DEVELOPMENT OF CLOSED LOOP ILLUMINANCE CONTROL USING MOTORIZED VERTICAL BLINDS AND DIMMABLE LED SOURCES FOR ENERGY SAVING

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled ***"DEVELOPMENT OF CLOSED LOOP ILLUMINANCE CONTROL USING MOTORIZED VERTICAL BLINDS AND DIMMABLE LED SOURCES FOR ENERGY SAVING"****, submitted by SOURAV BISWAS (Examination Roll No. M4ILN22021 & Registration No. 136089 of 2016-17) under our supervision and be accepted in partial fulfilment of the requirement for the degree of Master of Illumination Engineering.*

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The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a satisfactory manner to warrant its acceptance as a pre-requisite to the degree for which it has been submitted. It is notified to be understood that by this approval, the undersigned do not necessarily endorse or approve any statement made, opinion expressed and conclusion drawn therein but approve the thesis only for the purpose for which it has been submitted.

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I, hereby declare that this thesis contains literature survey and original thesis work by the undersigned candidate, as part of Master of Engineering in Illumination Engineering course.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

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Abstract

Daylight is a natural light source, which contributes a huge amount of light throughout the day and varies over time in quality (Co-related Color Temperature) and quantity (Illuminance). Modern offices, institutes, shopping malls etc. are made of glazing glasses and also to fulfil the illuminance criteria inside the rooms, artificial light sources are made on all over the day. In that case two things are happening, firstly, the person staying near the window or glazing glasses may receive excessive light, which may create visual disturbance, and secondly, the artificial light sources are glowing with its full brightness, which is unnecessary and energy waste is taking place. Considering these facts, in this work, a close loop room illuminance control system has been developed using motorized vertical blinds, LED light source and light sensor. Users can set the light level as per their requirement. A wide range of illuminance from 0 lx to 300 lx can be set by the users using a knob and the set illuminance is displayed on the LCD display. Based upon the set illuminance, the microcontroller will control the motorized vertical blinds to maintain the illuminance on the working plane. ATmega328P microcontroller has been used in this system. A ceiling mounted photo sensor is placed to detect the light level on the working plane and the response is fed to the microcontroller as feedback. If the light level is achieved through the motorized vertical blinds, then the LED will be turned off. If the light level cannot be achieved after complete opening of the blinds, then only microcontroller will increase the duty cycle of the PWM signal for the LED, and LED will start glowing and the light level will be maintained on the working plane. Using this system, visual comfort can be achieved inside the room, as well as energy saving can be done by dimming the LEDs inside the room. This system can be used in offices, institutes, shopping malls, hospitals etc.

Overview of the thesis

Chapter 1: Provides the introduction of the system

Chapter 2: Discusses the literature review

Chapter 3: Describes the main components

Chapter 4: provides the software and hardware implementation of the proposed system along with the block diagram, circuit diagram and the purpose and working of each hardware component.

Chapter 5: Experimental results

Chapter 6: Conclusion and Future scope.

References

Appendix I: ATmega328P programming code

Appendix II: Components used for hardware implementation

Contents

Chapter 1

Introduction

The energy crisis has recently emerged as a global issue that has to be resolved. The largest portion of global energy consumption is from domestic electricity use. In particular, the power consumption of lamps in a typical home is a factor which can not be ignored. The typical user needs various light intensities in various places. We do not always need to switch on any lights because the outside light is sometimes enough for the user. But sometimes the user leaves but forgets to turn off the light. These factors cause energy waste. Therefore, some power management and light control in a home are required in order to conserve energy.

The fast adoption of the light-emitting diode is one example of how semi-conductorization is affecting lighting (LED). The luminaire's light output may be precisely and readily controlled using LED luminaires. The majority of the electrical energy consumed worldwide is used for artificial lighting. On the system level, the energy consumed in artificial lighting may be reduced by adapting the artificial light output to daylight.

In order to obtain this information, light sensor can be used. This sensor provides information related to illumination. Using this sensing information as feedback input, a lighting controller can adapt the artificial light output so that desired illumination levels are maintained. Illumination levels can be monitored using light sensor. In a specific configuration, the light sensor may be collocated at the luminaire. The illumination values of interest are, however, over the workspace of user. An initial calibration phase with light meter is hence required to map the illuminance value at the workspace to the light sensor. Such a situation can also occur in certain daylight scenario when the mapping between the daylight contributions at the workspace and light sensor is different from the calibrated one using artificial lighting. Light sensor can detect the reflected light at workspace.

To achieve the desired illuminance, the LED sources are controlled by PWM technique. The PWM technique is used to control the average current through these light sources according to the duty cycles thereby controlling the average illuminance of the blended source. LED dimming can be performed in two ways – Analog dimming and PWM dimming. Analog dimming changes LED light output by simply adjusting the DC current in the string while PWM dimming completely turns on and off the LED current based on the duty cycle thereby controlling the average current flow through the LEDs. Analog dimming is inappropriate for many applications because it loses dimming accuracy by about 25 % at only 10:1 brightness level, and it skews the colour of the LEDs. In contrast, PWM dimming can produce 3000:1 and higher dimming ratios (at 100Hz) without any significant loss of accuracy, and no change in LED colour. Hence, where LED colour output and high dimming ratio are of utmost importance, PWM dimming is the most preferred technique. The mathematical formulations of blended light source are implemented in an 8-bit Atmega328P microcontroller and the microcontroller generates the PWM signals for the individual light sources. The ADC pin of the microcontroller is also used to generate digital signals for the Analog input of illuminance fed by varying potentiometers present in the controller module.

The automatic blinds are designed for office or home use for consuming less energy in the day time. Mostly in IT industries and large-scale companies, the working time is from 7 am to 5 pm which uses averagely 15000watts (15 kW) per day. With the use of smart blinds, it can reduce the light adjustments system to minimum use and which can reduce the energy consumption by up to 60%. By use of natural sources and controlling the intensity of light coming in can easily adjust illuminance of the room.

A curtain or blinds serves as cover against the sun, to manage air circulation and decorative purposes. In general, a blind can be classified as a decorative element or fully-operable item for controlling daylight illuminance. The blinds are modified to incorporate a small modulated DC motor to activate the traditional manually operated slat positioning rod. The thirteen vertical blinds are synchronized to provide the same angle, where a positive blind angle is defined from the horizontal plane with slats inclined downwards for a ground view by the occupant. For stable solar conditions (e.g., clear sunny weather), the blinds often did not move for over an hour. One of the means for indirect control is by controlling the blinds, which serves to regulate lighting source. To controlled blinds using a motor, it can be special type DC motor i.e., servo or stepper is most applicable for this case. Changing the rotation of motor, blinds are opening or closed. A microcontroller unit controls every component.

The purpose of this thesis is to investigate the effect of various configurations of manual and automatic controlled venetian blinds on the workspace daylight availability and the dimming control of LED-based on light sensor which is interfaced to an Arduino board. The proposed system is evaluated in a laboratory room. The specific objectives are

- to evaluate the lighting energy savings from daylighting with controlled continuous dimming lighting controls; and
- to evaluate the effect of manually and automatically operated vertical blinds on the performance of the lighting control system and their associated energy savings.

Chapter 2

Literature Review

Utilization of daylight as a renewable energy resource may reduce electricity consumption for lighting and heating energy [1,2,3,28].

Compared to conventional fluorescent lamps and incandescent lamps, high brightness light emitting diodes (LED) have gained a lot of popularity due to their luminous efficacy, high brightness, good colour rendering index (CRI), low power consumption, low ultraviolet emission, and environmentally friendly nature. People are doing research worldwide to increase the photometric and colorimetric parameters of LED like the CRI, efficacy, variable CCT, dimming control etc. Generally LED white light is generated for general application by applying a coating of YAG: Ce3+ yellow phosphor on the InGaN blue LED chips [4].

Instead of retrofitting the lightings with more energy-efficient lightings such as LED, T8, and T5 lamps [5], the deployment of building lighting control strategies has shown more significant energy savings potential [6]. Current building lighting control system can be developed with installation of switches, dimmers and scene setters, time scheduling, group control, occupancy adaptation, daylight harvesting, personal control, demand response, and combination of occupancy and daylight adaptation [7]. The control scheme controls the lumen delivery of individual light emitting diode arrays of the test luminaire by adjusting the duty cycles to follow the instantaneous correlated colour temperature of daylight and at the same time to respond to the variation of window plane illuminance in the reverse pattern [8].

A large body of research has been devoted to the design and implementation of efficient control methods for smart indoor lighting systems. Light dimming control and daylight can be saves the electrical energy. Desired illuminance can be achieved from daylight and artificial light. In this experiment we are controlling the LEDs as well as blinds using motor. The light sensors could measure the total illumination arising from daylight and artificial lighting independently. To getting desirable light level utilizing its switching property and pulse width modulation (PWM) or amplitude modulation (AM) control technique. The concept of dimming control getting changed day by day. There are two main control approaches in the determination of luminaires' dimming level; open-loop and closed-loop [9,10]. For the open-loop approach, no illuminance measurements are taken during the operational mode, since it is assumed that there are no uncontrollable light sources. Open-loop methods are simple, where daylight variation is estimated or no external illuminance variation is considered [11,12]. Several researches on office and commercial lighting control are going on. The communication systems and protocols for advanced lighting control systems are Digital Addressable Lighting Interface (DALI) and Digital Multiplexing (DMX) 512/1990 [13].

Light-emitting-diode (LED) lightings are expected to become a major kind of light source for the coming decades because of its high luminous efficacy. Besides, compared with other traditional lighting sources, with their unique physical structure, electrical and optical characteristics, LEDs have their own advantages. For example: 1) energy saving, 40% electricity is transformed to light; 2) long life span, more than 100000 hours; 3) fast response, the start time of LEDs is on nanosecond level; 4) solid-state encapsulation, belonged to cold light source; 5) environmentally friendly, harmful elements such as Pb and Hg are not included; 6) proper colour rendering index [14]. Besides, with the development of LED packaging and coating technology, the cost of LEDs decreased greatly and LEDs have been widely used in indoor lighting, street lighting, screens, message signs, architectural lighting and greenhouse lamps [15,16]. Lights are usually controlled by on/off switches. Of course, the user can switch a light on or off remotely by connecting a specific device to a PC [17,18].

Illumination levels can be monitored using light sensors. In industry practice, light sensors are located at the ceiling. In a specific configuration, the light sensors may be collocated at the luminaires [19,20]. This arrangement has the benefit of making it simple to commission sensors and to power them. But the important illumination values are above the users' workplace. Therefore, mapping the illuminance values at the workplaces to the ceiling light sensors requires a preliminary calibration process with light metres. A drawback of such calibration is that if the workspace environment changes, the initial calibration is rendered invalid and lighting control is ineffectual in reaching the target illuminance levels at the workspaces [21,22]. When the modelling between the daylight contributions at the workplaces and ceiling light sensors differs from the calibrated one using artificial lighting, such a situation may also arise in certain daylight conditions [19, 23, 24]. Light sensor located with the luminaire [25].

The accuracy of such system significantly benefits from large number of photodetectors, which increases the energy consumption and complexity. A novel efficient control mechanism which reduces the number of photodetectors with no significant loss in accuracy is presented. A linear optimization method and a clustering algorithm are applied to select the least number and appropriate locations of photodetectors [26].

With the use of smart curtains, it can reduce the light and temperature adjustments system to minimum use and which can reduce the energy consumption by up to 60%. By use of natural sources and controlling the intensity of light coming in can easily adjust the temperature and luminance of the room [27]. The automated blind control is to maximize the benefits of daylight by maximizing occupant comfort and minimizing energy consumption [28].

To implemented this system, we are following some technique of energy saving i.e., to implement an auto-intensity control of LED-based on LDR which is interfaced to an Arduino board. The light source will not be running at maximum power output while there is excess light coming through the window [29].

The motor is controlled using Arduino UNO which is chosen due to its low power consumption. The Arduino controls the direction of the motor by using a Pulse Width Modulation (PWM) logic signal emitted from input/output pins, meanwhile, the control is done by using the LDR sensor [30].

The performance indicators measured included the space illumination and the lighting energy consumption as a function of shading device type (manual or automatic blinds), and configuration (blind slat angle and retraction area). According to the level of sensitivity selected, the motorized blinds were expected to maintain a pre-set level of indoor illumination throughout the day and to close completely at night. During the day, the blinds system was built to operate with the following levels of sensitivity that could be selected from the control unit:

- always open (fixed position—blinds remained fully open regardless of changes in sunlight);
- low sensitivity (very strong sunlight was required before blinds started to close);
- normal sensitivity (moderate sunlight started to close the blinds and strong sunlight closed them completely);
- high sensitivity (blinds started to close with diffuse sunlight and closed completely with moderate sunlight);
- always closed (fixed position—blinds remained fully closed regardless of changes in sunlight). Only the ‘‘normal sensitivity’’ setting was included in this study. The automatic blind system and the lighting control systems worked independently of each other. Each system had its own control light sensor and routine algorithm and no attempt was made to integrate them [31].

Chapter 3

MAIN COMPONENTS OF THE SYSTEM

The proposed system consists of a string LEDs and LED drivers arranged in a luminaire, the CCT and Illuminance controller, switching MOSFETs and MOSFET drivers. The description of each component is given below.

3.1. LED

LEDs, also known as light-emitting diodes, are frequently employed as a common source of light in electrical apparatus. LEDs are used in many different industries, such as optical communication, remote-controlled operations, robotics, alarm and security systems, etc. Due to its durability, low power needs, quick reaction time, and quick switching capabilities, it is used in a variety of these applications. Below are a few standards LED uses:

- Used for TV back-lighting
- Uses in displays
- Used in automotive
- Used in dimming of lights

3.1.1. Overview of LED

A light emitting diode is a simple semiconductor device that emits light when electric current flows through it. When current passes through the LED, the electrons recombine with holes emitting light in the process. It is a specific type of diode having similar characteristics as the p-n junction diode. This means that an LED allows the flow of current in its forward direction while it blocks the flow in the reverse direction. Light-emitting diodes are built using a weak layer of heavily doped semiconductor material. Based on the semiconductor material used and the amount of doping, an LED will emit a coloured light at a particular spectral wavelength when forward biased as shown in Fig. 3.1.

Fig. 3.1: 5 mm blue, red, white, yellow, green LEDs

3.1.2. Working principle of LED

The LED diode activates when it is forward biased, much like a regular diode. The p-n junction is formed in this case when the n-type semiconductor is more heavily doped than the p-type. Light or photons are released or radiated in all directions when it is forward biased because the potential barrier is lowered and the electrons and holes combine at the depletion layer (or active layer). Fig. 3.2 below shows light emission due electron-hole pair combining on forward biasing [32].

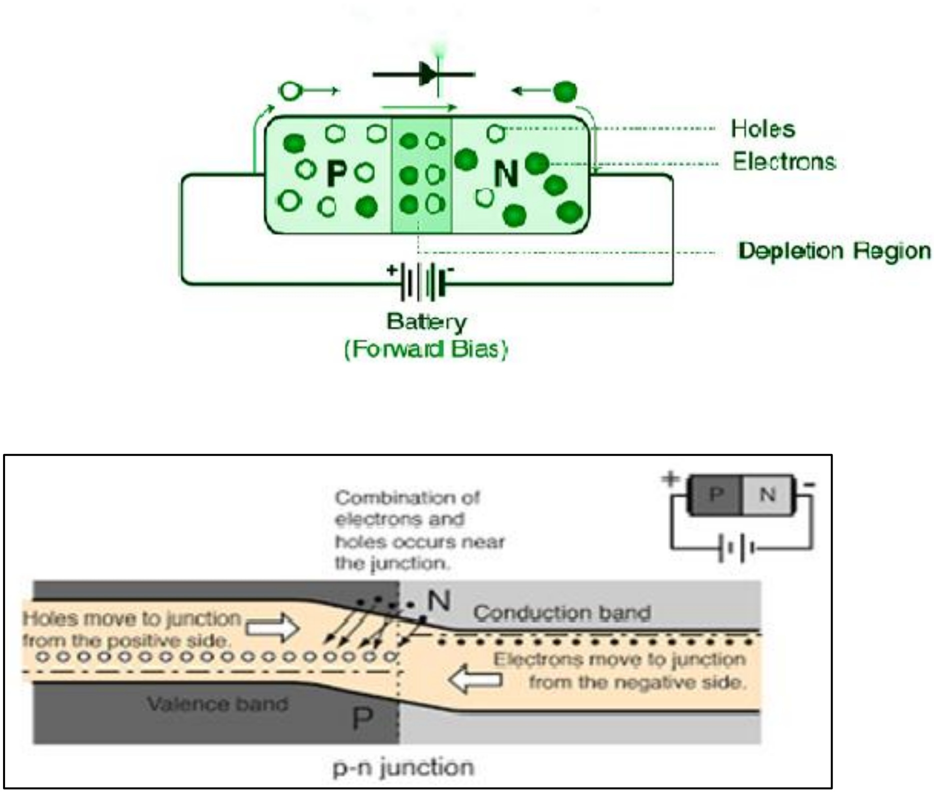

Fig. 3.2: Movement of electrons and holes in forward biased condition

The explanation behind the emission of photons in an LED diode lies in the energy band theory of solids. According to this theory, whether the electron-hole combination will give out photons or not depends on whether the material has a direct band gap or indirect band gap. Those semiconductor materials which have a direct band gap are the ones that emit photons. In a direct bandgap material, the bottom of the energy level of conduction band lies directly above the top most energy level of the valence band on the Energy vs Momentum (wave vector ‘k’) diagram. When electrons and hole recombine, energy $E = h\nu$ corresponding to the energy gap Δ (eV) is escaped in the form of light energy or photons where h is the Planck’s constant and ν is the frequency of light [33]. The entire process is known as electroluminescence.

3.1.3. Different types of LED

3.1.3.1. *Miniature LEDs*

- These are mostly used now these days. These are available in single shape and colour and are available in small sizes. It can be directly placed into a circuit board without the use of a heating or cooling device.
- These are classified into low-current, standard and ultra-high output depending upon various factors such as voltage, total watts, current, and manufacturer type.
- Miniature LEDs are used in small appliances such as remote controls, calculators and cell phones.

3.1.3.2. *High Power LEDs*

- These uses of LED results in high output compared to normal LEDs. The light emitted is measured in terms of lumens. These are again categorised based on luminous intensity, wavelength and voltage.
- These have a danger of overheating hence a heat-absorbing material is used to cool it down.
- High-Power LEDs are used in high-powered lamps, automobile headlights, in various industrial and mechanical equipment.
- High Power STAR LED is comparable in brightness with the standard incandescent and halogen light bulbs. The High Power LED is available in 1-watt, 3-watt and 5-watt models in assorted colours.

3.1.3.3. *Flash LED*

- With a normal LED, it contains an integrated circuit which flashes the light at a particular frequency. These are directly connected to a power supply without the help of series resistors. It is used in signboards, vehicles etc.

3.1.3.4. *Bi and Tri-colour*

- Bi-colour LED lights consist of two light-emitting dies in a single case. The wiring is inversely parallel which means one is in the forward direction and another in backward which makes one die lit at one time. The flow of current alternates between two dies which results in colour variation.
- Tri-Colour LED lights design lets the two dies to lit separately or together producing a third colour.

3.1.3.5. *Red Green Blue LEDs*

- These emit red, green and blue light and also allows to combine these three primary colours and produce a new colour. These are used in accent lighting; lights shows and status indicators.

3.1.3.6. *Alphanumeric LED*

- 14 and 16 segment- they cover full 26 characters of the Roman alphabet in uppercase and with numerals 0-9
- 7 segment- covers all numbers and limited set of letters
- Matrix segment- covers full alphabets (upper and lower), all number and a full variety of symbols.

3.2. LED DRIVER

LED driver changes the power supply to a specific voltage current to drive the LED voltage converter. In general, the input of the LED driver includes the high voltage power frequency AC (i.e., the city electricity), the low voltage DC, the high voltage DC, the low voltage and high-frequency AC (such as the output of the electronic transformer). The output of LED driver power is mostly a constant current source that can change voltage with the change of LED forward voltage drop. The core components of the LED driver include switch controller, inductor, switch component (MOSFET), feedback resistor, input filter device, output filter and so on. According to the requirements of different occasions, there must be input over-voltage protection circuit, input under-voltage protection circuit, LED open circuit protection, over-current protection circuit and so on. The LED driver has been shown in Fig.3.3.

Fig.3.3: LED driver

3.2.1. Characteristics of LED driver

- ***High Efficiency***

  As an energy-saving product, LEDs require good driving power efficiency. The lamp's construction, where the power source is located, is especially crucial. The heat dissipation of LEDs is crucial because the luminous efficiency of LEDs reduces as LED temperature rises. The efficiency of the power supply is high, its power consumption is small, the heat in the lamp is small, which reduces the temperature rise of the lamp. It is good for delaying the light decay of LED [34].

- ***High Power Factor***

  The demand on the electrical grid is measured by power factor. In general, electric appliances under 70 watts are not required to have an index. When people turn on their lights at night, the same type of load is overly concentrated, which will seriously pollute the power system even though the power factor of a single electric device with tiny power is slightly lower. It is said that in the near future, there may be certain index requirements for the power factor of 30 W ~ 40 W LED driving power supply [34].

- ***Driving Mode***

  There are two driving modes: the first one uses a constant voltage source to power several constant current sources, with each constant current source powering a different LED individually. Although the cost will be somewhat greater, the combination is flexible and one LED failure won't affect the performance of the other LEDs. The other is a direct constant current power source that operates LEDs in series or parallel. It has the advantage of low cost, but poor flexibility. It also has to solve the problem of one LED failure, which does not affect the operation of other LEDs. These two forms coexist for a period of time. Multi-channel constant current output power supply mode, in terms of cost and performance will be better [34].
- ***Surge Protection***

  LED anti surge ability is relatively poor, especially anti reverse voltage ability. Additionally, it is critical to improve security in this sector. LED street lights are one type of LED light that is mounted outside. All types of surges will invade from the power grid system due to the start-up and rejection of power grid load as well as the induction of lightning, and certain surges will cause LED damage. As a result, the LED driving power supply should be able to prevent surge invasion and shield the LED from harm [34].
- ***Protection Function***

  To prevent the LED temperature from becoming too high, it is preferable to provide LED temperature negative feedback in the constant current output in addition to the standard safety function [34].

3.2.2. Types of LED driver

- ***Constant Current (CC) LED Driver***

  Constant Current (CC) LED driver provides a constant current (e.g., 50mA, 100mA, 175mA, 350mA, 525mA, 700mA, or 1A), regardless of the voltage load, to an LED module within a specific voltage range. The driver may power a single module with LEDs connected in series or multiple LED modules connected in parallel. Series connection is preferred in CC circuit architectures because it ensures all the LEDs have the same current flowing across their semiconductor junctions and the light output is uniform across the LEDs. Driving multiple LED modules in parallel requires a resistor in each LED module, which leads to lower efficiency and poor current matching. Most CC driver can be programmed to operate over an output current range for precise pairing between the driver and a specific LED module. Constant current LED driver is used when light output should be independent of the input voltage fluctuation. They are found in many types of general lighting products, such as downlights, troffers, table/floor lamps, street lights and high bay lights, for which high current quality and precise output control are the priority. CC driver support both pulse-width modulation (PWM) and constant-current reduction (CCR) dimming. Operating a power supply in a CC mode usually requires overvoltage protection just in case an excessive load resistance is encountered or when the load is disconnected.

