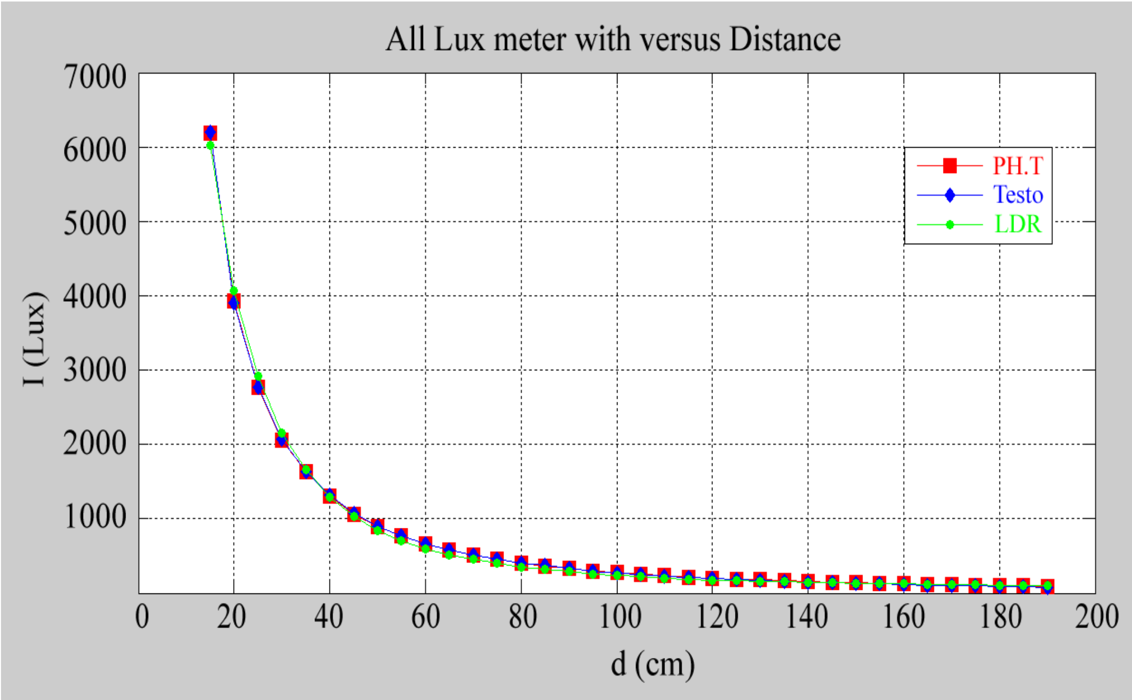


Figure 4.8 All lux measurements vs distance

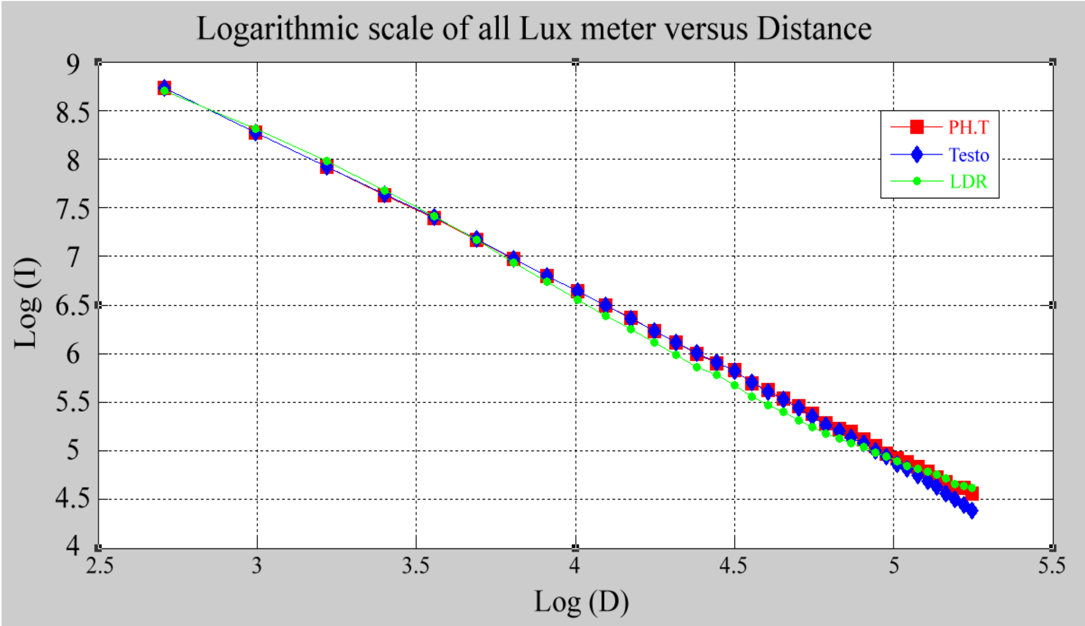


Figure 4.9 Logarithmic scales of all lux measurements vs distance

4.4 The Sensitivity of LDR

The sensitivity of (LDR) photo detector is the relationship between the light falling on the device and the