- ***Constant Voltage (CV) LED Driver***

  Constant Voltage (CV) LED driver is designed to operate LED modules at a fixed voltage, typically 12V or 24V. Each LED module has its own linear or switching current regulator to limit the current in order to maintain a constant output. It is generally preferred to provide a constant voltage supply to multiple LED modules or fixtures connected in parallel. The maximum number of LEDs or LED modules and the forward voltages across them must not exceed the DC electrical energy power supply. The CV circuit must tolerate the power dissipation when the load goes short circuit. The current limiters typically have thermal shutdown to protect the circuit when a voltage higher than the maximum allowable voltage is placed across the current limiter. CV driver is often used in low voltage LED lighting applications that demand ease of group connection in parallel control, e.g., driving LED strip lights, LED sign modules for light boxes. Constant voltage driver can only be PWM dimmed.

- ***Constant Current Constant Voltage (CC/CV) LED Driver***

  Constant Current or Constant Voltage (CC/CV) is designed to operate LED modules at constant voltage and constant current. Voltage feedback is connected to the output terminal of the driver to supply constant voltage and current feedback is connected in series between the driver and LED module to supply constant current.

3.3. CONTROLLER

The main components of the controller module are an 8-bit microcontroller, a selection unit, and an LCD display. A microcontroller is an integrated circuit (IC) device that controls other components of an electronic system, often through a memory, peripherals, and a microprocessor unit (MPU). These gadgets are designed for embedded applications that need both processing power and quick, accurate communication with electromechanical, Digital, or Analog components. The most common way to refer to this category of integrated circuits is “microcontroller” but the abbreviation “MCU” is used interchangeably as it stands for “microcontroller unit”. “Microcontroller” is a well-chosen name because it emphasizes defining characteristics of this product category. The prefix “micro” implies smallness and the term “controller” here implies an enhanced ability to perform control functions. As stated above, this functionality is the result of combining a digital processor and digital memory with additional hardware that is specifically designed to help the microcontroller interact with other components.

In this thesis work, Atmega328P microcontroller is used which is a low power, CMOS, 8-bit microcontroller based on the AVR enhanced RISC architecture. It processes the digitally converted Analog voltage and illuminance inputs to compute the individual duty cycles and generates PWM signals for LED light sources at 4 kHz operating frequency. A POT as an input of microcontroller to change the set illuminance of LED sources. There are three push buttons use as input to change the rotation of motor as well as blinds mode also changes as per requirement basis. LCD display is connected to the output of the microcontroller.

3.4. SWITCHING MOSFET

The most common type of insulated gate FET which is used in many different types of electronic circuits is called the Metal Oxide Semiconductor Field Effect Transistor or MOSFET for short. The IGFET or MOSFET is a voltage-controlled field effect transistor that differs from a JFET in that it has a “Metal Oxide” Gate electrode which is electrically insulated from the main semiconductor n-channel or p-channel by a very thin layer of insulating material usually silicon dioxide, commonly known as glass. This ultra-thin insulated metal gate electrode can be thought of as one plate of a capacitor. The isolation of the controlling Gate makes the input resistance of the MOSFET extremely high way up in the Mega-ohms (MΩ) region thereby making it almost infinite. As the Gate terminal is electrically isolated from the main current carrying channel between the drain and source, “NO current flows into the gate” and just like the JFET, the MOSFET also acts like a voltage-controlled resistor where the current flowing through the main channel between the Drain and Source is proportional to the input voltage. Also, like the JFET, the MOSFETs very high input resistance can easily accumulate large amounts of static charge resulting in the MOSFET becoming easily damaged unless carefully handled or protected. MOSFETs are three terminal devices with a Gate, Drain and Source and both P-channel (PMOS) and N-channel (NMOS) MOSFETs are available. The main difference this time is that MOSFETs are available in two basic forms:

Enhancement Type

The transistor requires a Gate-Source voltage, (V_{GS}) to switch the device “ON”. The enhancement mode MOSFET is equivalent to a “Normally Open” switch.

Depletion Type

The transistor requires the Gate-Source voltage, (V_{GS}) to switch the device “OFF”. The depletion mode MOSFET is equivalent to a “Normally Closed” switch.

The symbols and basic construction for both configurations of MOSFETs are shown in Fig. 3.4 [35]

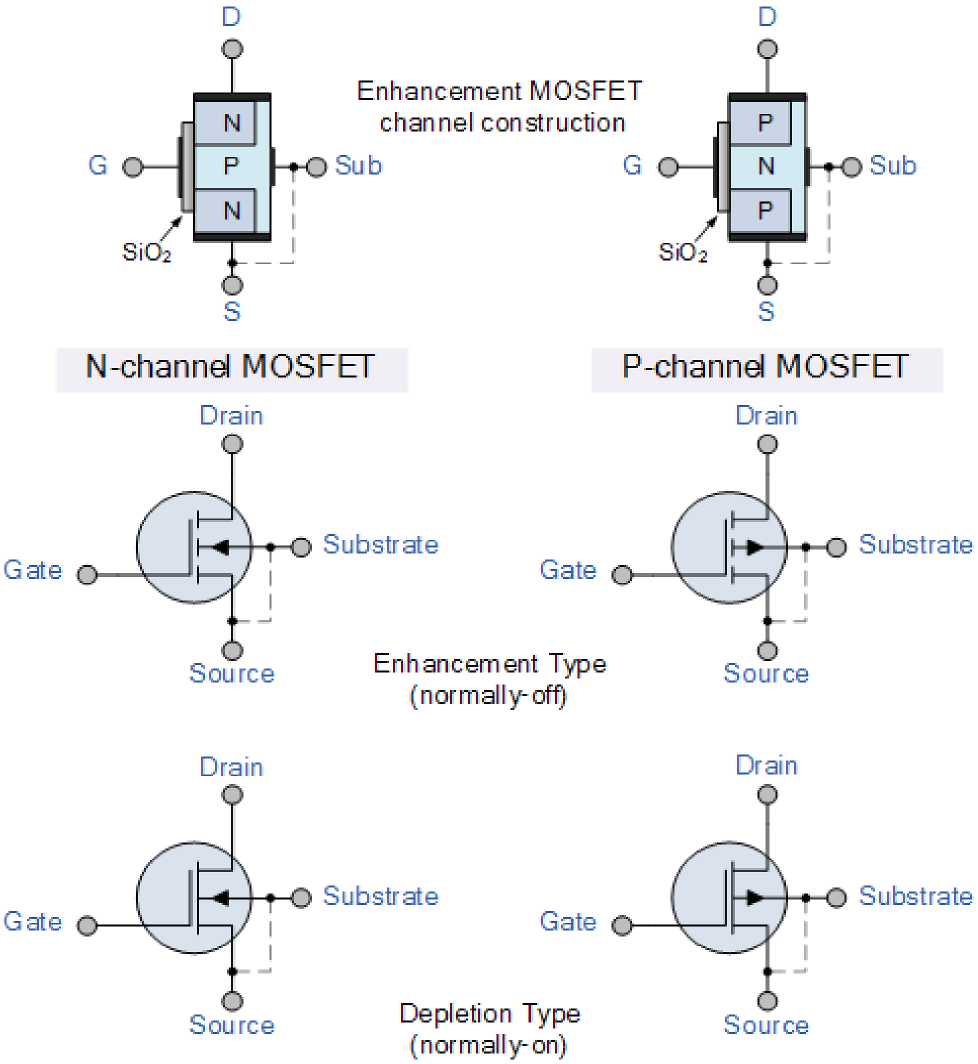

Fig. 3.4: Symbols and basic construction diagrams for switching MOSFETs

The MOSFET symbols above show an additional terminal called the Substrate and are not normally used as either an input or an output connection but instead it is used for grounding the substrate. It connects to the main semiconductive channel through a diode junction to the body or metal tab of the MOSFET. Usually in discrete type MOSFETs, this substrate lead is connected internally to the source terminal. When this is the case, as in enhancement types it is omitted from the symbol for clarification.

MOSFET Characteristics Curves

The curve between Drain-Source voltage (V_{DS}) and drain current (I_D) is shown in Fig. 3.5 [36].

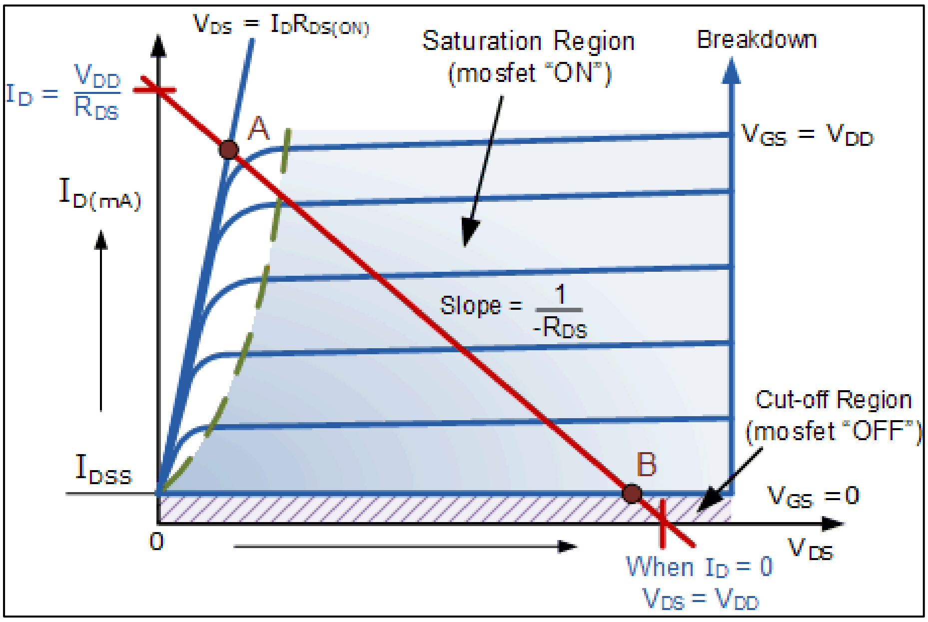

Fig. 3.5: MOSFET Characteristic Curve

The minimum ON-state gate voltage required to ensure that the MOSFET remains "ON" when carrying the selected drain current can be determined from the V-I transfer curves above. When V_{IN} is HIGH or equal to V_{DD}, the MOSFET Q-point moves to point A along the load line. The drain current I_D, increases to its maximum value due to a reduction in the channel resistance. I_D becomes a constant value independent of V_{DD}, and is dependent only on V_{GS}. Therefore, the transistor behaves like a closed switch but the channel ON-resistance does not reduce fully to zero due to its R_{DS} (on) value, but gets very small.

Likewise, when V_{IN} is LOW or reduced to zero, the MOSFET Q-point moves from point A to point B along the load line. The channel resistance is very high so the transistor acts like an open circuit and no current flows through the channel. So, if the gate voltage of the MOSFET toggles between two values, HIGH and LOW the MOSFET will behave as a "single-pole single-throw" (SPST) solid state switch and this action is defined as:

Cut-off region

Here the operating conditions of the transistor are zero input gate voltage (V_{IN}), zero drain current I_D and output voltage $V_{DS} = V_{DD}$. Therefore, for an enhancement type MOSFET the conductive channel is closed and the device is switched "OFF". Then we can define the cut-off region or "OFF mode" when using an e-MOSFET as a switch as being, gate voltage, $V_{GS} < V_{TH}$ thus $I_D = 0$. For a P-channel enhancement MOSFET, the Gate potential must be more positive with respect to the Source.

Saturation region

In the saturation or linear region, the transistor will be biased so that the maximum amount of gate voltage is applied to the device which results in the channel resistance R_{DS} on being as small as possible with maximum drain current flowing through the MOSFET switch. Therefore, for the enhancement type MOSFET the conductive channel is open and the device is switched "ON". Then we can define the saturation region or "ON mode" when using an e-MOSFET as a switch as gate-source voltage, $V_{GS} > V_{TH}$ thus I_D = Maximum. For a P-channel enhancement MOSFET, the Gate potential must be more negative with respect to the Source.

3.5. MOSFET DRIVER

In most applications, a system is in need of a switch to be able to work correctly. Since there are no ideal switches, most of the time, the component chosen for this task is a MOSFET. A MOSFET usually needs a gate driver to do the on/off operation at the desired frequency. For high frequencies, MOSFETs require a gate drive circuit to translate the on/off signals from an Analog or Digital controller into the power signals necessary to control the MOSFET. A MOSFET driver IC translates TTL or CMOS logical signals, to a higher voltage and higher current, with the goal of rapidly and completely switching the gate of a MOSFET. An output pin of a microcontroller is usually adequate to drive a small-signal logic level MOSFET. However, driving larger MOSFETs is a different story. Large MOSFETs have higher gate capacitance. Digital signals are meant to drive small loads (on the order of 10-100pF). This is much less than the many MOSFETs, which can be in the thousands of pF. Also, these MOSFETs have a higher gate voltage. A 3.3V or 5V signal, which is the maximum of a pulse modulated signal delivered by a microcontroller, is often not enough for the MOSFET. Usually 8-12V is required to fully turn on the MOSFET. There is also a third issue: a switching MOSFET can cause a back-current from the gate back to the driving circuit. MOSFET drivers are designed to handle this back current [37]. When choosing a gate driver, its output voltage capability has to be matched the turn on voltage of the MOSFET. In conclusion, a switch in power conversion circuit has to be composed of a MOSFET and a gate driver. The MOSFET has to be chosen such that it can operate in the circuit and the losses are minimal. A gate driver has to be used to rapidly and completely switch the gate of the MOSFET. A heat sink should be if the temperature in the system exceeds the maximum junction temperature specified by the manufacturer.

Chapter 4

IMPLEMENTATION OF THE PROPOSED SYSTEM

A closed loop indoor lighting system has been developed to control the illuminance on the working plane using motor controlling blinds, LED luminaire and Photo sensor. According to the requirement, users can set the required illuminance on the working plane from 0 lx to 300 lx. Both Software and Hardware components have been used to implement the system, this chapter has provided details on both.

4.1. BLOCK DIAGRAM OF THE PROPOSED SYSTEM

The block diagram of the proposed system is shown in Fig. 4.1 which consists of LED driver, LED luminaire, Photodetector as light sensor, DC power supply unit, Servo motor, Vertical blinds, Illuminance selector unit and a microcontroller unit etc. The Photodetector detects the ambient light and produces current which is converted to amplified voltage using the amplifier. The amplified voltage is fed to ADC pin of the microcontroller. Microcontroller unit generates PWM control signal. The amplitude of this control signal is 5 V, which needs to be converted to 12 V signal for driving the switching MOSFET. For that, MOSFET driver is used. The converted 12 V signal is fed to the gate of switching MOSFET. The cathodes of the LEDs are connected to the drain of the MOSFET. When the gate voltage of the MOSFET is high, the MOSFET will conduct and the LED will glow. When the gate signal is in low state, MOSFET will not conduct, and the LED will remain off. The average illuminance of individual LEDs is controlled by the controlling of current flow through it and the current of the LEDs are being controlled by the duty cycle of the PWM signal generated by the microcontroller. The frequency of the PWM signal is kept at 4.0 kHz. So, the LEDs are turned on and off at 4.0 kHz frequency, which cannot be detected by bare human eye. An interior light sensor measures the combination of daylight and artificial light. The sensor output is compared with a reference set illuminance. The electric lights are adjusted accordingly to maintain the illuminance at the working plane within a predefined range. In this block diagram, the microcontroller has been controlled the Servo motor rotation and brightness of the LEDs. The motor is coupled with the blinds. The output of the amplified signal has been controlled by the microcontroller and also it is the feedback path of the system.

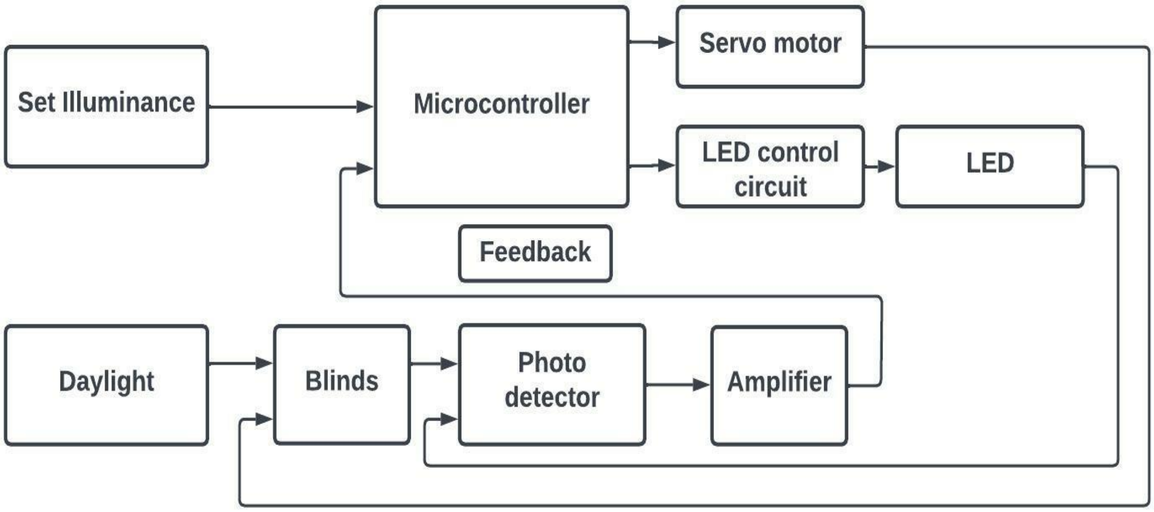

Fig.4.1: Block diagram of the proposed system

4.1.1 Description of Microcontroller unit

The controller has been implemented using ATmega328P microcontroller. The experimental results are displayed on real time basis on 20x4 LCD Display, connected to the microcontroller.

Every Arduino Uno board's core component, the ATmega328P, functions as an 8-bit microcontroller that interacts with and controls sensors, motors, LEDs and other electrical devices. The ATmega328P shown here is a dual in-line package microchip that can be placed on a breadboard, making it ideal for projects that require enclosure, or prototypes moving beyond the development board phase. Microchip Studio can also import Arduino sketches as C++ projects to provide you with a simple transition path from maker space to marketplace. Microchip Studio can be used with the debuggers, programmers and development kits.

The ATmega328P has a very low inherent power consumption, high performance CMOS 8-bit microcontroller. By executing powerful instructions in a single clock cycle, the ATmega32 achieves throughputs approaching 1 MIPS per MHz allowing the system designer to optimize power consumption versus processing speed [38]. The device has a 28 pin and there have 6 digital PWM channels and 6 pins are Analog input channel, 0-16 MHz frequency. It contains two 8-bit timers/counters with separate pre-scalers and compare modes and one 16-bit timer/counter with separate pre-scaler, compare mode and capture mode.

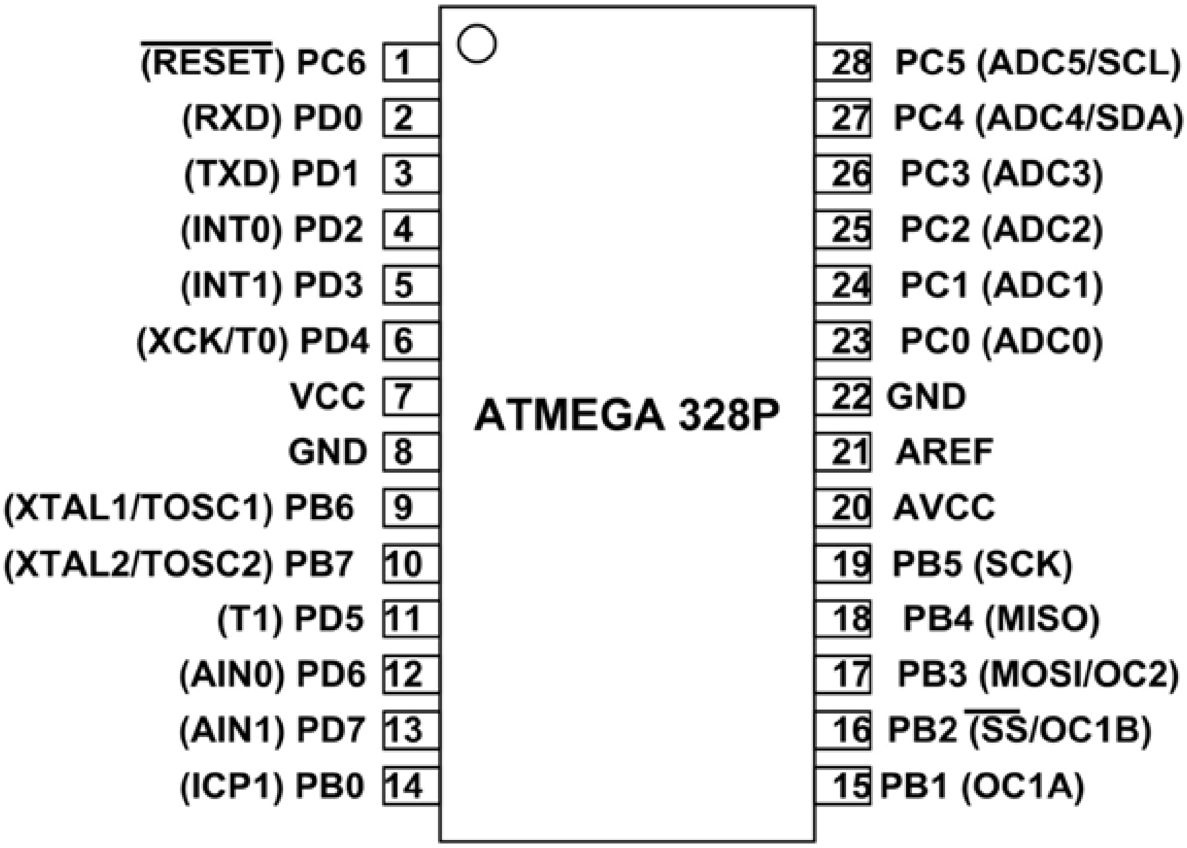

Fig 4.2: Pin configuration of 8-bit CMOS ATmega328P Microcontroller

The Fast PWM Mode uses single slope operation which allows it to generate high frequency waveform, almost twice than that of Phase correct PWM mode which uses dual slope operation [38]. This high frequency makes the PWM mode well suited for power regulation, rectification, and DAC applications. High frequency allows physically small sized external components (coils, capacitors), and therefore reduces total system cost.

4.1.1.1 Pin Description

1. PC6 (RESET): Pin by default is used as RESET pin. PC6 can only be used as I/O pin when RSTDISBL Fuse is programmed.
2. PD0 (RXD): USART serial communication interface. Data input pin for USART is RXD.
3. PD1 (TXD): It is also USART serial communication interface and the Data output for USART is TXD. The two-input external interrupt pin is INT2.
4. PD2 (INT0): External Interrupt source 0.

5. PD3 (INT1/OC2B): External Interrupt source 1. OC2B is a PWM – Timer/Counter2 output compare with match B output.
6. PD4 (XCK/T0): XCK is USART external clock I/O. T0 is defined as Timer0 external counter input.
7. VCC: Connected to positive voltage.
8. GND: Connected to ground.
9. PB6 (XTAL1/TOSC1): XTAL1 is chip clock oscillator i.e., pin 1 or external clock input. Timer oscillator pin 1 is called TOSC1.
10. PB7 (XTAL2/TOSC2): XTAL2 is chip clock oscillator i.e., pin 2. Timer oscillator pin 2 is called TOSC2.
11. PD5 (T1/OC0B): T1 is an external counter input. OC0B is a PWM – Timer/Counter0 output compare with match B output.
12. PD6 (AIN0/OC0A): AIN0, Analog comparator positive input. OC0A is a PWM – Timer/Counter0 output compare with match A output.
13. PD7 (AIN1): AIN1, Analog comparator negative input.
14. PB0 (ICP1/CLKO): ICP1 is a Timer/Counter1 input capture pin. CLKO is a divided system clock and it can be output on the PB0 pin.
15. PB1 (OC1A): OC1A is a Timer/Counter1 output compare with match A output.
16. PB2 (SS/OC1B): SS is a serial peripheral interface slave select input. This pin is low when controller acts as slave. OC1B is a Timer/Counter1 output compare with match B output.
17. PB3 (MOSI/OC2A): When controller acts as slave, the data is received by this pin3 of PORTB. OC2A is a Timer/Counter2 output compare with match A output.
18. PB4 (MISO): When controller acts as slave, the data is sent to master by this controller through this pin.
19. PB5 (SCK): It is a SPI bus serial clock. This is the clock shared between this controller and other system for accurate data transfer.
20. AVCC: Power for internal ADC converter.
21. AREF: Analog reference pin for ADC.
22. GND: Connected to the ground.
23. PC0 (ADC0): Analog input digital value channel 0
24. PC1 (ADC1): Analog input digital value channel 1
25. PC2 (ADC2): Analog input digital value channel 2

26. PC3 (ADC3): Analog input digital value channel 3
27. PC4 (ADC4): Analog input digital value channel 4. This pin can also be used as serial interface connection for data.
28. PC5 (ADC5): Analog input digital value channel 5. This pin also used as serial interface clock line.

4.1.1.2 Pin description of this proposed system

In this thesis work, the ADC pins PC0 (ADC0) and PC1 (ADC1) have been used for the Set Illuminance and Measured Illuminance.

The 8-bit microcontroller pins PD3 (OC2B), PD5 (OC0B), PD6 (OC0A), PB1 (OC1A), PB2 (SS/OC1B) and PB3 (MOSI/OC2A) are to generate suitable duty cycles of operating frequency 4.0 kHz. Out of this pin, only PD3 (OC2B) and PB1 (OC1A) pin i.e., pin5 and pin15 have been used for LED and motor control unit.

The data pins of the 16-pin 20x4 LCD display are connected to PORT C of the microcontroller whereas the control pins are connected to PORT D. The LCD display pins connected to the microcontroller are pin1, pin4, pin6, pin7, pin8, pin9, pin10, pin11, pin12, pin13 and pin14 respectively. The pin description of the LCD has been discussed below.

<u>Pin connection of LCD with the microcontroller</u>

1. VSS (Ground): Connected with pin8 of the microcontroller.
2. VCC (+5V): Connected with pin7 of the microcontroller though a resistance.
3. VEE (Contrast control): Connected with pin8 through a variable resistance of the microcontroller.
4. RS (Register select): Connected with pin14 of the microcontroller.
5. RW (Read/Write): Connected with pin8 of the microcontroller.
6. E (Enable): Connected with pin13 of the microcontroller.
7. D0 (Data pin 0): Not used
8. D1 (Data pin 1): Not used
9. D2 (Data pin 2): Not used
10. D3 (Data pin 3): Not used
11. D4 (Data pin 4): Connected with pin12 of the microcontroller.
12. D5 (Data pin 5): Connected with pin11 of the microcontroller.
13. D6 (Data pin 6): Connected with pin6 of the microcontroller.

14. D7 (Data pin 7): Connected with pin4 of the microcontroller.
15. LED+ (+5V): Connected with pin7 of the microcontroller through a resistance.
16. LED- (Ground): Connected with pin8 of the microcontroller

4.1.2 Selection of Motor

It is common practice to choose motors based on the mechanical power calculations, or the required speed and torque. Brushed motors run without electronic commutation, the control electronics can be made simpler and cost effective. There are several types of motor that can be used in this system i.e., servo motor, stepper motor, TT gear motor etc.

Stepper motor is not used because of low torque and less efficiency. Controlling a stepper motor requires a driver with two H-bridges that can be controlled independently to alternate the direction of the current through each of the conductors. The H-bridges needs to be controlled timely. TT gear motor has a high speed but torque is very low and needed a driver. So, servo motor is best for this system.

In motion controlled dynamic servo applications mostly brushless motors will be selected exhibiting a very high service life and reliability as well as allowing higher speeds. Servo motor has three wires coming out of them. Out of which two will be used for Supply (positive and negative) and one will be used for the signal that is connected to PB1 i.e., pin15 of the microcontroller unit. Servo motor works on PWM (Pulse Width Modulation) principle, means its angle of rotation is controlled by the duration of applied pulse to its control pin. Basically, servo motor is made up of DC motor which is controlled by a variable resistor (potentiometer) and some gears. High speed force of DC motor is converted into torque by Gears.

Fig. 4.3: MG995 servo motor

An MG995 metal gear servo motor has been used in this system i.e., high torque and more efficiency. It can be operated with both AC and DC power supplies. The driver circuit is not required to control the rotation of the motor. The MG995 servo motor has lower current consumption, around 100-200mA. This motor gear is coupled with the tilt rod of the blinds. The position of the blinds has changed with the changing of motor rotation. For manual and automatic operation, it can work properly. The schematic diagram of the servo motor with blinds has shown in Fig. 4.4.

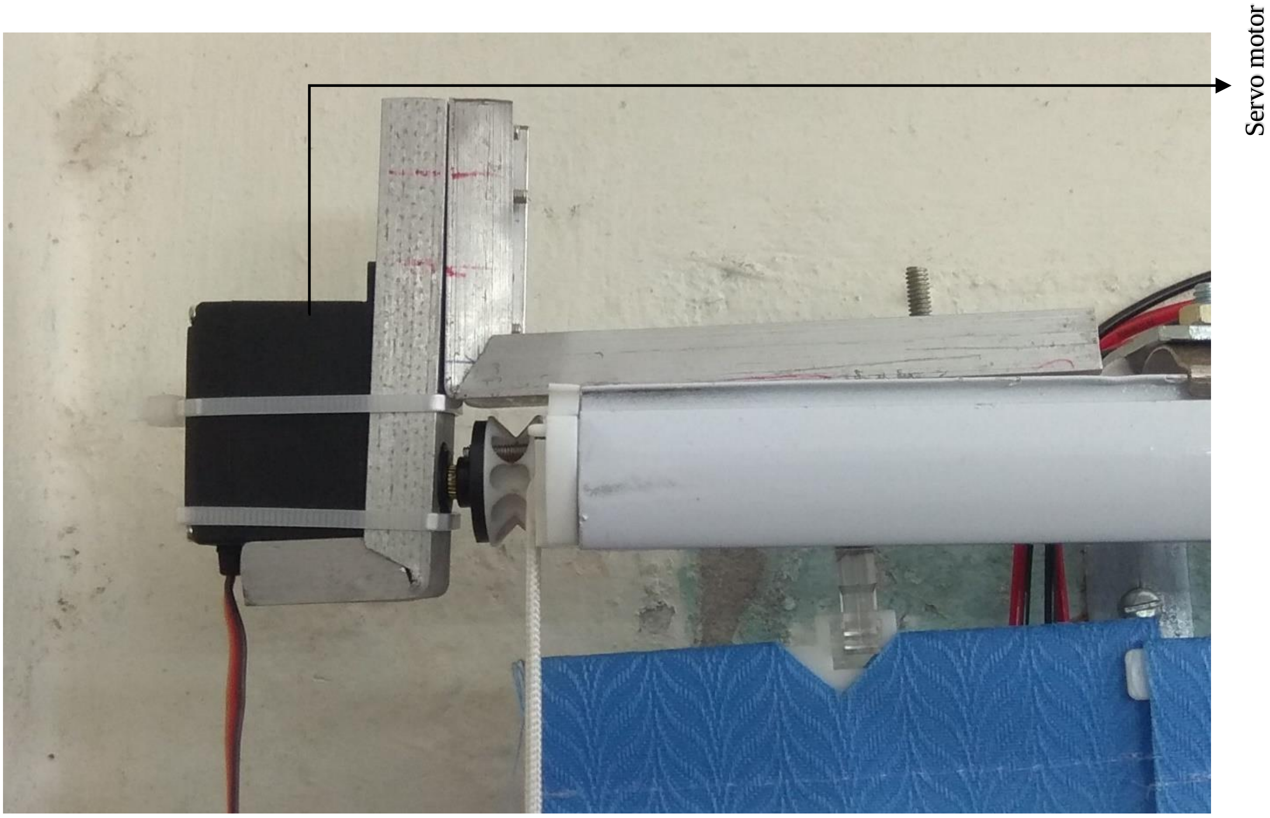

Fig. 4.4: Connected Servo motor with blinds

4.1.3 Description of LEDs used in this system

The lighting system has a luminaire which is located at the mounting height of 2.57m. To save the electrical energy, it can be dimmed by control circuit. To implement this system, the brightness of the LEDs can be controlled by 8-bit microcontroller. A 40 V DC power is sufficient to drive the LED driver circuit. The forward voltage drop across the LEDs is 36 V. There are 72 numbers of LED used in the proposed system. The luminaire and the arrangement of the LEDs is shown in the Fig.4.5 (a) and Fig.4.5 (b).

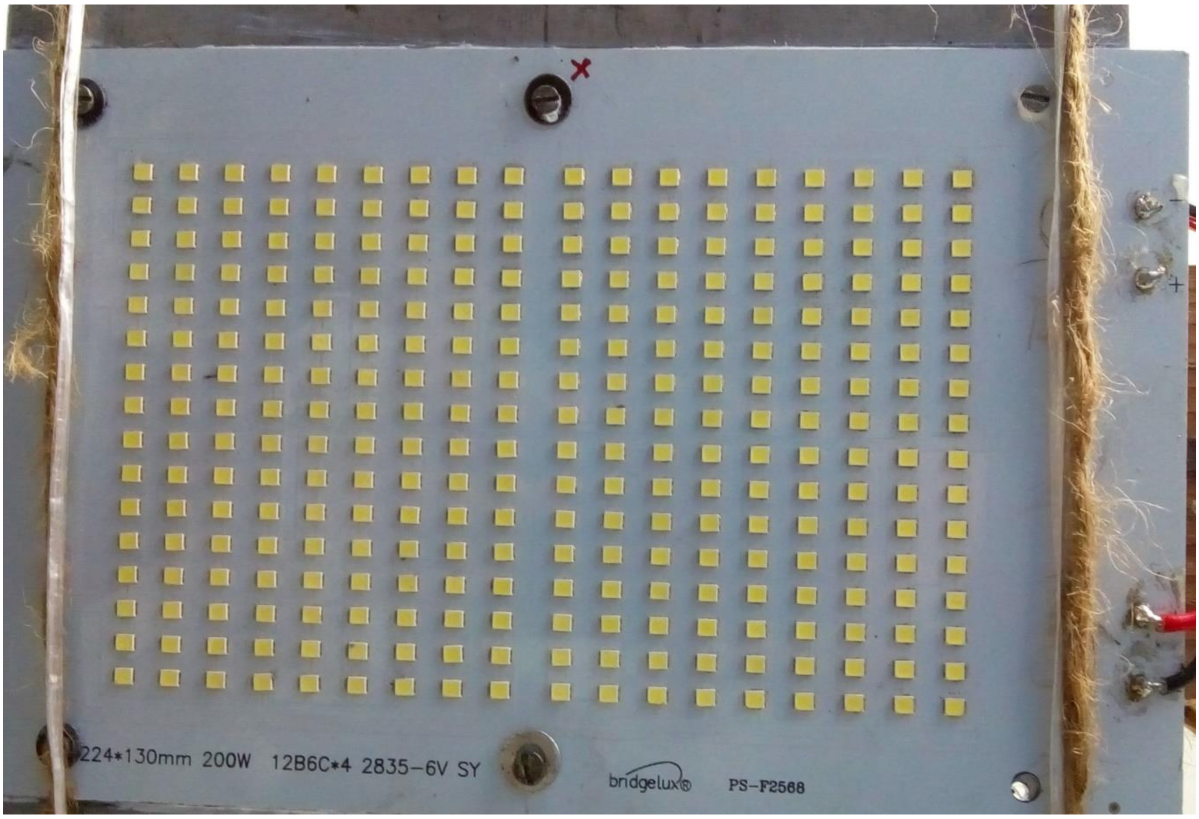

Fig.4.5 (a): The LED luminaire used in this system

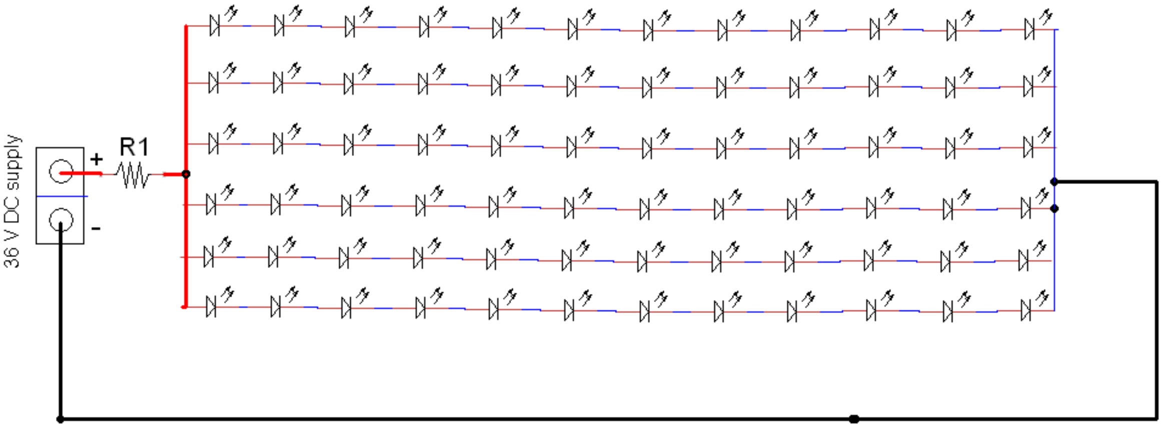

Fig.4.5 (b): The arrangement of LEDs

The 12 number of LEDs are connected in series combination and 6 parallel chains are connected with the power source. The current flowing of each section of LEDs is 100 mA.

The obtained maximum average illuminance of LED source is 376 lx and Correlated Colour Temperature (CCT) is 6000 K. The luminaire is located at 1.77m from the working plane and the working plane height is 0.8m from the ground. Output pin of LED is connected to the digital pin 5 with the microcontroller. The dimming of LED is controlled by PWM technique. The intensity of LED is controlled by changing the duty cycle of the PWM signal. When the duty cycle of the signal decreases from 100% to 0% the current value also decreases from 700 mA to 0 mA.

4.1.4 Description of Sensor

A sensor is a device that detects and responds to some type of input from the physical environment. The specific inputs can be light, heat, motion, moisture, pressure etc. A sensor as an input device which provides the output of the microcontroller. There are several classifications of sensor. In the first classification of the sensor, they are divided in to Active and Passive. Active sensors are those which require an external excitation signal or a power signal. For Passive sensor, do not require any external power signal and directly generates output response. The other type of classification is based on detection used in sensor. The detections are Electric, Chemical, Radioactive etc. The next classification is based on conversion i.e., the input and the output. The final classification of the sensors are Analog and Digital sensors.

4.1.4.1 Different types of sensors

There are several types sensors.

- Temperature sensor
- IR sensor
- Light sensor
- Proximity sensor
- Ultrasonic sensor

Temperature sensor, senses the temperature i.e., it measures the changes the temperature. It is not used for this thesis. IR sensor or Infrared sensor are light based sensor that are used in various applications like proximity and object detection.

4.1.4.2 Selection of light sensor

Light Dependent Resistor (LDR) is that its resistance is inversely proportional of the ambient light. A Light Dependent Resistor changes its electrical resistance from a high value of several thousand Ohms in the dark to only a few hundreds of Ohms when light is incident on it by creating electron – hole pairs in the material. Cadmium Sulphide (CdS) is used in Photo resistors that are sensitive to near infrared and visible light. Cadmium Sulphide is deposited as a thread pattern on an insulator in the shape of a zigzag line as shown in Fig. 4.6.

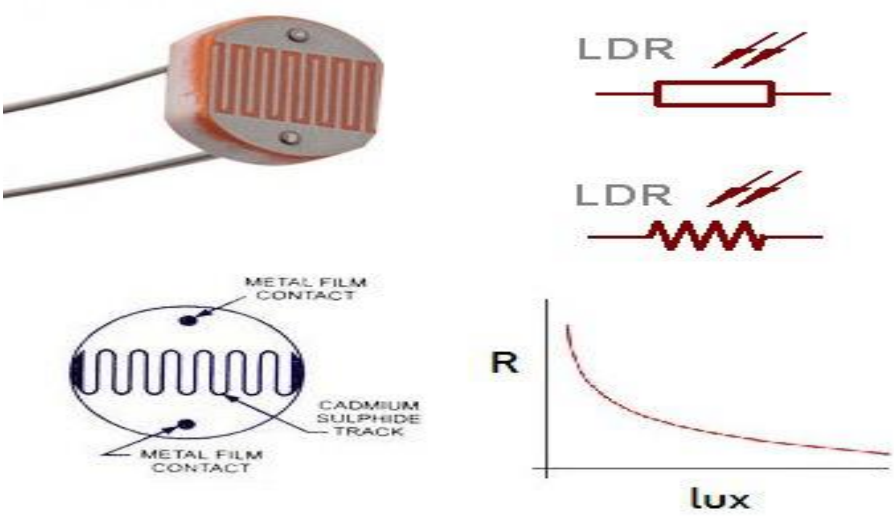

Fig. 4.6: Light Dependent Resistor (LDR)

The graph between Illuminance (lx) and Resistance (R in ohm) is not linear. For this non-linearity the system become unstable. So LDR is not suitable for detection of light in this experiment.

There are two types of light sensor. They are Photodiode and Phototransistor. When light is incident on a Photodiode, the electrons and holes are separated and will allow the junction to conduct. When a photo diode is used as a light sensor, for Germanium type diodes, the dark current is around 10 µA and for Silicon type diodes, it is 1 µA [39]. The diagram of Photo diode and Photo transistor is shown in Fig. 4.7.

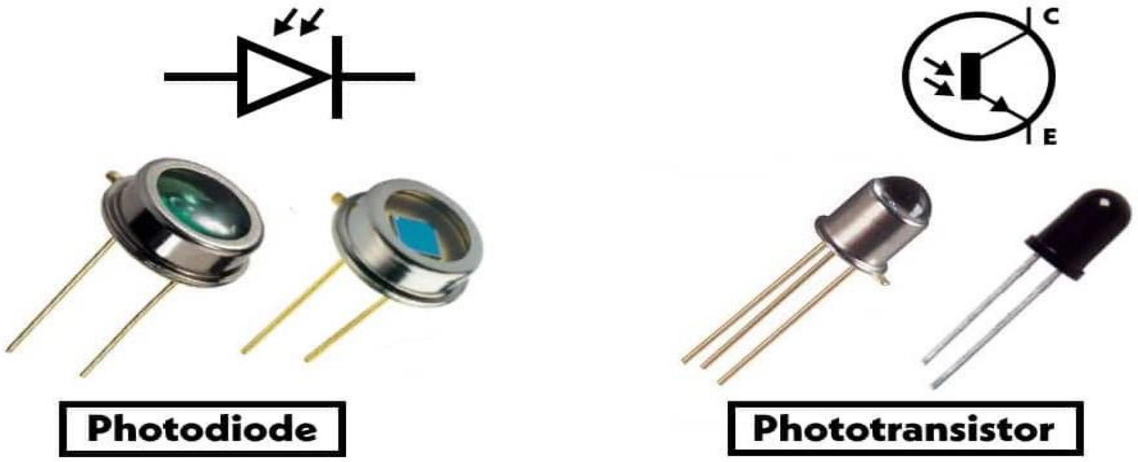

Fig. 4.7: Symbol of Photo diode and Photo transistor

A Phototransistor is basically a combination of a photo diode and an amplification transistor. Phototransistors are basically NPN transistors with their large base terminal electrically isolated or unconnected. To control the sensitivity, some phototransistors allow base connection. If a base connection is used, a base current is generated when the photons hit the surface, and causes a collector to emitter current to flow. The sensitivity of a phototransistor is dependent on the DC current gain of the transistor. Hence, the overall sensitivity, which is a function of collector current, can be controlled by the resistance between emitter and base.

4.1.4.3 Description of phototransistor circuit

To achieve more accurate linearity using a phototransistor. The luminaire height from the working plane is 1.77m at the window side, the phototransistor is placed at the same height as the luminaire. To block direct the ambient light, a black cylindrical baffle is implemented. A +12V supply is connected across Phototransistor. Phototransistor detects the reflected light at the workspace. The range of the Analog value of the Phototransistor is a very small voltage signal in millivolt (mV). As an alternative, the sensor's signal can be converted to a Volt output, in the range of 0-5 volts. The Output of the amplifier is connected to the microcontroller. The schematic diagram of the Photo Detector has shown in Fig.4.8(a) and Fig.4.8(b). The Analog value is converted into a Digital value by the microcontroller.

Fig.4.8(a): A black cylindrical baffle

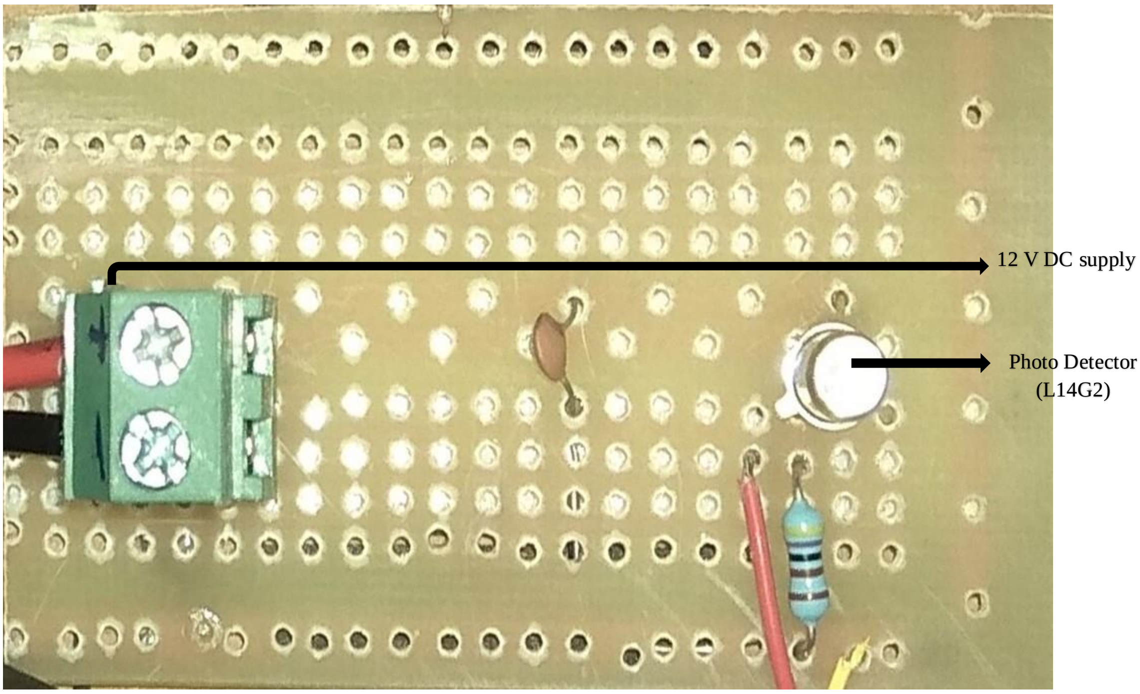

Fig. 4.8(b): The connection circuit diagram of Photo Detector

The values of capacitor C and resistance R is 0.1 μF and 5.6 kΩ. The connection circuit diagram is shown in Fig.4.9.