resulting output signal, as shown in the figure (4.10), and logarithmic scales in the figure (4.11). In the case of a photocell, one is dealing with the relationship between the incident light and the corresponding resistance of the cell.

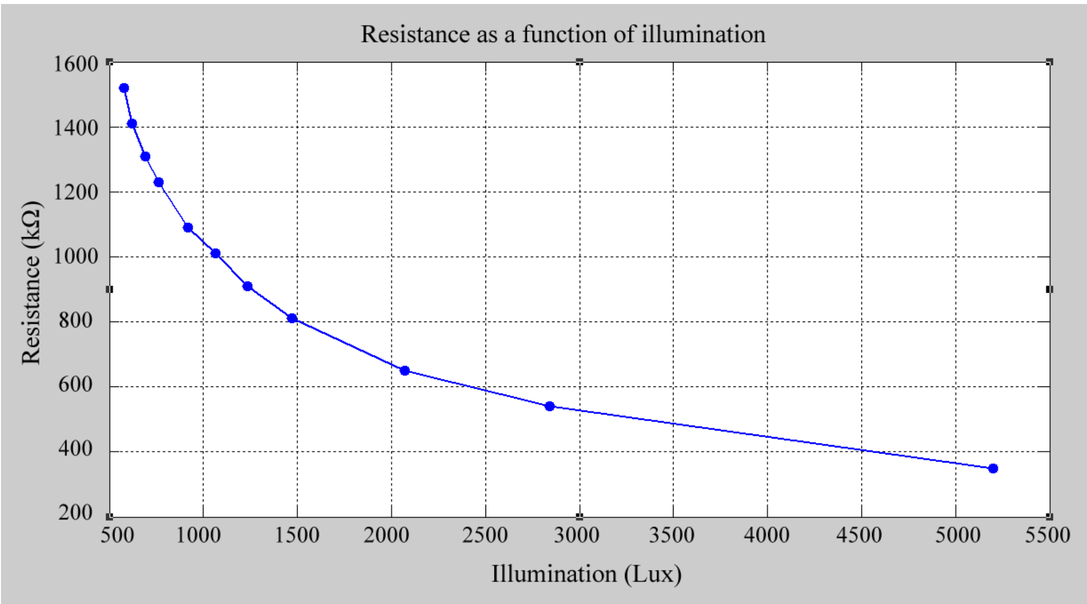


Figure 4.10 Resistance as a function of Illumination.

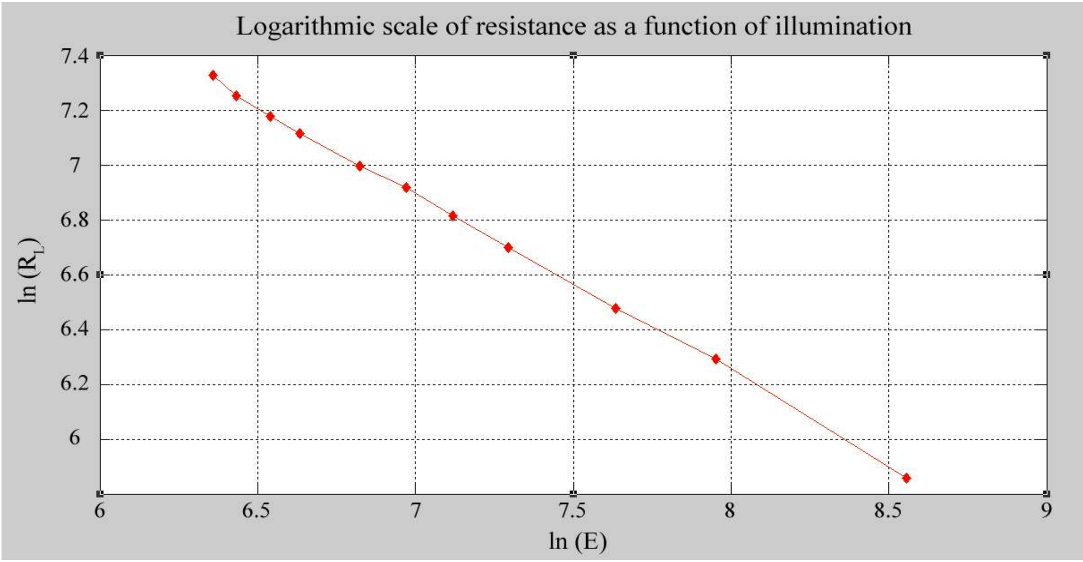


Figure 4.11 Logarithmic scales of resistance as a function of illumination.

4.5 The spectral response

The spectral response is conceptually similar to the quantum efficiency. The quantum efficiency gives the number of electrons output by the photo detector cells compared to the number of photons incident on the device, while the spectral response is the ratio of the current generated by the photo detector cells to the power incident on the photo detector cells.

The spectral response of LDR and PHT are similar to the human eye. The relative sensitivity of a photo detector cell is dependent on the wavelength (color) of the incident light. Each photo detector material type has its own unique spectral response curve or plot of the relative response of the photocell versus wavelength of light. A spectral response of LDR and PHT curve is shown in figure (4.12) respectively.

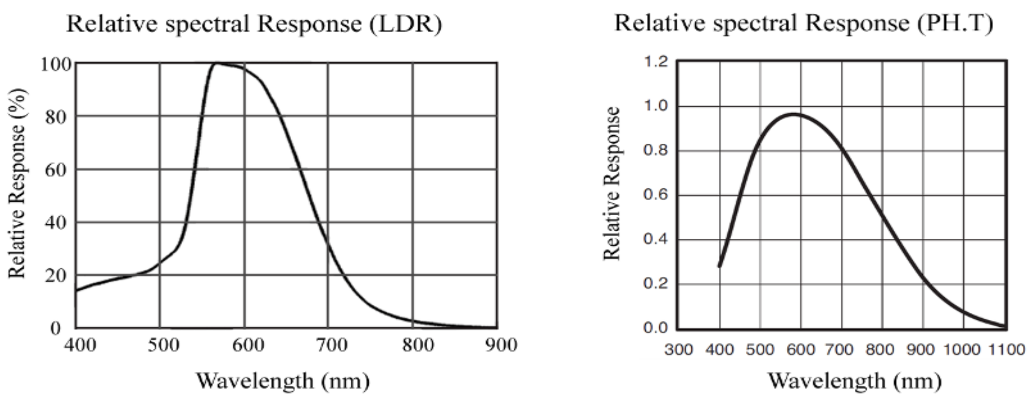


Figure 4.12 Relative spectral Response LDR and PHT.

CHAPTER 5

CONCLUSION

In this study, we have shown that a toolbox involving a digital lux meter and a thermometer can be made by using very cheap sensors, widely used data acquisition board Arduino Uno and the 4x20 LCD screen. The calibrations of the light sensors (a photo resistor and a photo transistor) have been performed by using the reference lux meter TESTO 0635 0545. Also the software developed by MATLAB is useful for visualization of the data as function of time

The measurement ranges of the sensors are 0-10,000 for lux meter(s) and 0-100 oC for the thermometer. In addition, the maximum associated uncertainties are in the order of 30 lux and 0.5 oC respectively. These uncertainties are also displayed on the LCD screen. As a result, this toolbox is useful in the standard undergraduate and graduate laboratory experiments and indoor light and temperature measurements.