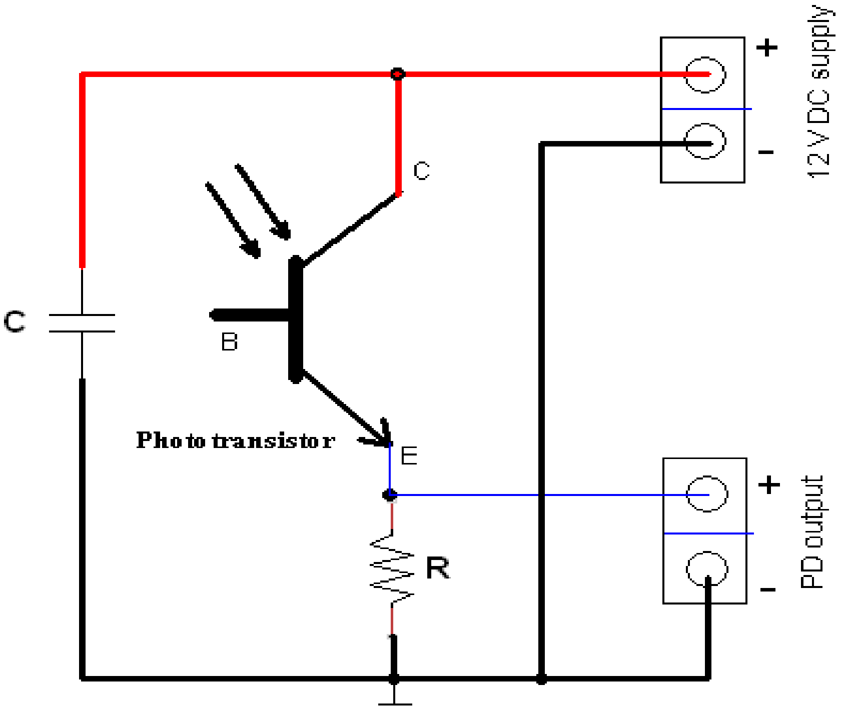

Fig. 4.9: The connection diagram of Photo Detector

4.1.5 Window Blinds

The lighting system, which is often operated by manually and automatically, will be affected by blind use in buildings. Closing blinds may improve comfort, but excluding daylight, may also increase electric light use. Therefore, to better model energy consumption, the potential impact of the manual and automatic blind operation on lighting should be considered [39]. For smart indoor lighting systems, generally two types of blinds are used.

1.Vertical blinds and,

2.Venetian blinds

The blinds have used in this system which is known as Vertical blinds. It has controlled by a motor. Two modes have been operated i.e., Closing the blinds and opening the blinds. For manual mode, the position of the blinds can be shift by the use of switches. For automatic mode, it can be control by the microcontroller. Vertical and venetian blinds have been shown in Fig.4.9(a). The condition of blinds closing and opening have shown in Fig.4.9(b) and Fig.4.9(c).

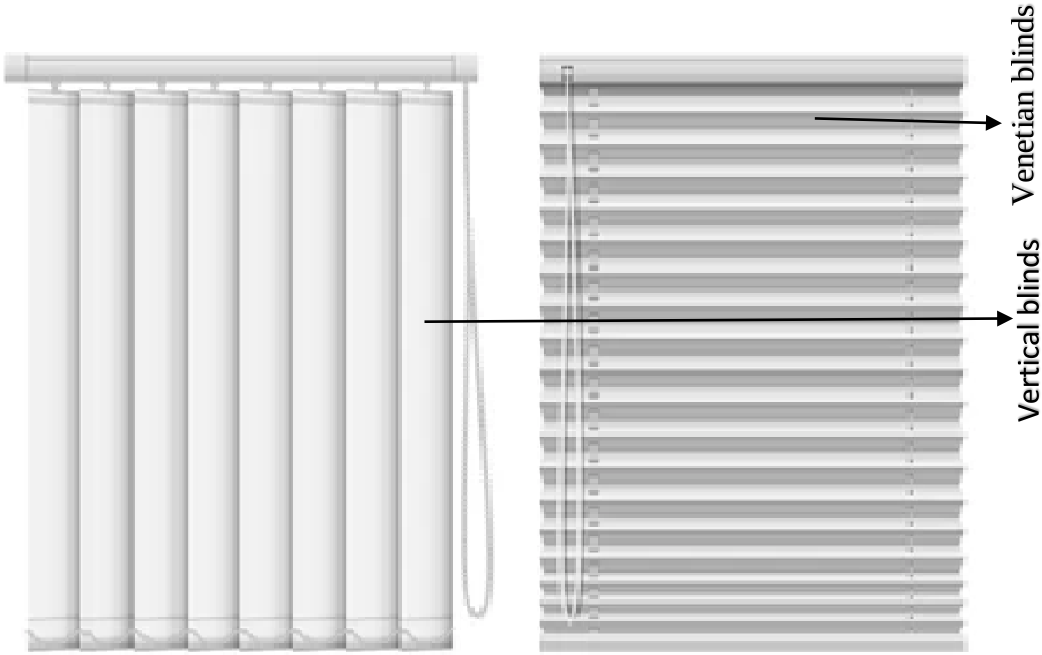

Fig.4.9(a): The image of vertical and venetian blinds

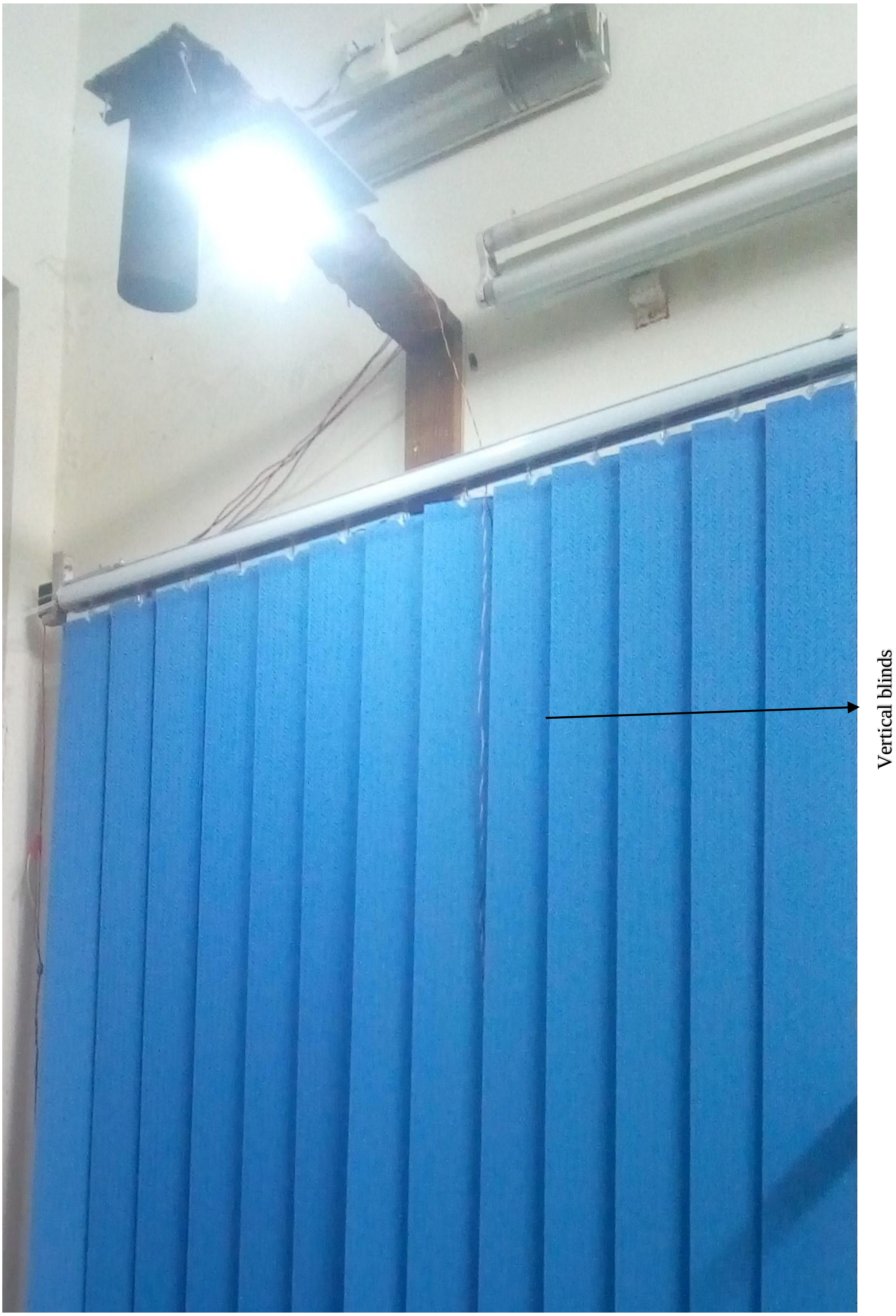

Fig. 4.9 (b): Blinds at closing condition

Fig.4.9 (c): Blinds at opening condition

4.2 SOFTWARE IMPLEMENTATION OF THE PROPOSED SYSTEM

The proposed system has been explained by an algorithm. This can be implemented step by step. The following steps are discussing below.

4.2.1 Step by step analysis of Algorithm of the proposed system

Step1: Initialize the Analog and Digital pins of microcontroller ATmega328P.

Step2: Enable the microcontroller pins i.e., LCD display pin, motor rotation control pin, LEDs pin, Photo detector pin and Set illuminance pin.

Step3: Set the illuminance (Es) between 0 lx to 300 lx by the use of potentiometer (10k).

Step4: Photo Detector (PD) detects the light level at that condition and the amplified signal is converted into Digital value using ADC.

Step5: Convert the PD digital value into illuminance value by the equation which is used as Measured Illuminance (Em).

Step6: Compare between Set Illuminance (Es) and Measured Illuminance (Em). This is denoted by absolute error (Er).

Step7: When Er > 0, the blinds is opening. If the desired illuminance is achieved, the lights as OFF condition. When the blinds are completely open and error is still greater than zero, then the duty of the PWM signal for LED will be increased and contribute the illuminance until the required illuminance is achieved.

Step8: When Er < 0, the blinds is closing. When the blinds are completely close and error is still less than zero, then the duty of the PWM signal for LED will be decreased. This process will be stop if the required illuminance is achieved.

Step9: when the Error is zero, no change in PWM and blinds condition.

The detailed flowchart of the software implementation of the controller is given in Fig.4.10. The system is first turned on with supply of 12 V DC power supply which initializes the ports and ADC of microcontroller as well as the LCD is turned on. The LCD is interfaced with the microcontroller and programmed to display the percentage of the duty cycle of LEDs. The percentage of the duty cycle has been converted into 8-bit digital value. The Set Illuminance values have been given from the graph between PD digital and measured illuminance (CL-70F). The illuminance value is set by the user by varying the potentiometer as per his requirement which is displayed on the LCD. Then PD reads the illuminance value on the working plane. The PD output signal has been modified by the use of amplifier circuit. The amplified PD Analog signal is converted into 8-bit Digital value. The Measured Illuminance has been considered with proper scaling. The error has been occurred between them. When the error less than zero and if the blinds are closed, the duty of the PWM signal is reduced by 1%. If the blinds are not closed then close the blinds by step wise. When the error is greater than zero and if the blinds are fully opened, the duty of the PWM signal is increased by 1%. Again, the condition is not maintained then opened the blinds by step wise. If the error is equal to zero then the duty has not been changed of the PWM signal. Again, the error is greater than zero then no change of PWM and no change of the blinds position. If the condition is not fulfilled then the process will be continued.

Fig.4.10: Flowchart of the software implementation of the program

4.3 HARDWARE IMPLEMENTATION OF THE PROPOSED SYSTEM

The main hardware components of the proposed system are power supply for microcontroller unit, Photo Detector, Servo motor, Liquid Crystal Display, amplifier circuit, controller circuit, and motor rotation controlling circuit. The block diagram of the closed loop system has been shown in Fig.4.10.

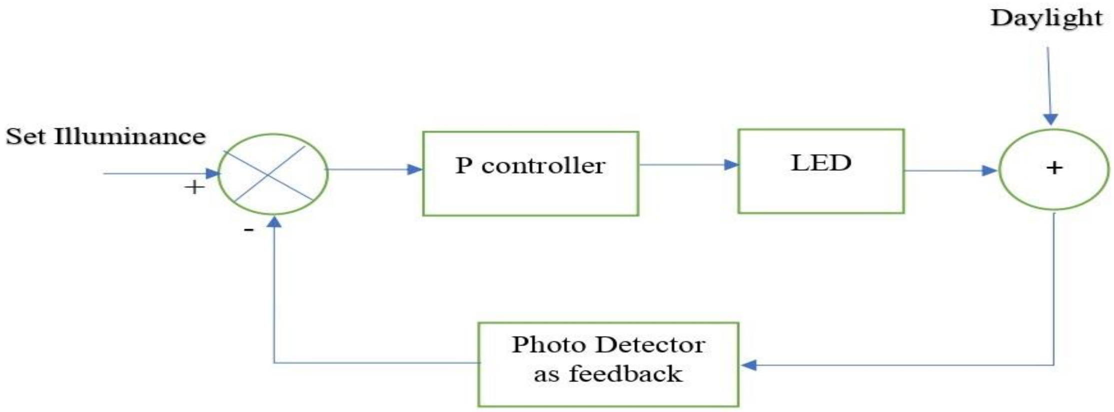

Fig.4.11: The block diagram of the system

4.3.1 The block diagram of the controller circuit

The block diagram of the controller circuit is shown in Fig.4.12.

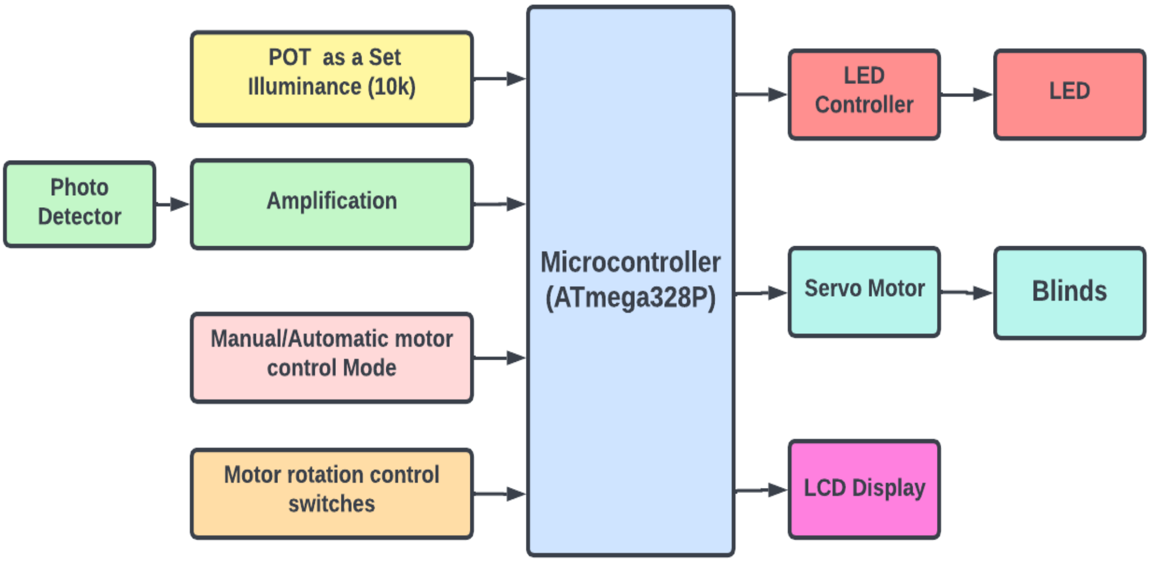

Fig.4.12: The block diagram of the controller circuit

4.3.1.1 Photo Detector and amplification of the signal

The Photo Detector reads the Analog value on the working plane and this value can be modified by the use of an amplifier circuit. So, the operational amplifier (Op-amp) is needed for the modification of the signal. The TL082 Op-amp is used for the amplification of the signal. The TL082 is a high-speed JFET input dual operational amplifier incorporating well-matched, high voltage JFET and bipolar transistors in a monolithic integrated circuit. This device features high slew rates, low input bias and offset current, and low offset voltage temperature coefficient. The input of the Op-amp is used which as the output of the Photo Detector (PD). The amplified signal is connected to pin24 of the 8-bit microcontroller. The Amplification circuit of this system is shown in Fig.4.13.

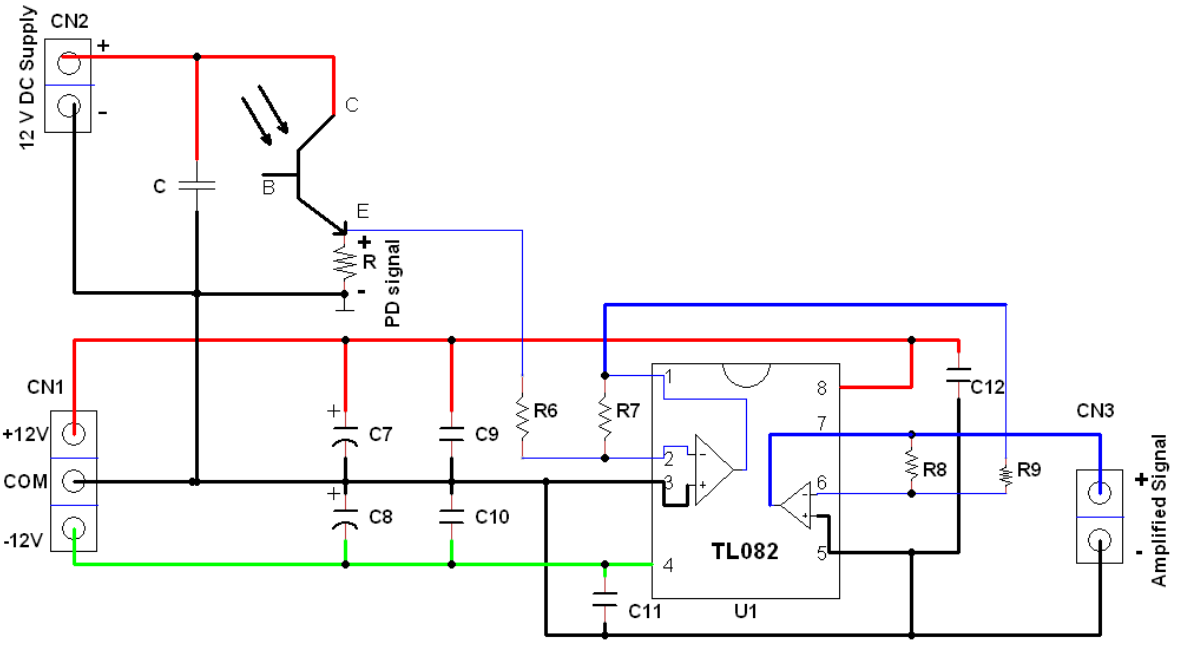

Fig.4.13: Amplification circuit diagram

In this Circuit, C7 and C8 is using as an electrolytic capacitor of 100 µF. The ceramic disc capacitor i.e., C, C9, C10, C11 and C12, values are 0.1 µF respectively. The values of R, R6, R7, R8 and R9 are 5.6 kΩ 10 kΩ, 82 kΩ, 82 kΩ and 10 kΩ respectively. To activate the circuit a 12 Volt DC power supply is connected to the channel 1 (CN1). The Amplified signal is used to operate the control circuit.

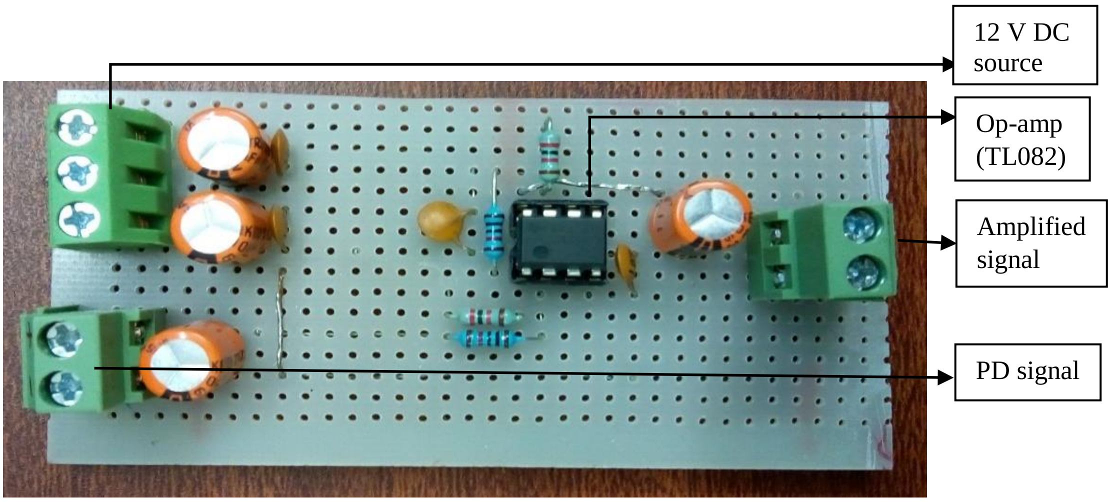

Fig.4.14: Amplifier circuit

In the above diagram, the non-amplified signal is connected to two-pin connector and the Op-amp has been modified the signal. The amplified signal has been collected from the output of the circuit and the signal will be generated PWM signal by use of microcontroller digital pin.

4.3.1.2 LED controller and LED

Every LED light source requires a driver circuit. The LED driver circuit is generally two types, constant-current, and constant-voltage. The LED driver acts not only as an electrical current management system, but also as a protective buffer. In this experiment, a constant-current and constant-voltage type LED driver is used. The control signal coming from the PWM pins of the microcontroller are 5 V TTL signal which are not sufficient to drive the MOSFET and make it operate as ON switch in saturation region. For satisfactory conduction of the switching MOSFET, MOSFET driver IR2011PBF IC has been used which convert the TTL level signal to 12 V power signal which is sufficient to make the MOSFET operate in saturation region. The schematic diagram of the switching circuit is shown in Fig.4.15. When the pulse of the PWM control signal is HIGH, the switching MOSFET Q conduct and is driven to saturation region where it operates as ON switch. This turns ON the LED sources. When the pulse of the PWM control signal is LOW, the switching MOSFET is open-circuited and remains in cut-off region where it operates as OFF switch as a result of which the LED sources are turned OFF. The average illuminance depends on the duty cycle of the PWM signal.