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APPENDIX 1

Source code of Arduino Loader

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
 LiquidCrystal_I2C lcd (0x27, 2, 1, 0, 4, 5, 6, 7, 3, POSITIVE);
 int L, P, m, n, y, k, u;
 double a, b, c, d, p1,  p2, na , ma, T, F ;
 void setup()
{
  Serial.begin(9600);
  lcd.begin(20,4);
  lcd.backlight();
 }
 int sL=0;
 int counL=0;
 int sP=0;
 int counP=0;
 int st=0;
 int count=0;
void loop()
{
 //LDR
  delay(10);
sL=sL+ analogRead(A2);
   counL++;
 if(counL==40){
  int av=sL/counL;
       a =       50.91; //  (45.82, 56)
       b =    0.006425 ; // (0.006279, 0.006572)
       m = a*exp(b*av) ;
```

```
ma = sqrt( (6.477 + 2.591e3*5.4007e-9*av*av)*exp(2*b*av) );
     u = ma*2;
 Serial.print(av);
 Serial.print("   ");
 //lcd.clear();
 lcd.setCursor(0,0);
 lcd.print("EL =");
 lcd.setCursor(11,0);
 lcd.print("+-");
 lcd.setCursor(15,0);
 lcd.print(" Lux ");
 lcd.setCursor(0,1);
 lcd.print("EP =");
 lcd.setCursor(11,1);
 lcd.print("+-");
 lcd.setCursor(15,1);
 lcd.print(" Lux ");
 lcd.setCursor(5,0);
 lcd.print(m,1);
 lcd.setCursor(13,0);
 lcd.print(u,1);
  counL=0;
  sL=0;
}
//PHOTODIODE
  delay(10);
  sP=sP+ analogRead(A0);
   counP++;
 if(counP==40){
  int avP=sP/counP;
  p1 =   0.002464 ; //(0.002399, 0.002529)
  p2 =      5.923 ; //(5.883, 5.962)
   n = p1*avP*avP + p2*avP;
   na = sqrt( (1.0556e-9*avP*avP*avP*avP) + (3.8025e-4*avP*avP) );
   k=na*2;
 Serial.println(avP);
  lcd.setCursor(5,1);
  lcd.print(n,1);
```

```
  lcd.setCursor(13,1);
  lcd.print(k,1);
  counP=0;
  sP=0;
}
 // LM35 Temperature sensor
delay(10);
  st=st+ analogRead(A1);
   count++;
if(count==10){
  int avt=st/count;
T = 0.48828125 * avt;
  lcd.setCursor(0,2);
  lcd.print("Tc =");
  lcd.setCursor(5,2);
  lcd.print(T,1);
  lcd.setCursor(13,2);
  lcd.print(0.5,1);
  lcd.setCursor(11,2);
  lcd.print("+-");
  lcd.setCursor(16,2);
  lcd.print(" oC ");
  count=0;
  st=0;
 }
  F = T*1.8+32;
  lcd.setCursor(0,3);
  lcd.print("Tf =");
  lcd.setCursor(5,3);
  lcd.print(F,1);
  lcd.setCursor(13,3);
  lcd.print(0.9,1);
  lcd.setCursor(11,3);
  lcd.print("+-");
  lcd.setCursor(16,3);
  lcd.print(" oF ");
 }
```

APPENDIX 2

MATLAB GUI source code for collecting and displaying data

```
function varargout = project(varargin)
% PROJECT MATLAB code for project.fig
% PROJECT, by itself, creates a new PROJECT or raises the existing
%      singleton*.
%
gui_Singleton = 1;
gui_State = struct('gui_Name',mfilename,...
                 'gui_Singleton',gui_Singleton,...
         'gui_OpeningFcn',@project_OpeningFcn,...
                   'gui_OutputFcn',  @project_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT

% --- Executes just before project is made visible.
function project_OpeningFcn(hObject, eventdata, handles, varargin)

% Update handles structure
guidata(hObject, handles);
clear all; clc;
global b;
b=arduino('com3');

% --- Outputs from this function are returned to the command line.
function varargout = project_OutputFcn(hObject, eventdata, handles)
varargout{1} = handles.output;


function time_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function time_CreateFcn(hObject, eventdata, handles)
```

```
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor')
set(hObject,'BackgroundColor','white');
end


function com_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function com_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function max1_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function max1_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function average1_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function average1_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function mim1_Callback(hObject, eventdata, handles)
% hObject    handle to mim1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of mim1 as text
%        str2double(get(hObject,'String')) returns contents of mim1 as
a double


% --- Executes during object creation, after setting all properties.
function mim1_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function std1_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function std1_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function std2_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function std2_CreateFcn(hObject, eventdata, handles)
% hObject    handle to std2 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns
called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function edit16_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function edit16_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function min2_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function min2_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


function max2_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function max2_CreateFcn(hObject, eventdata, handles)
```

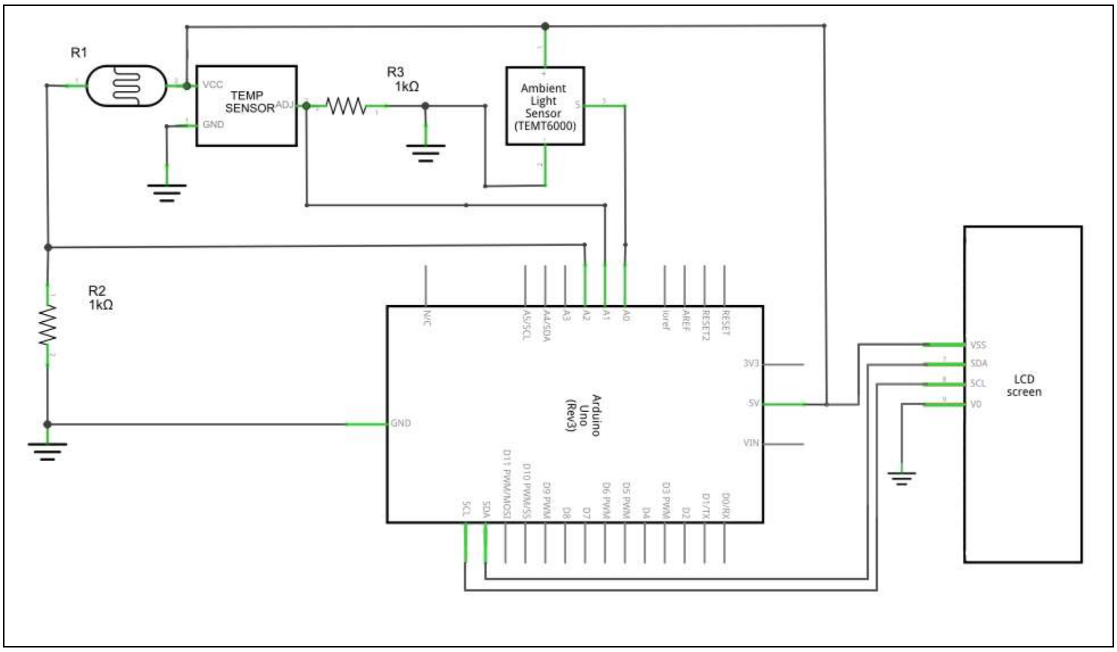
```
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function stdT_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function stdT_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit20_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function edit20_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function minT_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function minT_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function maxT_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function maxT_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

% --- Executes on button press in Run.
function Run_Callback(hObject, eventdata, handles)

% --- Executes on button press in run1.
function run1_Callback(hObject, eventdata, handles)

global b;
tic;
i=0;
j=0;
k=0;
ph_pin=0;
```

```
te_pin=1;
ld_pin=2;
t = str2num(get(handles.time,'String'));
y1 = str2num(get(handles.minlux,'String'));
y2 = str2num(get(handles.maxlux,'String'));
%-------------------------------------LDR light dependent resistor
sensor
while toc<t
    i=i+1;
    time(i)=toc;
    d = zeros(20,1);
    for f=1:20;
        d(f) = b.analogRead(ld_pin);
      pause(0.005);
    end
    m(i) = mean(d);

    mm = 50.91*exp(0.006425*m) ;
    axes(handles.axes1);
   pl= plot(time,mm,'*b-');
   axis([0 t y1 y2]);
   grid on
   xa = mean(mm);
   xs = std(mm);
   xx = max(mm);
   xn = min(mm);
%-------------------------------------PH.T (TEMT6000)light sensor
   j=j+1;
    time(j)=toc;
    dd = zeros(20,1);
    for g=1:20;
        dd(g) = b.analogRead(ph_pin);
      pause(0.005);
    end
    n(j) = mean(dd);
    nn = 0.002464.*n.*n + 5.923.*n ;
    axes(handles.axes2);
    plot(time,nn,'ok-');
    axis([0 t y1 y2]);
    grid on
    ya = mean(nn);
    ys = std(nn);
    yx = max(nn);
    yn = min(nn);
%------------------------------------- LM35 Temperature sensor

   k=k+1;
    time(k)=toc;
    dt = zeros(20,1);
    for h=1:20;
        dt(h) = b.analogRead(te_pin);
      pause(0.005);
    end
    o(k) = mean(dt);
    oo = 0.48828125*o ;
    axes(handles.axes3);
    plot(time,oo,'+r-');
```

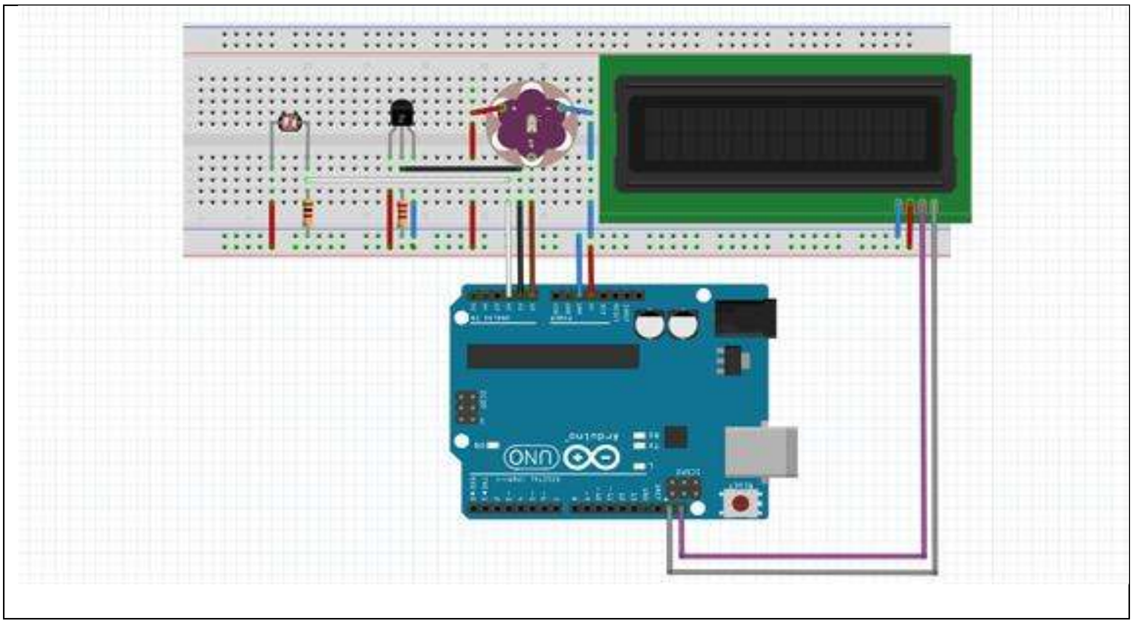
```
    axis([0 t 0 60]);
    grid on
    za = mean(oo);
    zs = std(oo);
    zx = max(oo);
    zn = min(oo);