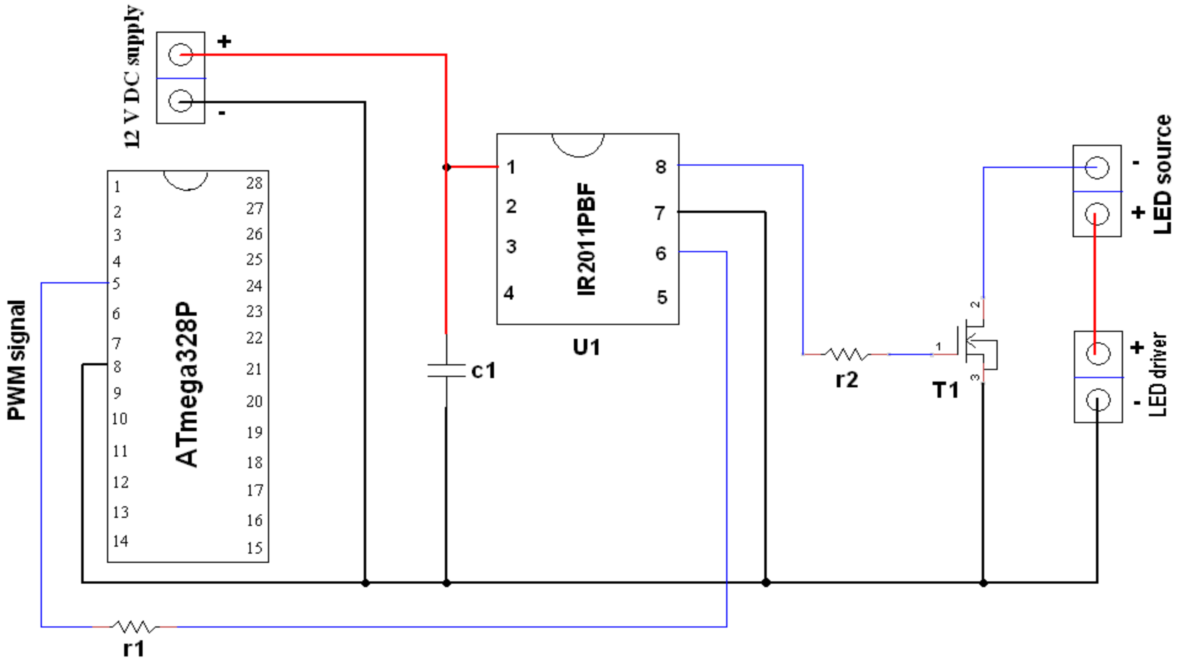

Fig.4.15: LED controller circuit

In this circuit, the value of r1 and r2 are 10 Ω and the value of capacitance c1 is 0.1µF. The number 1, 2 and 3 are denotes Gate, Drain and Source terminal of the MOSFET respectively. The digital PWM pin of the microcontroller is connected with the pin6 of the IC U1.

4.3.1.3 Controller and LCD display

The illuminance value can be changed by the user requirement. In this system, A POT is used as a potentiometer (10k) which is provided a variable resistance by simply varying the knob on top of its head. It has three terminals; the middle of the terminals has connected to pin22 of the 8-bit microcontroller. Terminal with red wire and black wire have connected to a power source and the ground. The schematic diagram of potentiometer is shown in Fig.4.16. It has been used to change the Set Illuminance (Es) from 0 lx to 300 lx.

Fig.4.16: A diagram of POT

The LCD stands for liquid crystal display, which works on the light modulation features of liquid crystals. It has available in electronic visible display, video display, and flat panel display. The Set Illuminance value, Measured Illuminance value, error etc have shown in Fig.4.17.

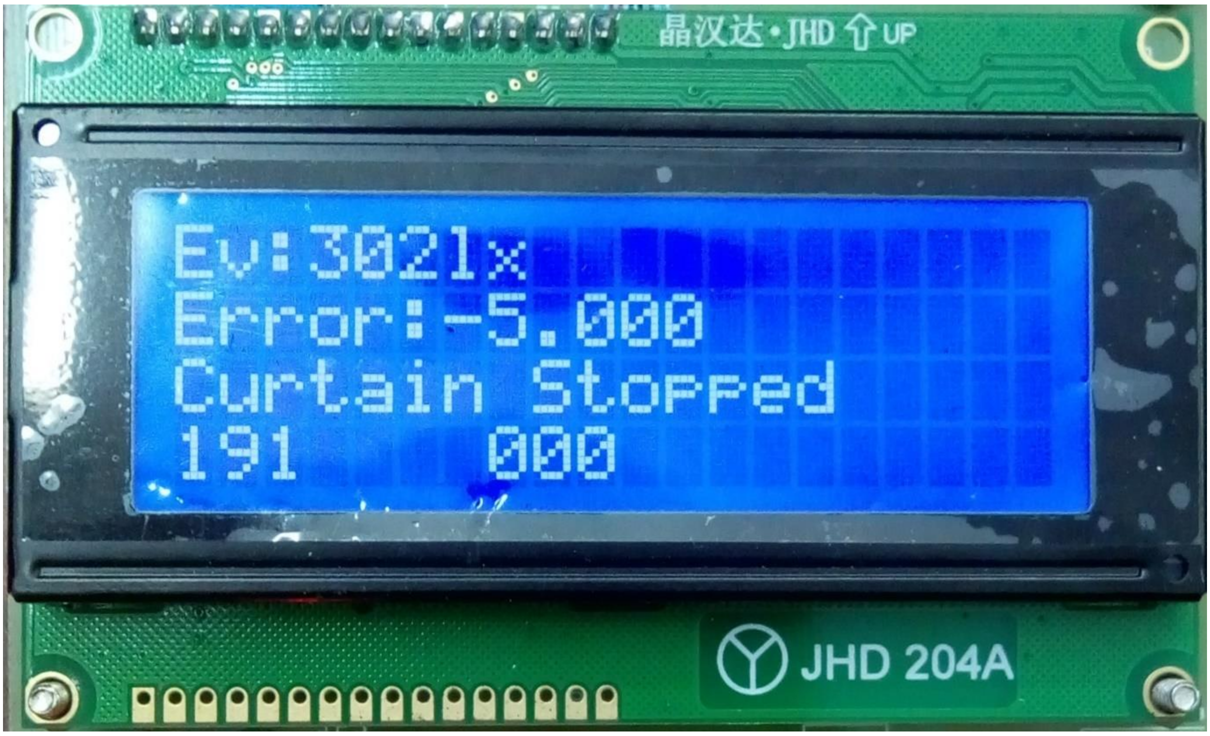

Fig.4.17: A diagram of LCD display

The circuit diagram of POT and LCD with the microcontroller has shown in Fig.4.18.

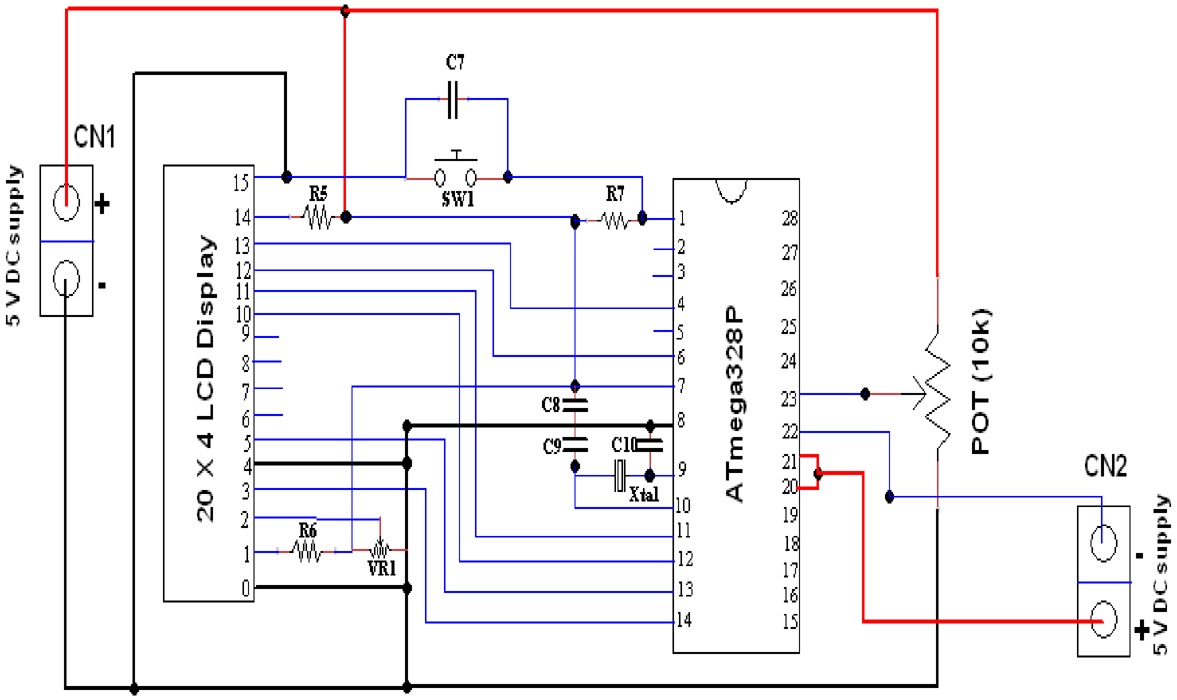

Fig.4.18: The circuit diagram of POT and LCD with microcontroller

4.3.1.4 Operation of manual/automatic control of blinds using switches

The push button switch is usually used to turn on and off the control circuit, and it is a kind of control switch appliance that is widely used. It is used in electrical automatic control circuits to manually send control signals to control contactors, relays, electromagnetic starters, etc. The push button switch can complete basic controls such as start, stop, forward and reverse rotation, speed change, and interlock. In this experiment, three push button has been used for controlling the rotation of servo motor as STOP, Clockwise rotation, and Counter clockwise rotation. The connection diagram of the push button switch is shown in Fig.4.19.

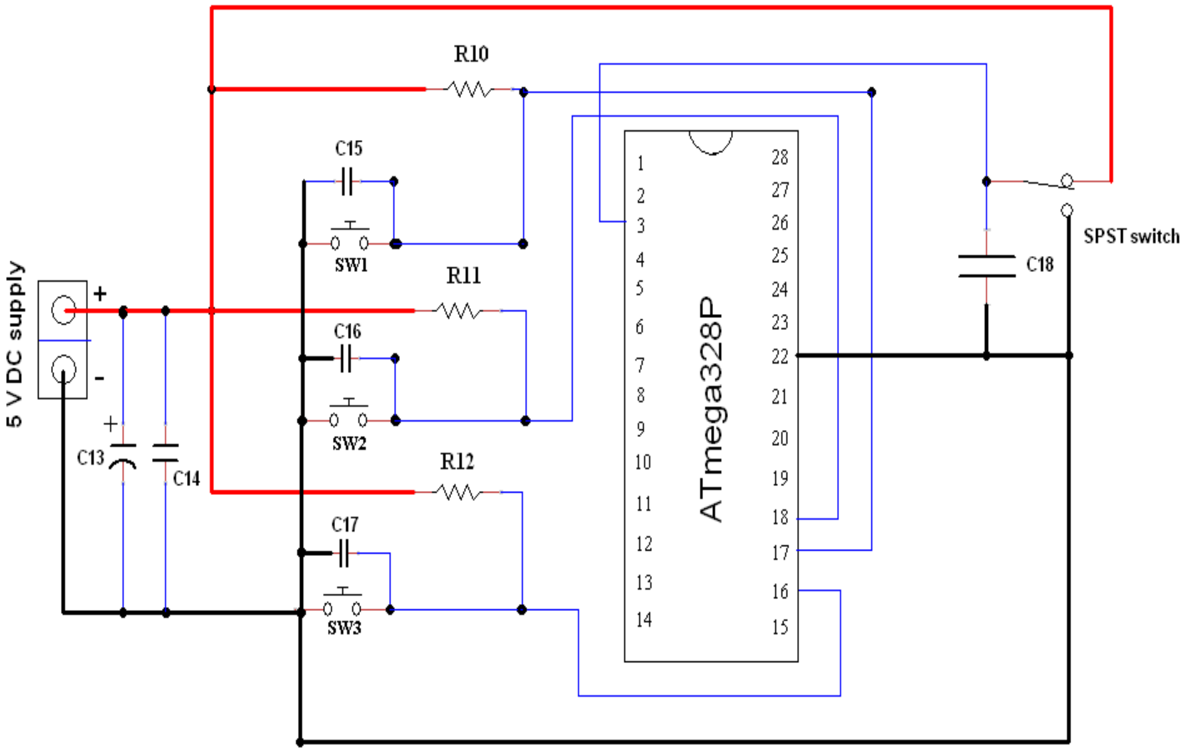

Fig.4.19: Connection diagram of push button switches

The values of capacitance C13, C14, C15, C16, C17 and C18 are 100µF, 0.01µF, 0.01µF, 0.01µF, 0.01µF and 0.01µF respectively. The values of resistance R10, R11, R12 are 10 kΩ.

The push button switches SW1, SW2 and SW3 has been considered as STOP, Clockwise rotation and Counter clockwise rotation and the pin connection of the switches with the microcontroller are Pin17, Pin18, Pin16 respectively. With respect to Set Illuminance, the switches can be operated by manually. The operation of switches has been followed by the table 4.3.1.

Table 4.3.1: Operation of switches

Mode of blinds	SW1	SW2	SW3
Opening	HIGH	HIGH	LOW
Closing	LOW	HIGH	HIGH
Stop	HIGH	LOW	HIGH

In the circuit of push button, a toggle switch is installed. It can be changed by the mode of operation i.e., manual to automatic or vice-versa. For automatic mode, the position of blinds can be shifted by the change of desired illuminance. For an example, the Set Illuminance (Es) is greater than the Measured Illuminance (Em) then the blinds are completely opened. If the desired illuminance is not achieved then the light turns ON and the intensity is increased up to Set Illuminance. When the Set Illuminance (Es) is less than the Measured Illuminance (Em) then the blinds are fully closed. If the desired illuminance is not achieved then the light intensity is decreasing up to Set Illuminance. The circuit diagram of this switches is shown in Fig.4.20.

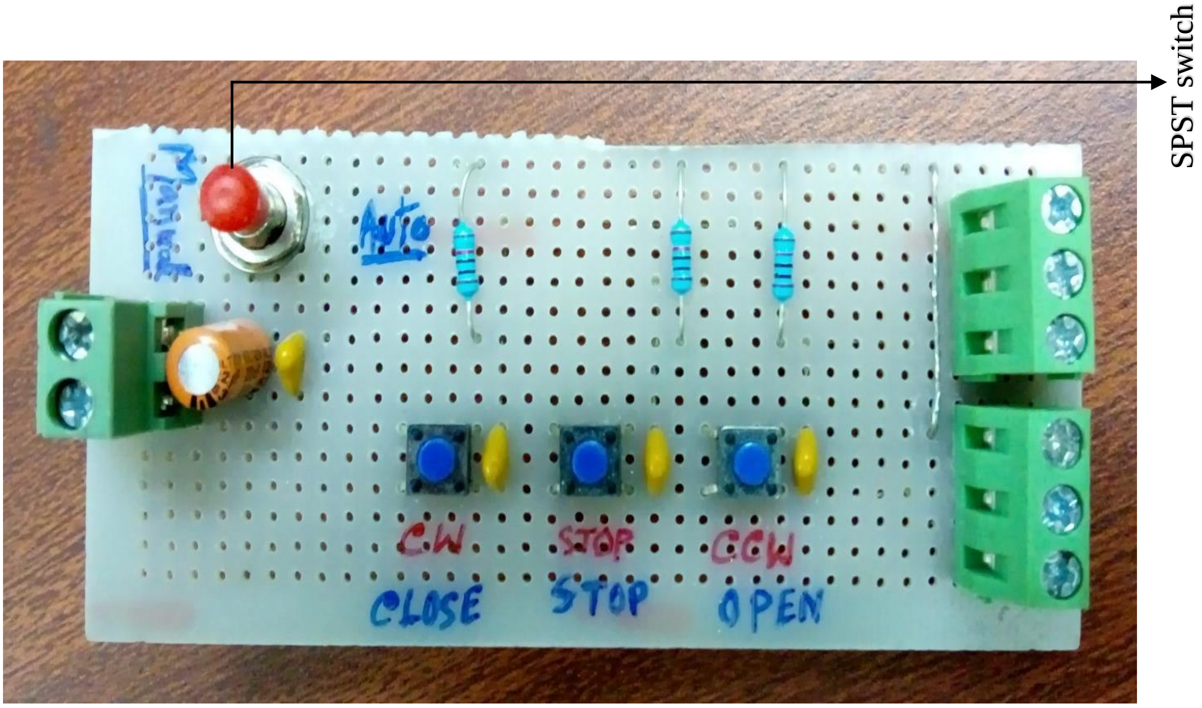

Fig.4.20: Circuit diagram of switches

The complete circuit diagram of the system is shown in Fig.4.21.

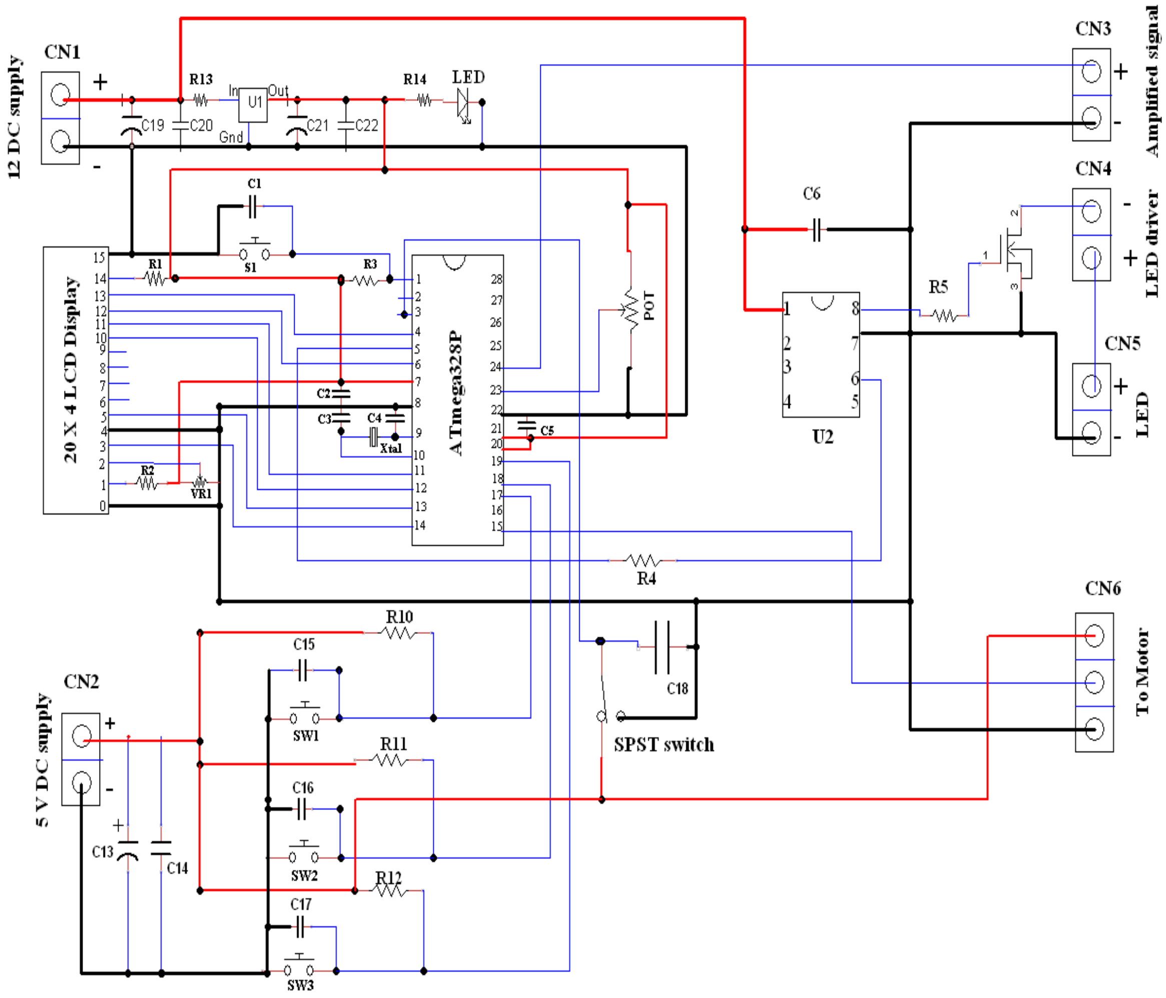

Fig.4.21: The Complete circuit diagram of the proposed system

In this diagram, the channel CN1 and CN2 has been connect to a 12 V and 5 V DC power supply. The output of the amplified signal has been connected to the channel CN3. The LED driver and LED has been connected to the channel of CN4 and CN5. The servo motor has also connected by the channel CN6. The SPST switch is connected by the pin3 of the microcontroller. To change the operation mode of the system, the switch is required. In one diagram, all circuits have been shown by properly connection with the microcontroller.

The configuration of the controller circuit board is shown in Fig.4.22. Four circuits have been developed to build the system.

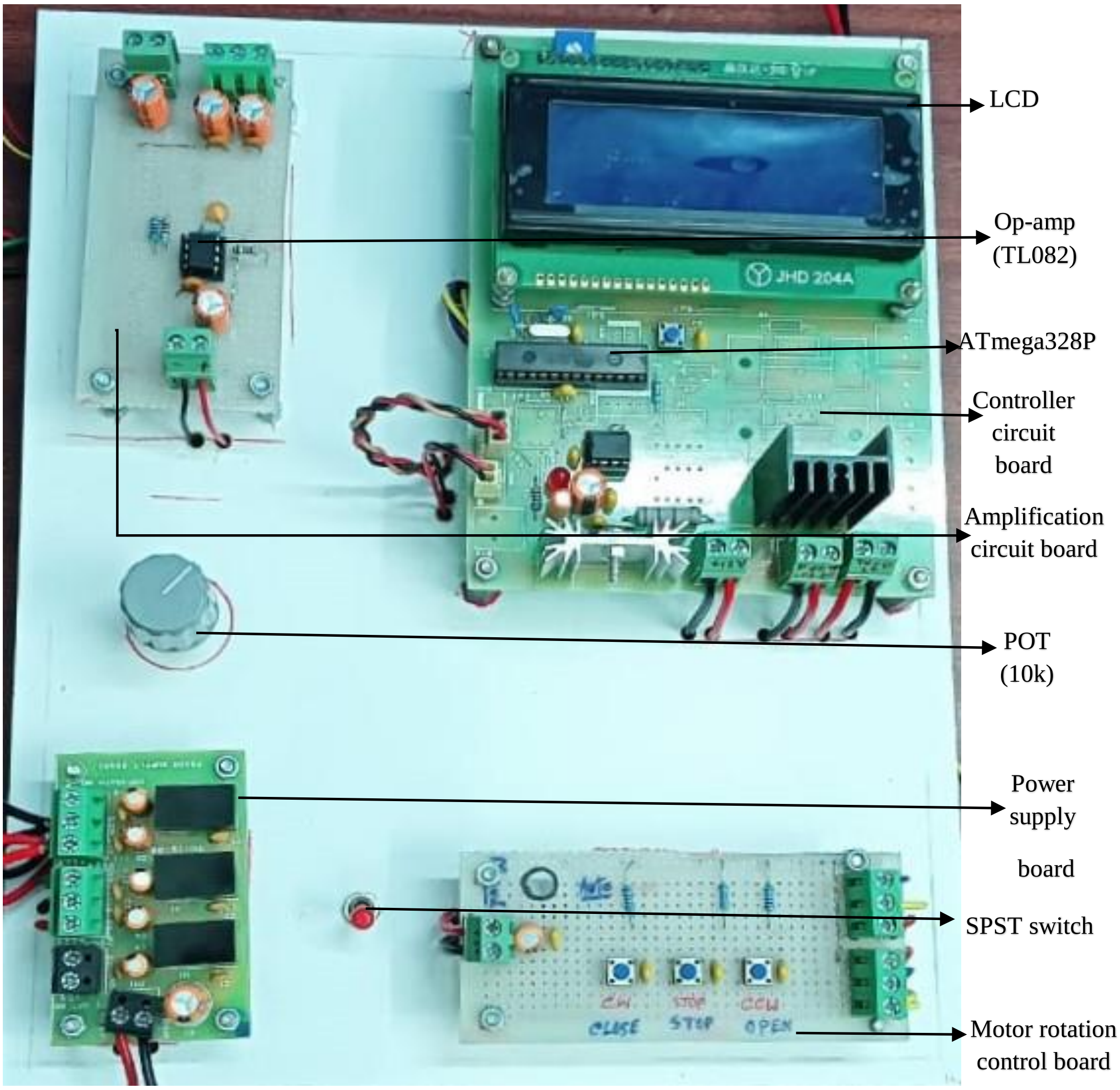

Fig.4.22: Configuration of main circuit board

Chapter 5

Experimental results

5.1. Formulation of Set Illuminance

The proposed control technique has been implemented with an LED luminaire and light sensor. Using the CRI illuminance meter CL-70F, measure the brightness of the LEDs at the working plane. Then The duty cycle is changed by a potentiometer from 1% to 100% with an interval of 5%. The percentage of the duty cycle can be converted into an 8-bit digital value. The data table of duty cycle and measured illuminance is shown in Table 5.1.

Table 5.1: Table of illuminance value for increasing duty cycle

Duty Digital (%)	Digital value of duty cycle	Measured Illuminance (lx) (CL-70F)
1	2	1.3
5	13	18.2
10	26	38.8
15	38	62.8
20	51	82.6
25	64	106.0
30	77	127.0
35	89	153.0
40	102	173.0
45	115	194.0
50	128	218.0
55	140	243.0
60	153	267.0
65	166	290.0
70	179	314.0
75	191	340.0
80	204	366.0
85	217	370.0
90	230	373.0
95	242	375.0
100	255	376.0

From Table 5.1, Illuminance values are obtained from 1.3 lx to 376.0 lx. The graph between the digital value of the duty cycle and measured illuminance is shown in Fig.5.1.

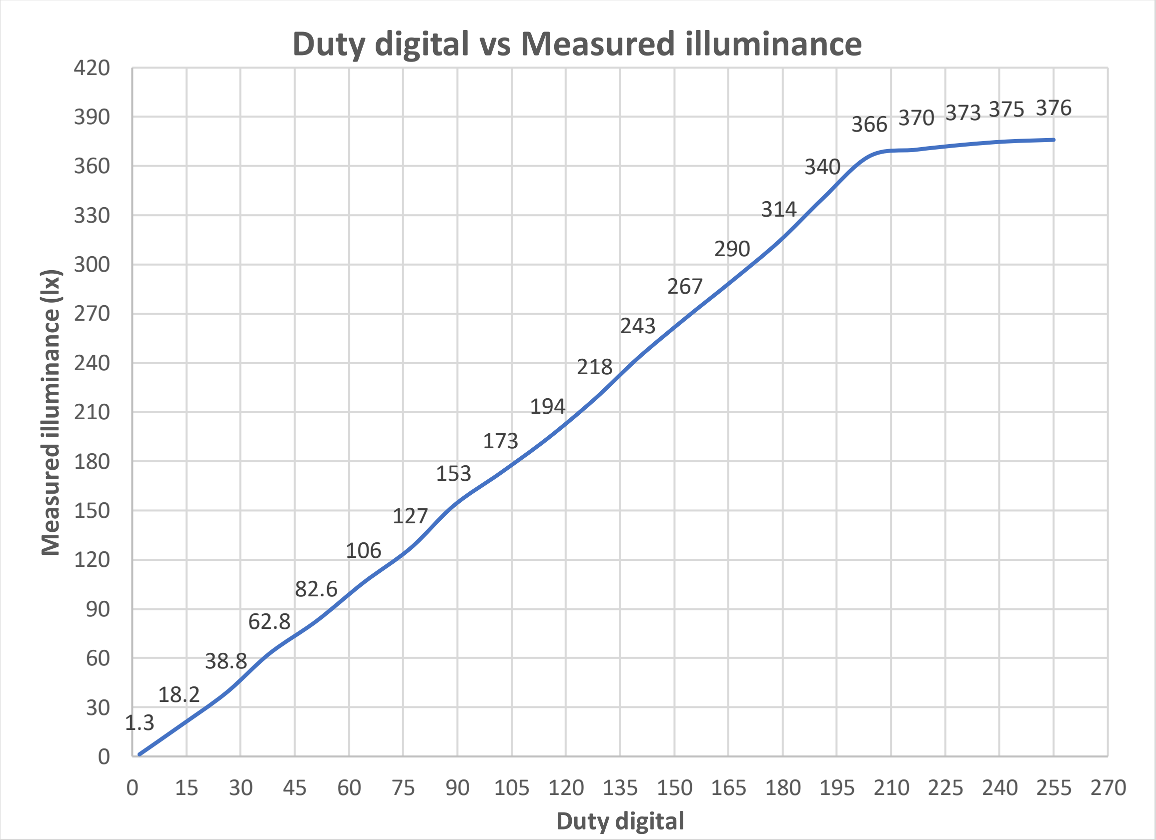

Fig.5.1: Duty digital vs Measured illuminance

The following graph is not linear characteristics. For this experiment, only linear region has been considered. In this case, measured illuminance will be used as a set illuminance. Set illuminance can be expressed mathematically.

Considering the points (5,18.2) and (204,366)

The equation is

$$Y = 1.810303283\ X - 9.330406189 \qquad \text{……………………………………………} (1)$$

Where, X= Duty digital value

Y= Measured illuminance in lx

Here, Y value represents as set illuminance (Es) in lx. The modified equation is

$$Es = 1.810303283\ X - 9.330406189 \qquad \text{………………………………………} (2)$$

5.2 Formulation of Measured Illuminance

Every close loop system requires a feedback path. In this close loop system, PD will be used as the feedback. Keeping the same condition of the room, the Set Illuminance value is varying from 0 lx to 300 lx using a knob with the interval of 10 lx. PD reads the Analog value and converted into digital value by the microcontroller. For an example, the Set Illuminance value is 200 lx then the PD output value is 26. The data table of Set Illuminance (Es), PD Analog value, PD digital value, and measured illuminance (CL-70F) are shown in Table 5.2.

The open loop system is shown in Fig. 5.2.

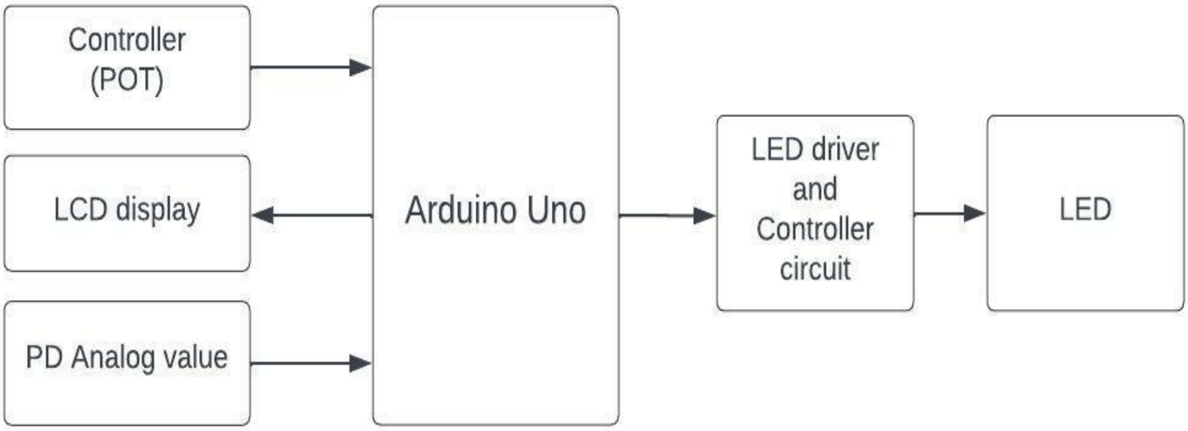

Fig.5.2: Block diagram of the open loop system

As shown in the diagram, PD output is connected to Analog pin A1 and Set Illuminance are connected to Analog pin A0 with the Arduino board. The LEDs is connected with the Arduino board of pin3. The Set Illuminance (Es) value and ADC value of PD are displayed on the LCD screen. Accordingly, changing the light intensity of LEDs with the change of Set Illuminance.

Table 5.2: Measured illuminance for increasing Set Illuminance

Set Illuminance (Es) (lx)	PD Analog value (mVolt)	PD digital	Measured Illuminance (lx) (CL-70F)
0	58.8	3	4.2
10	78.4	4	13.9
20	98.0	5	23.7
30	117.6	6	31.8
40	137.3	7	40.5
50	156.9	8	50.9
60	176.5	9	59.3
70	196.1	10	69.8
80	215.7	11	78.4
90	235.3	12	87.2
100	274.5	14	97.7
110	294.1	15	107.0
120	313.7	16	117.0
130	333.3	17	126.0
140	353.0	18	136.0
150	392.2	20	148.0
160	411.8	21	157.0
170	431.4	22	168.0
180	451.0	23	174.0
190	490.2	25	186.0
200	509.9	26	196.0
210	529.4	27	206.0
220	568.6	29	216.0
230	588.2	30	226.0
240	607.8	31	237.0
250	627.5	32	247.0
260	666.7	34	257.0
270	686.3	35	267.0
280	705.9	36	277.0
290	725.5	37	288.0
300	745.1	38	298.0

From the Table 5.2, a graph has been drawn between Set Illuminance (Es) and PD digital value. The graph is showing in Fig.5.2.

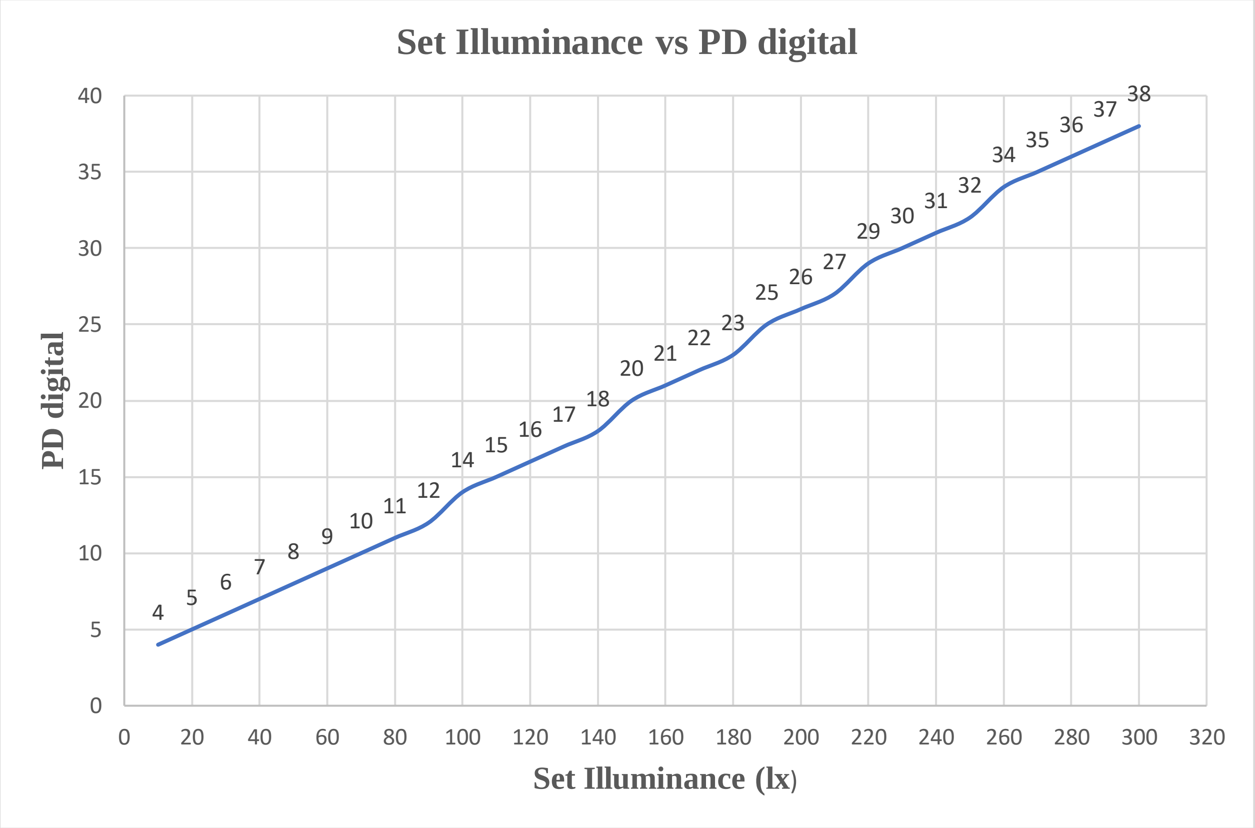

Fig.5.2: Set Illuminance (lx) vs PD digital

An equation has been developed by using this graph. In this case Set Illuminance using as Measured Illuminance (Em).

Considering the points (10, 4) and (300, 37)

The equation is

$$y = 0.12097886\,x + 1.848275862 \quad \text{(3)}$$

$$\text{or, } x = 8.265906953\,y - 15.277676299 \quad \text{(4)}$$

Where, x = Set Illuminance in lx

y = PD digital value

The modified equation is

$$Em = 8.265906953\,x - 15.277676299 \quad \text{(5)}$$

5.3 Analysis of the system

In this section, the experimental results have been presented to evaluate the performance of the proposed system. The illuminance value has been set by the user between 0 lx to 300 lx. Now the Photo Detector reads the Analog value on the working plane and this value can be converted into digital value by the 8-bit microcontroller. The digital value of Measured Illuminance is changed into lx value with the help of Eq.5. The comparison between Set Illuminance (Es) and Measured Illuminance (Em) is denoted by Error (Er). With varying the Set Illuminance (Es) value by the interval of 10 lx, the obtained measured Illuminance and error is shown in Table5.3**.**

Table 5.3: The data table of measurement illuminance

Set Illuminance (Es) (lx)	PD digital	Measured Illuminance (Em) through PD (lx)	Measured illuminance (CL-70F) (lx)	Error (Er) (Es-Em)
0	2	1	4.2	-1
10	3	9	13.9	1
20	4	7	23.7	13
30	5	26	31.8	4
40	6	34	40.5	6
50	7	42	50.9	8
60	8	50	59.3	10
70	9	59	69.8	11
80	10	67	78.4	13
90	11	75	87.2	15
100	12	83	97.7	17
110	13	92	107.0	18
120	15	108	117.0	12
130	16	116	126.0	14
140	17	125	136.0	15
150	19	133	148.0	17
160	20	150	157.0	10
170	21	158	168.0	12
180	22	166	174.0	14
190	23	174	186.0	16

200	24	183	196.0	17
210	26	199	206.0	11
220	27	207	216.0	13
230	28	216	226.0	14
240	29	224	237.0	16
250	31	240	247.0	10
260	32	249	257.0	11
270	33	257	267.0	23
280	35	274	277.0	6
290	36	282	288.0	8
300	37	290	298.0	10

If Er > 0; the duty cycle of the LED is increased,

Er < 0; the duty cycle of the LED is decreased,

Er = 0; no change of the duty cycle.

The variation of Error with changing Set Illuminance (Es) is shown in Fig.5.3 (a) and Fig.5.3(b).

For Without feedback, the error value is obtained from -1 to 23.

For With feedback, the error value is obtained from -5 to 5.

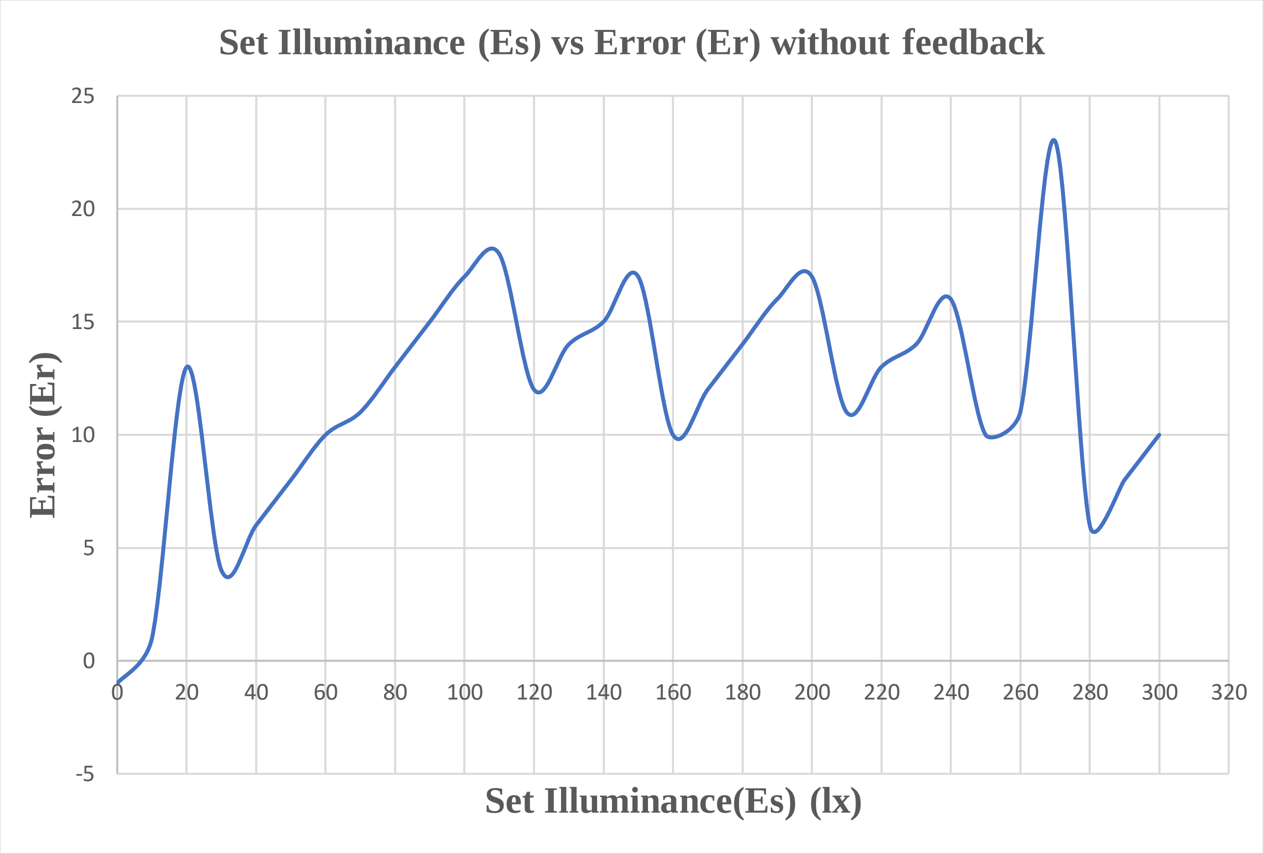

Fig.5.3 (a): Variation of Error with changing Set Illuminance without feedback

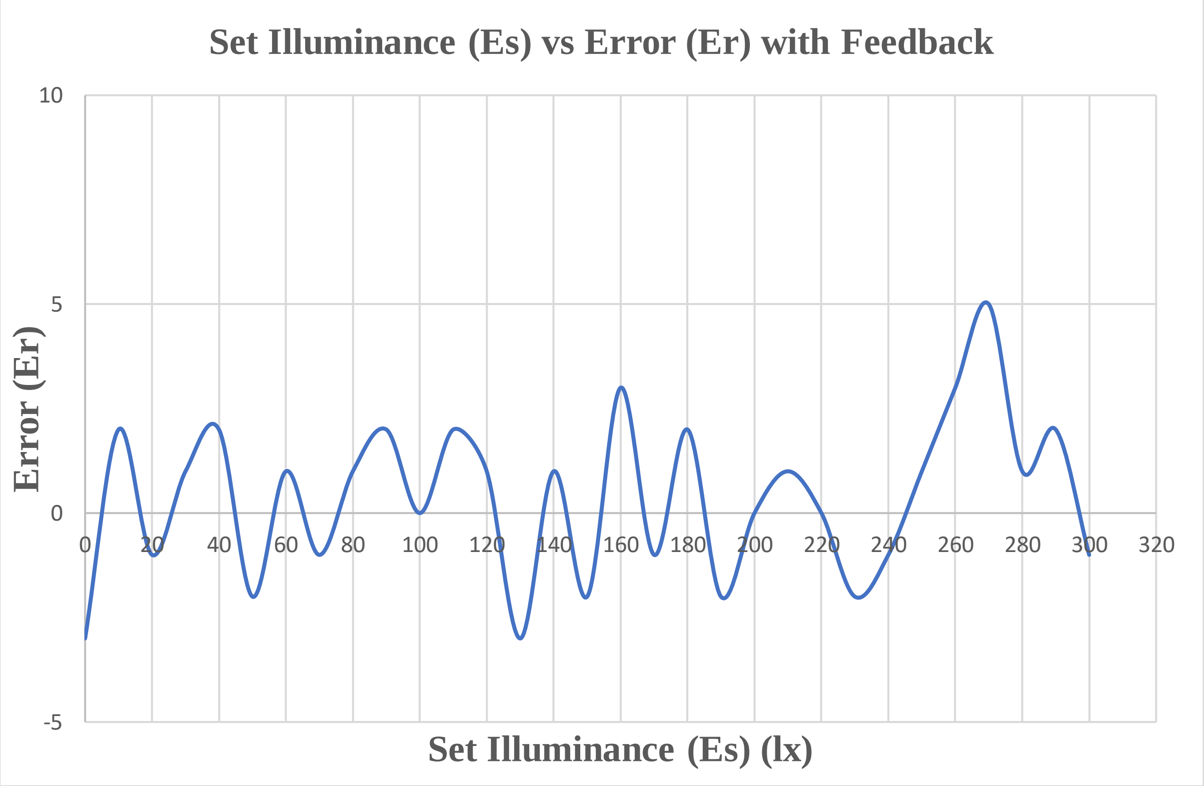

Fig.5.3 (b): Variation of Error with changing Set Illuminance with feedback

Chapter 7

Conclusion and Future scope

We have proposed a close loop lighting control system that adjusts to daylight and artificial light. The proposed system has been improved by the closed loop illuminance control of dimmable LED sources and motorized blinds. The performance of the proposed system is evaluated using an experimental testbed that only use information from high-rate Photo detector. An automated vertical blind is operated in synchronization with dimmable LED lighting to optimize working plane illuminance and block the direct daylight. The prototype that is developed used a servo motor to opened and closed the blinds. A servo motor has been controlled the position of the blinds. The PWM technique is used to controlled the dimming of the LED. In this system, only considered the linear region of the graph between Duty digital and measured illuminance. The minimum and maximum illuminance value is achieved of 1.3 lx and 376 lx respectively. The minimum and maximum measurement illuminance is achieved by Photo detector of 1 lx and 364 lx respectively. The proposed system provides a good balance between energy savings and the amount of illumination at the working plane.