   set(handles.av1, 'String',xa);
   set(handles.std1,'String',xs);
   set(handles.max1,'String',xx);
   set(handles.min1,'String',xn);

   set(handles.av2, 'String',ya);
   set(handles.std2,'String',ys);
   set(handles.max2,'String',yx);
   set(handles.min2,'String',yn);

   set(handles.avt, 'String',za);
   set(handles.stdt,'String',zs);
   set(handles.maxt,'String',zx);
   set(handles.mint,'String',zn);

    end

% --- Executes on key press with focus on run1 and none of its
controls.
function run1_KeyPressFcn(hObject, eventdata, handles)

function minlux_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function minlux_CreateFcn(hObject, eventdata, handles)

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function maxlux_Callback(hObject, eventdata, handles)

% --- Executes during object creation, after setting all properties.
function maxlux_CreateFcn(hObject, eventdata, handles)
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

APPENDIX 3

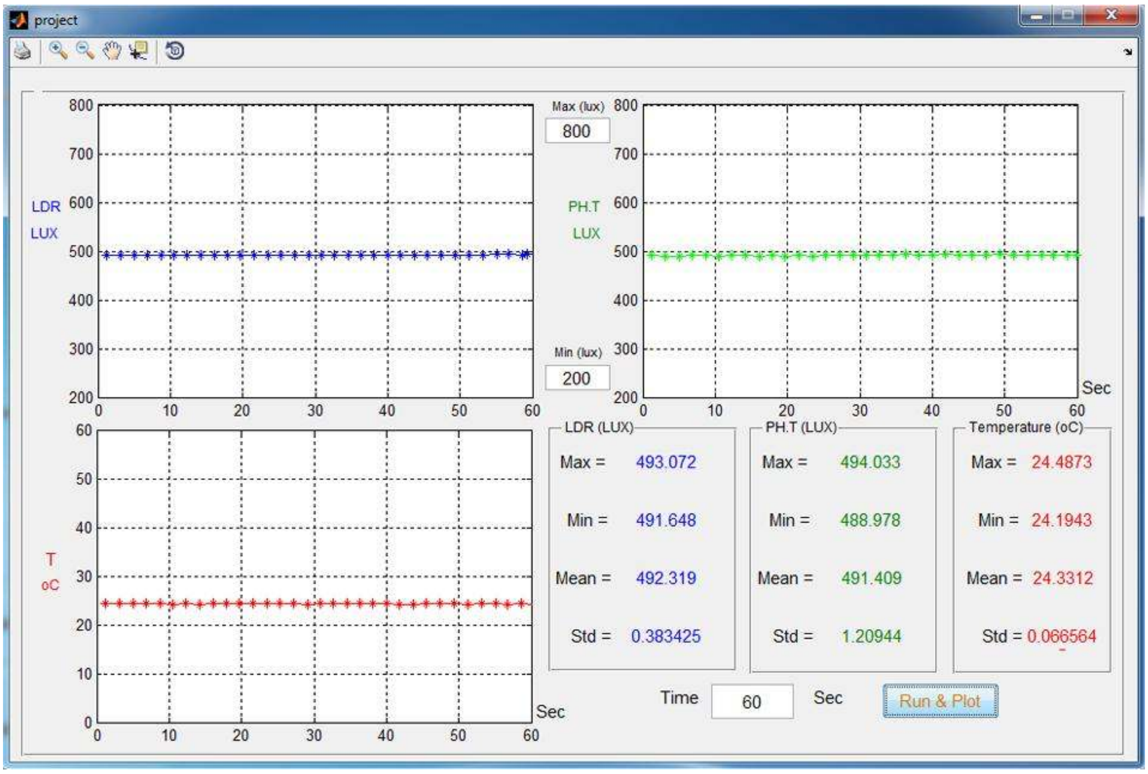
The Schematic diagram of the toolbox



The Breadboard diagram of the toolbox



The screenshot of MATLAB GUI



The picture of our reference lux meter (TESTO 0635 0545)

The constructed toolbox consisting of Lux meter and Thermometer