The future scope of the system i.e., the system can be developed by the use of PID controller. In this experiment, suddenly the power is disconnected then the microcontroller is not working. So, Solar energy will be best for provides the power to the microcontroller and the developed system will be run properly.

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Appendix-I

Atmega328 programming code

1. LED DIMMING PROGRAM

```
#include <LiquidCrystal.h>
#include <PWM.h>
#define LED 3
int X;
int32_t frequency= 4000;
const int rs = 8, en = 7, d4 = 6, d5 = 5, d6 = 4, d7 = 2;
LiquidCrystal lcd (rs, en, d4, d5, d6, d7);
void setup ()
{
  lcd.begin (20, 4);
  InitTimersSafe ();
  bool success= SetPinFrequencySafe (LED, frequency);
  pinMode (LED, OUTPUT);
}
void loop ()
{
  int Value1 = analogRead (A0);
  X= map (Value1,0,1023,0,255);
  pwmWrite (LED, X);
  int D=(X*100)/255;
  lcd.setCursor(0, 0);
  lcd.print ("Duty Cycle:");
  lcd.setCursor(14, 0);
  lcd.print ("%");
  lcd.setCursor(11, 0);
  lcd.print(D);
  if (D<100)
  {
```

```
  lcd.setCursor(13, 0);
  lcd.print ("%");
  }
}
```

2. MANUAL CONTROL OF BLINDS PROGRAM

```
#include <LiquidCrystal.h>
const int rs = 8, en = 7, d4 = 6, d5 = 5, d6 = 4, d7 = 2;
LiquidCrystal lcd (rs, en, d4, d5, d6, d7);
#include <Servo.h>
#define Servo_PWM 9
Servo MG995_Servo;
#define STOPpin 12
#define CWpin 11
#define CCWpin 13
int CWBS, CCWBS, SBS;
int X=0;
int State=0;

void setup () {
  MG995_Servo.attach(Servo_PWM);
  lcd.begin(20, 4);
  pinMode (STOPpin,INPUT_PULLUP);
  pinMode (CCWpin,INPUT_PULLUP);
  pinMode (CWpin,INPUT_PULLUP);
  MG995_Servo.detach();
}
void loop ()
{
    CCWBS = digitalRead(CCWpin);
    SBS = digitalRead (STOPpin);
    CWBS = digitalRead (CWpin);
    lcd.setCursor(0, 0);
    lcd.print("X:");
```

```
  if (CCWBS ==LOW)
  {
    MG995_Servo.attach(Servo_PWM);
    MG995_Servo.write(180);
    State=1;
  }
  If (SBS ==LOW)
  {
    MG995_Servo.detach(); //Stop. You can use deatch function or use write(x), as x is the middle of 0-180 which is 90, but some lack of precision may change this value
    State=2;
  }
  If (CWBS ==LOW)
  {
    MG995_Servo.attach(Servo_PWM);
    MG995_Servo.write(0);
    State=3;
  }
  if (State==1)
  {
   X++;
   lcd.setCursor(2, 0);
   lcd.print(X);
   delay (100);
  }
  if (X<1000)
  {
   lcd.setCursor(5, 0);
   lcd.print (" ");
  }
  if (X<100)
  {
   lcd.setCursor(4, 0);
```

```
 lcd.print (" ");
}
if (X<10)
{
 lcd.setCursor(3, 0);
 lcd.print (" ");
}
if (State==2)
{
 X==0;
 lcd.setCursor(2, 0);
 lcd.print(X);
 delay (100);
}
if (State==3)
{
 X--;
 lcd.setCursor(2, 0);
 lcd.print(X);
 delay (100);
}
if (X<-1000)
{
 lcd.setCursor(6, 0);
 lcd.print (" ");
}
if (X<-100)
{
 lcd.setCursor(5, 0);
 lcd.print (" ");
}
if (X<-10)
{
```

```
      lcd.setCursor(4, 0);
      lcd.print (" ");
     }
 }
```

3. AUTOMATIC CONTROL OF BLINDS PROGRAM

```
#include <LiquidCrystal.h>
const int rs = 8, en = 7, d4 = 6, d5 = 5, d6 = 4, d7 = 2;
LiquidCrystal lcd (rs, en, d4, d5, d6, d7);
#include <Servo.h>
#define Servo_PWM 9
Servo MG995_Servo;
int X=0;
int State=0;
void setup ()
{
  MG995_Servo.attach(Servo_PWM);
  lcd.begin(20, 4);
  MG995_Servo.detach();
}
void loop ()
{
   if (State==0)
   {
      MG995_Servo.attach(Servo_PWM);
      MG995_Servo.write(180);
      X++;
      Delay (100);
      lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print ("Curtain Opening");
      if (X==193)
        {
         MG995_Servo.detach();
```

```
        lcd.clear();
        lcd.setCursor(0, 0);
        lcd.print ("Curtain Opened");
        delay (5000);
        State=1;
       }
    }
    if (State==1)
    {
      MG995_Servo.attach(Servo_PWM);
      MG995_Servo.write(0);
      X--;
      Delay (100);
      lcd.clear();
      lcd.setCursor(0, 0);
      lcd.print("Curtain closing");
      if (X==0)
       {
        MG995_Servo.detach();
        lcd.clear();
        lcd.setCursor(0, 0);
        lcd.print("Curtain closed");
        delay (5000);
        State=0;
       }
    }
}
```

4. MAIN PROGRAM

```
#include <LiquidCrystal.h>
#include <PWM.h>
#include <Servo.h>
#define Servo_PWM 9
Servo MG995_Servo;
const int rs = 8, en = 7, d4 = 6, d5 = 5, d6 = 4, d7 = 2;
LiquidCrystal lcd (rs, en, d4, d5, d6, d7);
int LED=3;
int Set_value=A0;
int Measured_value=A1;
int X;
int Y;
int Es;
int Em;
int Duty=0;
int32_t frequency= 4000;
int count=0;
int State=0;
void setup ()
{
  lcd.begin(20, 4);
  InitTimersSafe ();
  bool success= SetPinFrequencySafe(LED, frequency);
  pinMode (LED, OUTPUT);
  MG995_Servo.attach(Servo_PWM);
  MG995_Servo.detach();
}
void loop ()
{
   ADC_value();
   Calculation ();
    switch (State)
```

```
 {
 case 1:
 {
  if (count<=190)
  {
  MG995_Servo.attach(Servo_PWM);
  MG995_Servo.write(180);
  count++;
  delay (100);
  lcd.setCursor(0, 3);
  lcd.print(count);
  //lcd.clear();
  lcd.setCursor(0, 2);
  lcd.print("Curtain Opening");
  }
  else if (count>190)
    {
    MG995_Servo.detach();
   // lcd.clear();
    lcd.setCursor(0, 2);
    lcd.print ("Curtain Stopped");
    Duty++;
    Delay (100);
    if (Duty>255)
    {
     Duty=255;
     }
    PWM ();
   }
  break;
}
 case 2:
{
```

```
 if (count>0)
 {
  MG995_Servo.attach(Servo_PWM);
  MG995_Servo.write(0);
  count--;
  delay (100);
  lcd.setCursor(7, 3);
  lcd.print(count);
 // lcd.clear();
  lcd.setCursor(0, 2);
  lcd.print ("Curtain closing");
 }
  else if (count<=0)
    {
     MG995_Servo.detach();
    // lcd.clear();
     lcd.setCursor(0, 2);
     lcd.print ("Curtain Stopped");
     Duty--;
     Delay (100);
     if (Duty<0)
     {
     Duty=0;
      }
    PWM ();
    }
    break;
}
case 3:

 {
  MG995_Servo.detach();
  }
```

```
     break;
}
  }
 void ADC_value(void)
 {
int Value1 = analogRead (Set_value);
int Value2 = analogRead (Measured_value);
X= map (Value1,0,1023,0,255);
Y= map (Value2,0,1023,0,255);
Es= (X * 1.810303283)-9.330406189;
//if (Es>300)
//{
 //Es=300;
 //}
lcd.setCursor(0, 0);
lcd.print("Es:");
lcd.setCursor(6, 0);
lcd.print("lx");
lcd.setCursor(3, 0);
lcd.print (Es);
if (Es<100)
{
lcd.setCursor(5, 0);
lcd.print (" ");
}
if (Es<10)
{
lcd.setCursor(4, 0);
lcd.print (" ");
}
 }
 void Calculation(void)
{
```

```
 int Em=0;
 Em=Y * 8.265906953-15.277676299;
 lcd.setCursor(9, 0);
 lcd.print("Em:");
 lcd.setCursor(15, 0);
 lcd.print("lx");
 lcd.setCursor(12, 0);
 lcd.print (Em);
 if (Em<100)
 {
 lcd.setCursor(14, 0);
 lcd.print (" ");
 }
 if (Em<10)
 {
 lcd.setCursor(13, 0);
 lcd.print (" ");
 }
float Er=Es-Em;
 if (Er>5)
 {
State=1;
 }
else if (Er<-5)
 {
  State=2;
 }
  else if(-5<=Er<=5)
  {
    State=3;
}
 lcd.setCursor(0, 1);
 lcd.print("Error:");
```

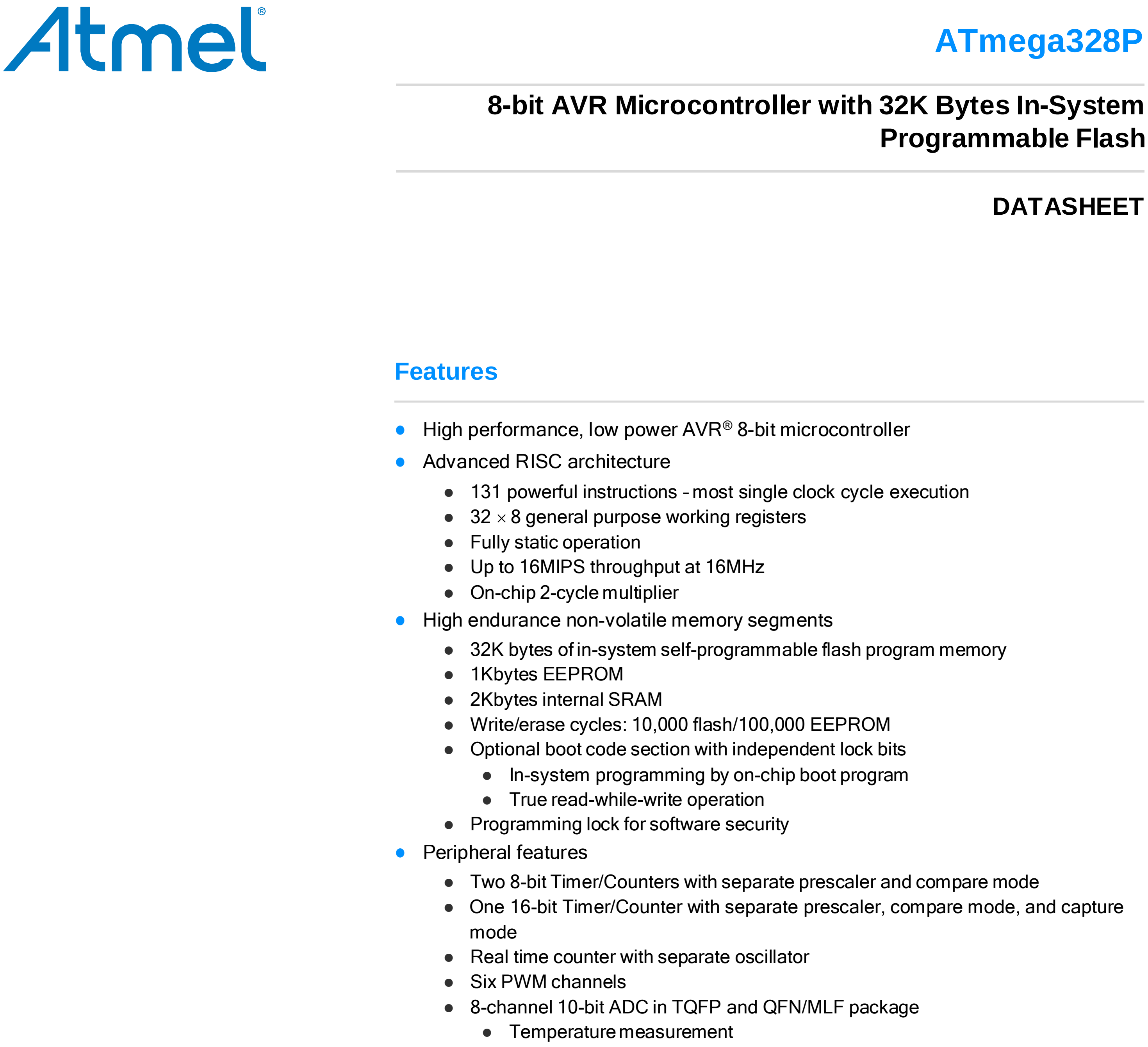
```
 lcd.setCursor(6, 1);
 lcd.print (Er);
 //DC=(Duty*255)/100;
  }
  void PWM (void)
{
pwmWrite (LED,Duty);
 }
```

Appendix-II

Components used for hardware implementation

---

1. ATmega328P Microcontroller



Atmel®

ATmega328P

8-bit AVR Microcontroller with 32K Bytes In-System Programmable Flash

DATASHEET

Features

- High performance, low power AVR® 8-bit microcontroller
- Advanced RISC architecture
  - 131 powerful instructions - most single clock cycle execution
  - 32 × 8 general purpose working registers
  - Fully static operation
  - Up to 16MIPS throughput at 16MHz
  - On-chip 2-cycle multiplier
- High endurance non-volatile memory segments
  - 32K bytes of in-system self-programmable flash program memory
  - 1Kbytes EEPROM
  - 2Kbytes internal SRAM
  - Write/erase cycles: 10,000 flash/100,000 EEPROM
  - Optional boot code section with independent lock bits
    - In-system programming by on-chip boot program
    - True read-while-write operation
  - Programming lock for software security
- Peripheral features
  - Two 8-bit Timer/Counters with separate prescaler and compare mode
  - One 16-bit Timer/Counter with separate prescaler, compare mode, and capture mode
  - Real time counter with separate oscillator
  - Six PWM channels
  - 8-channel 10-bit ADC in TQFP and QFN/MLF package
    - Temperature measurement

  - Programmable serial USART
  - Master/slave SPI serial interface
  - Byte-oriented 2-wire serial interface (Phillips I^{2}C compatible)
  - Programmable watchdog timer with separate on-chip oscillator
  - On-chip analog comparator
  - Interrupt and wake-up on pin change
- Special microcontroller features
  - Power-on reset and programmable brown-out detection
  - Internal calibrated oscillator
  - External and internal interrupt sources
  - Six sleep modes: Idle, ADC noise reduction, power-save, power-down, standby, and extended standby

2. 5 V Voltage Regulator (LM7805)

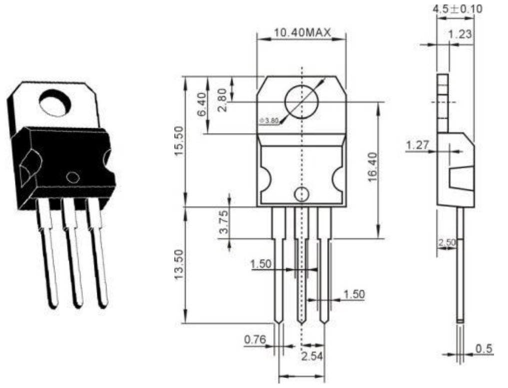
LM78XX

RoHS Pb

3-Terminal 1 A Positive Voltage Regulator

Features

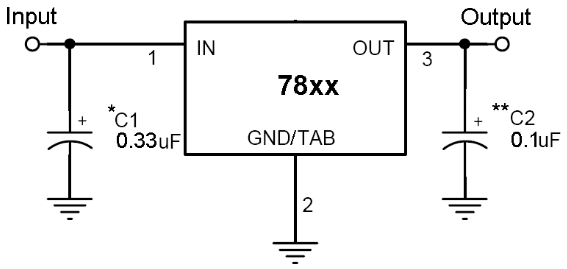
- Output Voltage Range 5 to 24V
- Output current up to 1A
- No external components required
- Internal thermal overload protection
- Internal short-circuit current limiting
- Output transistor safe-area compensation
- Output voltage offered in 4% tolerance



TO-220M-1

Unit : (mm)

Standard Application Circuit



A common ground is required between the input and the output voltages. The input voltage must remain typically 2.0V above the output voltage even during the low point on the Input ripple voltage.

XX = these two digits of the type number indicate voltage.

* = Cin is required if regulator is located an appreciable distance from power supply filter.

** = Co is not needed for stability; however, it does improve transient response.

Absolute Maximum Rating (Ta = 25°C unless otherwise noted)

Parameter		Symbol	Limit	Unit
Input Voltage	V_{OUT}=5~18V	V_{IN}	35	V
	V_{OUT}=24V		40	
Output Current		I_{OUT}	Internal Limited	
Power Dissipation		P_D	Internal Limited	
Operating Junction Temperature		T_J	0~+125	°C
Storage Temperature Range		T_{STG}	-65~+150	°C
Thermal Resistance - Junction to Case	TO-220	$RΘ_{JC}$	5	°C/W
	ITO-220		5	
Thermal Resistance - Junction to Ambient	TO-220	$RΘ_{JA}$	50	°C/W
	ITO-220		60	

Note: Absolute maximum ratings are those values beyond which damage to the device may occur.

LM7805 Electrical Characteristics

(Vin=10V, Iout=500mA, 0°C≤Tj≤125°C, Cin=0.33uF, Cout=0.1uF; unless otherwise specified.)

Parameter	**Symbol**	**Test Condition**		**Min**	**Typ**	**Max**	**Unit**
Output voltage	Vout	Tj=25°C		4.80	5	5.20	V
		7.5V≤Vin≤20V, 10mA≤Iout≤1A, PD≤15W		4.75	5	5.25	
Line Regulation	REGline	Tj=25 °C	7.5V≤Vin≤25V	--	3	100	mV
			8V≤Vin≤12V	--	1	50	
Load Regulation	REGload	Tj=25 °C	10mA≤Iout≤1A	--	15	100	
			250mA≤Iout≤750mA	--	5	50	
Quiescent Current	Iq	Iout=0, Tj=25°C		--	4.2	8	mA
Quiescent Current Change	ΔIq	7.5V≤Vin≤25V		--	--	1.3	
		10mA≤Iout≤1A		--	--	0.5	
Output Noise Voltage	Vn	10Hz≤f≤100KHz, Tj=25°C		--	40	--	µV
Ripple Rejection Ratio	RR	f=120Hz, 8V≤Vin≤18V		62	78	--	dB
Voltage Drop	Vdrop	Iout=1.0A, Tj=25°C		--	2	--	V
Output Resistance	Rout	f=1KHz		--	17	--	mΛ
Output Short Circuit Current	Ios	Tj=25°C		--	750	--	mA
Peak Output Current	Io peak	Tj=25°C		--	2.2	--	A
Temperature Coefficient of Output Voltage	ΔVout/ ΔTj	Iout=10mA, 0°C≤Tj≤125°C		--	-0.6	--	mV/ °C

STB55NF06, STP55NF06, STP55NF06FP

N-channel 60 V, 0.015 Λ, 50 A STripFET™ II Power MOSFET in D²PAK, TO-220 and TO-220FP packages

Datasheet — production data

3. Switching MOSFET STP55NF06

Features

Order code	V_{DSS}	$R_{DS(on)}$ max.	I_D
STB55NF06	60 V	< 0.018 Λ	50 A
STP55NF06			
STP55NF06FP			50 A (1)

1. Refer to soa for the max allowable current value on FP-type due to Rth value

- 100% avalanche tested
- Exceptional dv/dt capability

Applications

- Switching application

Description

These Power MOSFETs have been developed using STMicroelectronics' unique STripFET process, which is specifically designed to minimize input capacitance and gate charge. This renders the devices suitable for use as primary switch in advanced high-efficiency isolated DC-DC converters for telecom and computer applications, and applications with low gate charge driving requirements.

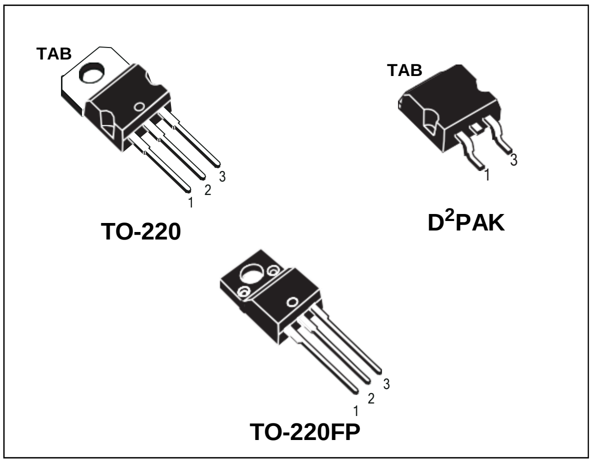


Figure 1. Internal schematic diagram

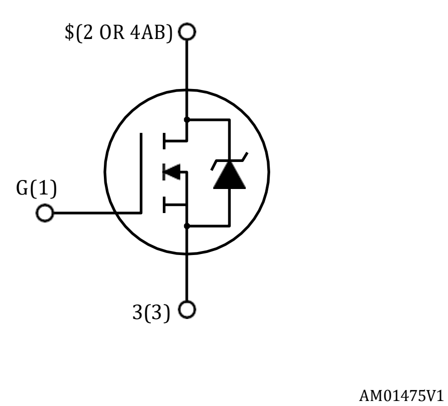
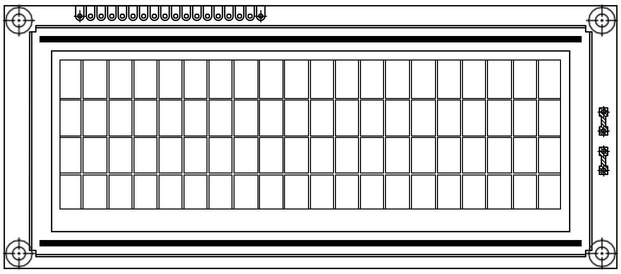


Table 1. Device summary

Order code	Marking	Package	Packaging
STB55NF06	B55NF06	D²PAK	Tape and reel
STP55NF06	P55NF06	TO-220	Tube
STP55NF06FP	P55NF06FP	TO-220	

4. 20x4 LCD

20 x 4 Character
LCD



FEATURES

- Type: Character
- Display format: 20 x 4 characters
- Built-in controller: ST 7066 (or equivalent)
- Duty cycle: 1/16
- 5 x 8 dots includes cursor
- + 5 V power supply (also available for + 3 V)
- LED can be driven by pin 1, pin 2, pin 15, pin 16 or A and K
- N.V. optional for + 3 V power supply
- Material categorization: For definitions of compliancеplease see www.vishay.com/doc?99912

MECHANICAL DATA

ITEM	STANDARD VALUE	UNIT
Module Dimension	146.0 x 62.5	mm
Viewing Area	123.5 x 43.0	
Dot Size	0.92 x 1.10	
Dot Pitch	0.98 x 1.16	
Mounting Hole	139.0 x 55.5	
Character Size	4.84 x 9.22	

ABSOLUTE MAXIMUM RATINGS

ITEM	SYMBOL	STANDARD VALUE			UNIT
		MIN.	TYP.	MAX.	
Power Supply	V_{DD} to V_{SS}	- 0.3	-	7.0	V
Input Voltage	V_I	- 0.3	-	V_{DD}	

Note

- V_{SS} = 0 V, V_{DD} = 5.0 V

ELECTRICAL CHARACTERISTICS

ITEM	SYMBOL	CONDITION	STANDARD VALUE			UNIT
			MIN.	TYP.	MAX.	
Input Voltage	V_{DD}	V_{DD} = + 5 V	4.7	5.0	5.3	V
		V_{DD} = + 3 V	2.7	3.0	5.3	
Supply Current	I_{DD}	V_{DD} = + 5 V	-	8.0	10.0	mA
Recommended LC Driving Voltage for Normal Temperature Version Module	V_{DD} to V_0	- 20 °C	5.0	5.1	5.7	V
		0 °C	4.6	4.8	5.2	
		25 °C	4.1	4.5	4.7	
		50 °C	3.9	4.2	4.5	
		70 °C	3.7	3.9	4.3	
LED Forward Voltage	V_F	25 °C	-	4.2	4.6	V
LED Forward Current	I_F	25 °C	-	540	1080	mA
EL Power Supply Current	I_{EL}	V_{EL} = 110 V_{AC}, 400 Hz	-	-	5.0	mA

OPTIONS

PROCESS COLOR						BACKLIGHT			
TN	STN Gray	STN Yellow	STN Blue	FSTN B&W	STN Color	None	LED	EL	CCFL
x	x	x	x	x		x	x	x	

For detailed information, please see the “Product Numbering System” document.

DISPLAY CHARACTER ADDRESS CODE

Display Position

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
DD RAM Address	00	01	02	03	04	05	06	07	08	09	0A	0B	0C	0D	0E	0F	10	11	12	13
DD RAM Address	40	41	42	43	44	45	46	47	48	49	4A	4B	4C	4D	4E	4F	50	51	52	53
DD RAM Address	14	15	16	17	18	19	1A	1B	1C	1D	1E	1F	20	21	22	23	24	25	26	27
DD RAM Address	54	55	56	57	58	59	5A	5B	5C	5D	5E	5F	60	61	62	63	64	65	66	67

INTERFACE PIN FUNCTION

PIN NO.	SYMBOL	FUNCTION
1	V_{SS}	Ground
2	V_{DD}	+ 3 V or + 5 V
3	V_0	Contrast adjustment
4	RS	H/L register select signal
5	R/W	H/L read/write signal
6	E	H → L enable signal
7	DB0	H/L data bus line
8	DB1	H/L data bus line
9	DB2	H/L data bus line
10	DB3	H/L data bus line
11	DB4	H/L data bus line
12	DB5	H/L data bus line
13	DB6	H/L data bus line
14	DB7	H/L data bus line
15	A	Power supply for LED (4.2 V)
16	K	Power supply for B/L (0 V)
17	NC/V_{EE}	NC or negative voltage output
18	NC	NC connection

5.TL082

TL081, TL081A, TL081B, TL081H
TL082, TL082A, TL082B, TL082H
TL084, TL084A, TL084B, TL084H

SLOS081M - FEBRUARY 1977 - REVISED DECEMBER 2021

TL08xx FET-Input Operational Amplifiers

1 Features

- High slew rate: 20 V/µs (TL08xH, typ)
- Low offset voltage: 1 mV (TL08xH, typ)
- Low offset voltage drift: 2 µV/°C
- Low power consumption: 940 µA/ch (TL08xH, typ)
- Wide common-mode and differential voltage ranges
  - Common-mode input voltage range includes V_{CC+}
- Low input bias and offset currents
- Low noise: $V_n = 18\ \text{nV}/\sqrt{\text{Hz}}$ (typ) at f = 1 kHz
- Output short-circuit protection
- Low total harmonic distortion: 0.003% (typ)
- Wide supply voltage: ±2.25 V to ±20 V, 4.5 V to 40 V

2 Applications

- Solar energy: string and central inverter
- Motor drives: AC and servo drive control and power stage modules
- Single phase online UPS
- Three phase UPS
- Pro audio mixers
- Battery test equipment

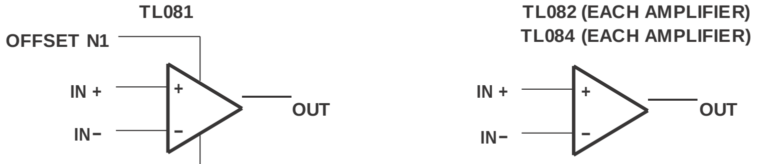
3 Description

The TL08xH (TL081H, TL082H, and TL084H) family of devices are the next-generation versions of the industry-standard TL08x (TL081, TL082, and TL084) devices. These devices provide outstanding value for cost-sensitive applications, with features including low offset (1 mV, typical), high slew rate (20 V/µs), and common-mode input to the positive supply. High ESD (1.5 kV, HBM), integrated EMI and RF filters, and operation across the full -40°C to 125°C enable the TL08xH devices to be used in the most rugged and demanding applications.

Device Information

PART NUMBER[1]	PACKAGE	BODY SIZE (NOM)
TL081x	PDIP (8)	9.59 mm × 6.35 mm
	SC70 (5)	2.00 mm × 1.25 mm
	SO (8)	6.20 mm × 5.30 mm
	SOIC (8)	4.90 mm × 3.90 mm
	SOT-23 (5)	1.60 mm × 1.20 mm
TL082x	PDIP (8)	9.59 mm × 6.35 mm
	SO (8)	6.20 mm × 5.30 mm
	SOIC (8)	4.90 mm × 3.90 mm
	SOT-23 (8)	2.90 mm × 1.60 mm
	TSSOP (8)	4.40 mm × 3.00 mm
TL082M	CDIP (8)	9.59 mm × 6.67 mm
	LCCC (20)	8.89 mm × 8.89 mm
TL084x	PDIP (14)	19.30 mm × 6.35 mm
	SO (14)	10.30 mm × 5.30 mm
	SOIC (14)	8.65 mm × 3.91 mm
	SOT-23 (14)	4.20 mm × 2.00 mm
	TSSOP (14)	5.00 mm × 4.40 mm
TL084M	CDIP (14)	19.56 mm × 6.92 mm
	LCCC (20)	8.89 mm × 8.89 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.



Logic Symbols

6. IR2011PBF

International
IOR Rectifier

Data Sheet No.PD60217 Rev A

IR2011(S) & (PbF)

HIGH AND LOW SIDE DRIVER

Features

- Floating channel designed for bootstrap operation
  Fully operational up to +200V
  Tolerant to negative transient voltage, dV/dt immune
- Gate drive supply range from 10V to 20V
- Independent low and high side channels
- Input logicHIN/LIN active high
- Undervoltage lockout for both channels
- 3.3V and 5V input logic compatible
- CMOS Schmitt-triggered inputs with pull-down
- Matched propagation delay for both channels
- 8-Lead SOIC is also available LEAD-FREE (PbF)

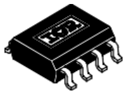
Product Summary

V_{OFFSET}	200V max.
I_O+/-	1.0A /1.0A typ.
V_{OUT}	10 - 20V
$t_{on/off}$	80 & 60 ns typ.
Delay Matching	20 ns max.

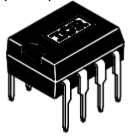
Applications

- Audio Class D amplifiers
- High power DC-DC SMPS converters
- Other high frequency applications

Packages



8-Lead SOIC
IR2011S
also available
LEAD-FREE (PbF)

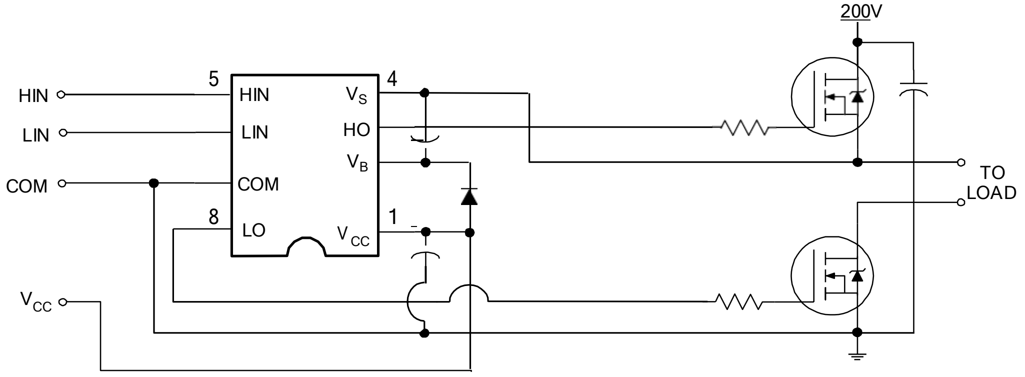


8-Lead PDIP
IR2011

Description

The IR2011 is a highpower, highspeed power MOSFET driver with independent high and low side referenced output channels, ideal for Audio Class D and DC-DC converter applications. Logic inputs are compatible with standard CMOS or LSTTL output, down to 3.0V logic. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction. Propagation delays are matched to simplify use in high frequency applications. The floating channel can be used to drive an N-channel power MOSFET in the high side configuration which operates up to 200 volts. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction.

Typical Connection



(Refer to Lead Assignments for correct configuration). This/These diagram(s) show electrical connections only. Please refer to our Application Notes and DesignTips for proper circuit board layout.

Absolute Maximum Ratings

Absolute maximum ratings indicate sustained limits beyond which damage to the device may occur. All voltage parameters are absolute voltages referenced to COM. The thermal resistance and power dissipation ratings are measured under board mounted and still air conditions.

Symbol	Definition		Min.	Max.	Units
V_B	High side floating supply voltage		-0.3	250	V
V_S	High side floating supply offset voltage		V_B - 25	V_B + 0.3	
V_{HO}	High side floating output voltage		V_S - 0.3	V_B + 0.3	
V_{CC}	Low side fixed supply voltage		-0.3	25	
V_{LO}	Low side output voltage		-0.3	V_{CC} +0.3	
V_{IN}	Logic input voltage (HIN & LIN)		COM -0.3	V_{CC} +0.3	
dV_S/dt	Allowable offset supply voltage transient (figure 2)		—	50	V/ns
P_D	Package power dissipation @ $T_A \le +25°C$	(8-lead DIP)	—	1.0	W
		(8-lead SOIC)	—	0.625	
R_{THJA}	Thermal resistance, junction to ambient	(8-lead DIP)	—	125	°C/W
		(8-lead SOIC)	—	200	
T_J	Junction temperature		—	150	°C
T_S	Storage temperature		-55	150	
T_L	Lead temperature (soldering, 10 seconds)		—	300	

Recommended Operating Conditions

For proper operation the device should be used within the recommended conditions. The V_S and COM offset ratings are tested with all supplies biased at 15V differential.

Symbol	Definition	Min.	Max.	Units
V_B	High side floating supply absolute voltage	V_S + 10	V_S + 20	V
V_S	High side floating supply offset voltage	Note 1	200	
V_{HO}	High side floating output voltage	V_S	V_B	
V_{CC}	Low side fixed supply voltage	10	20	
V_{LO}	Low side output voltage	0	V_{CC}	
V_{IN}	Logic input voltage (HIN & LIN)	COM	5.5	
T_A	Ambient temperature	-40	125	

Note 1: Logic operational for V_S of -4 to +200V. Logic state held for V_S of -4V to $-V_{BS}$.

Dynamic Electrical Characteristics

V_{BIAS} (V_{CC}, V_{BS}) = 15V, C_L = 1000 pF, T_A = 25°C unless otherwise specified. Figure 1 shows the timing definitions.

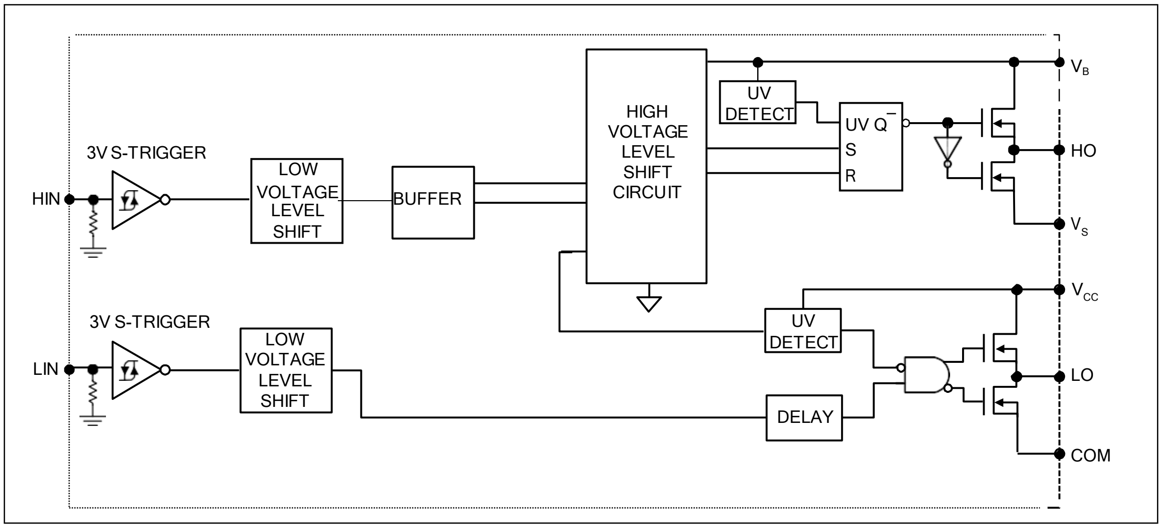
Symbol	Definition	Min.	Typ.	Max.	Units	Test Conditions
t_{on}	Turn-on propagation delay	—	80	—	ns	V_S = 0V
t_{off}	Turn-off propagation delay	—	75	—		V_S = 200V
t_r	Turn-on rise time	—	35	50		
t_f	Turn-off fall time	—	20	35		
DM1	Turn-on delay matching | t_{on} (H) - t_{on} (L) |	—	5	20		
DM2	Turn-off delay matching | t_{off} (H) - t_{off} (L) |	—	5	20		

Static Electrical Characteristics

V_{BIAS} (V_{CC}, V_{BS}) = 15V, and T_A = 25°C unless otherwise specified. The V_{IN}, V_{TH} and I_{IN} parameters are referenced to COM and are applicable to all logic input leads: HIN and LIN. The V_O and I_O parameters are referenced to COM and are applicable to the respective output leads: HO or LO.

Symbol	Definition	Min.	Typ.	Max.	Units	Test Conditions
V_{IH}	Logic "1" input voltage	2.2	—	—	V	V_{CC} = 10V - 20V
V_{IL}	Logic "0" input voltage	—	—	0.7		
V_{OH}	High level output voltage, V_{BIAS} - V_O	—	—	2.0		I_O = 0A
V_{OL}	Low level output voltage, V_O	—	—	0.2		20mA
I_{LK}	Offset supply leakage current	—	—	50	µA	V_B=V_S = 200V
I_{QBS}	Quiescent V_{BS} supply current	—	90	210		V_{IN} = 0V or 3.3V
I_{QCC}	Quiescent V_{CC} supply current	—	140	230		V_{IN} = 0V or 3.3V
I_{IN+}	Logic "1" input bias current	—	7.0	20		V_{IN} = 3.3V
I_{IN-}	Logic "0" input bias current	—	—	1.0		V_{IN} = 0V
V_{BSUV+}	V_{BS} supply undervoltage positive going threshold	8.2	9.0	9.8	V	
V_{BSUV-}	V_{BS} supply undervoltage negative going threshold	7.4	8.2	9.0		
V_{CCUV+}	V_{CC} supply undervoltage positive going threshold	8.2	9.0	9.8		
V_{CCUV-}	V_{CC} supply undervoltage negative going threshold	7.4	8.2	9.0		
I_{O+}	Output high short circuit pulsed current	—	1.0	—	A	V_O= 0V, PW ≤ 10 µs
I_{O-}	Output low short circuit pulsed current	—	1.0	—		V_O = 15V, PW ≤ 10 µs

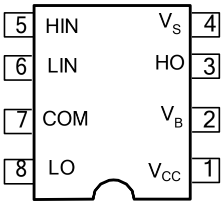
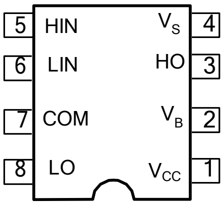
Functional Block Diagram



Lead Definitions

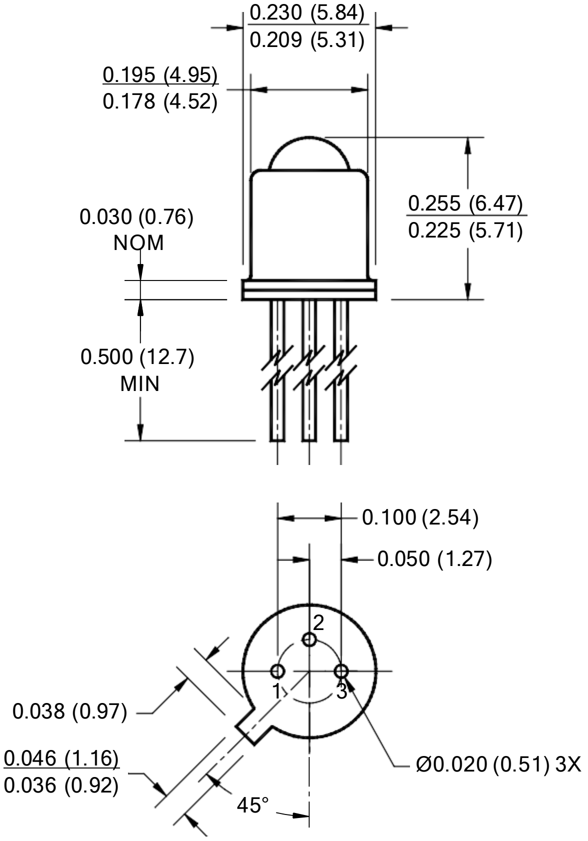
Symbol	Description
HIN	Logic input for high side gate driver output (HO), in phase
LIN	Logic input for low side gate driver output (LO), in phase
V_B	High side floating supply
HO	High side gate drive output
V_S	High side floating supply return
V_{CC}	Low side supply
LO	Low side gate drive output
COM	Low side return

Lead Assignments

 8-Lead PDIP	 8-Lead SOIC also available LEAD-FREE (PbF)
IR2011	**IR2011S**
Part Number	

L14G1 L14G2 L14G3

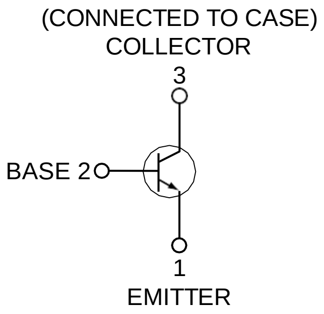
PACKAGE DIMENSIONS



NOTES:

1. Dimensions for all drawings are in inches (mm).
2. Tolerance of ± .010 (.25) on all non-nominal dimensions unless otherwise specified.

SCHEMATIC



DESCRIPTION

The L14G1/L14G2/L14G3 are silicon phototransistors mounted in a narrow angle, TO-18 package.

FEATURES

- Hermetically sealed package
- Narrow reception angle

FAIRCHILD
SEMICONDUCTOR®

HERMETIC SILICON PHOTOTRANSISTOR

L14G1 L14G2 L14G3

ABSOLUTE MAXIMUM RATINGS (T_A = 25°C unless otherwise specified)

Parameter	Symbol	Rating	Unit
Operating Temperature	T_{OPR}	-65 to +125	°C
Storage Temperature	T_{STG}	-65 to +150	°C
Soldering Temperature (Iron)(3,4,5 and 6)	T_{SOL-I}	240 for 5 sec	°C
Soldering Temperature (Flow)(3,4 and 6)	T_{SOL-F}	260 for 10 sec	°C
Collector to Emitter Breakdown Voltage	V_{CEO}	45	V
Collector to Base Breakdown Voltage	V_{CBO}	45	V
Emitter to Base Breakdwon Voltage	V_{EBO}	5	V
Power Dissipation (T_A = 25°C)(1)	P_D	300	mW
Power Dissipation (T_C = 25°C)(2)	P_D	600	mW

NOTE:

1. Derate power dissipation linearly 3.00 mW/°C above 25°C ambient.
2. Derate power dissipation linearly 6.00 mW/°C above 25°C case.
3. RMA flux is recommended.
4. Methanol or isopropyl alcohols are recommended as cleaning agents.
5. Soldering iron tip 1/16” (1.6mm) minimum from housing.
6. As long as leads are not under any stress or spring tension.
7. Light source is a GaAs LED emitting light at a peak wavelength of 940 nm.
8. Figure 1 and figure 2 use light source of tungsten lamp at 2870°K color temperature. A GaAs source of 3.0 mW/cm^2 is approximately equivalent to a tungsten source, at 2870°K, of 10 mW/cm^2.

ELECTRICAL / OPTICAL CHARACTERISTICS (T_A =25°C) (All measurements made under pulse conditions)

PARAMETER	TEST CONDITIONS	SYMBOL	MIN	TYP	MAX	UNITS
Collector-Emitter Breakdown	I_C = 10 mA, Ee = 0	BV_{CEO}	45		—	V
Emitter-Base Breakdown	I_E = 100 µA, Ee = 0	BV_{EBO}	5.0		—	V
Collector-Base Breakdown	I_C = 100 µA, Ee = 0	BV_{CBO}	45		—	V
Collector-Emitter Leakage	V_{CE} = 10 V, Ee = 0	I_{CEO}	—		100	nA
Reception Angle at 1/2 Sensitivity		θ		±10		Degrees
On-State Collector Current L14G1	Ee = 0.5 mW/cm^2, V_{CE} = 5 V(7,8)	$I_{C(ON)}$	1.0		—	mA
On-State Collector Current L14G2	Ee = 0.5 mW/cm^2, V_{CE} = 5 V(7,8)	$I_{C(ON)}$	0.5			mA
On-State Collector Current L14G3	Ee = 0.5 mW/cm^2, V_{CE} = 5 V(7,8)	$I_{C(ON)}$	2.0			mA
Turn-On Time	I_C = 2 mA, V_{CC} = 10 V, R_L =100 Ω	t_{on}		8		µs
Turn-Off Time	I_C = 2 mA, V_{CC} = 10 V, R_L =100 Ω	t_{off}		7		µs
Saturation Voltage	I_C = 1.0 mA, Ee = 3.0 mW/cm^2(7,8)	$V_{CE(SAT)}$	—		0.40	V