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DEVELOPMENT OF A LOW-COST MICROCONTROLLER BASED LUX-METER WITH PHOTORESISTOR SENSOR

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Abstract

This work discussed the development of a low cost microcontroller based lux-meter, a device which measures the amountof light illuminance over a surface in "lux", from in expensive materials. The meter consists of fourmajor units: the input unit, control unit, display unit and the power unit.The input unit is the sensing part of the meter whichcomprises of photoresistor(light dependent resistor, LDR) and a 1kΩ resistor arranged in voltage divider configuration to detect light and provide output voltage signal corresponding to the value of light detected. The control unit is based onarduinomicrocontroller that converts the output voltage signal from the input unit into equivalent digital signal.With some codes and calculations, the microcontroller further processesthe digital signal into a readable form corresponding to the value of light intensity detected by the LDR. The display unit is accomplished with a 16 x 2 liquid crystal display (LCD) that display the readings processed by the microcontroller on the screen and the power unit is obtained using a 9 V Can battery. By graphically comparing the readings obtained by the locally developed lux-meter with that of the standard lux-meter, it was shown that the meter has a good correlationwith the standard one, and this has proven that the locally developedlux-meter is capable of measuring light illuminance over a surface with an accuracy of 99.27% and a tolerance value of ±0.73% at high intensity. The meter can be applied in photometry as a measure of intensity, as perceived by the human eye, of light that hits or passes through a surface.Also, it can be used in the Laboratory for demonstration and research purposes aswell as in health and allied industries.

Keyword**:** Lux-meter, light illuminance, Arduinomicrocontroller and light-dependent resistor(LDR).

1. INTRODUCTION

The study of light illuminance, that is, the amount of light falling on a unit given surface have been widely explored as a result of its significance in many applications of day-to-day technology. It is known to be useful in playing an important role as a common parameter to be measured in lighting assessment. It is used to evaluate the adequacy of lighting for seeing an object and to read clearly. Accordingly, there should be an appropriate level of the light falling on an environment where people are working for safety and prevention of hazards.Excessive contrast, strong glare and light flickering in the fields of vision are inappropriate [1].

To ensure good lighting, a suitable lighting assessment and measurement of light illuminance is required. To perform these tasks, technicians often make use of "lux-meter", a device used to measure the intensity of light falling on a surface area in "lux".

The lux (symbol: lx) is the SI unit of illuminance and luminous emittance.It is equal to one lumen per square meter(lumen/m^2)[2, 3].

A simpler way to describe this meter is to say that it measures the degree of brightness of light falling on a given surface area as perceived by human eye

Measuring the intensity of light is very important nowadays in the fields of solar energy technology and LED bulbs lighting solutions for different places like offices, homes, etc. The light intensity measurement is also required in the field of testing and experimentation like photolithography setup, green house effects [3].

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In photometry, such as photography and video filming respectively, where light brightness is required for photographers to adjust their shutter speed and depth of field to get the best picture quality, lux-meter is an important device to carried out the task. It is also very useful in filming outdoor scenes of television programs or movies as it allows adjustments to make sure scenes filmed in different light levels have a consistent brightness on screen [4].

The meter enables printing machine to measure lux of light needed to coat a plate when triggered, and subsequently raise an obstruction between the plate and the light source to prevent further illumination, or raise an alarm automatically through its lighting device [5].

Another common use of a lux-meter is in meeting health and safety regulations, as it can be used to check whether a room is bright enough to meet any rules designed to protect workers from having damages to their eyesight. It allows employees to read labels and safety instructions (such as those affixed to chemical containers) to ensure compliance with safety measures for the prevention of hazards.

In view of the reasons stated above, this work is aimedat developing a low cost microcontroller based lux-meter to measure the intensity of illumination (brightness).

The light detecting sensors, photocells; that may be used to build this meter include;photoresistors, photodiodes andphototransistorsto capture light. The photoresistors are made from a film of the semiconductor materials such as cadmium sulfide (CdS), cadmium selenide (CdSe), lead sulfide (PbS), lead selenide (PbS) [6]and gallium arsenide (GaAs) [7]. Their resistance varies according to the amount of light falling on their "windows", for this reason they are often called light-dependent resistors(LDR).

The resistance of the LDR falls from mega-ohm (MΩ) in the darkness to a fewohms (Ω) in the brightness asthe level of lightwhich falls on its surface changes.

The photodiode, usually silicon, has a small window that allows light to fall on the p-n junction. This light creates hole-electron pairs at the junction and therefore induces current in the diode. The diode can be used in a forward or reverse mode. In the forward mode, it operates in exactly the same manner as a solar cell, thereby producing a voltage output for any light input.

For the diode to be used as light sensor, it must be reverse bias so that its dark current is very low. Then, as incident light on its window is increased, the output current will rise in proportion and this relationship is very linear. The phototransistor uses the same principle as the photodiode, but because it is an amplifier the device is even more sensitive than photodiode [8].

Light falling on the base of the transistor via the glass window sets up a base current and this is amplified to appear as a large collector current.

The phototransistors and photodiodes are much faster than the LDR with rise times of a few microseconds (μs) or even nanoseconds (ns) in most cases.

In this case, aphotoresistor(light-dependent resistors, LDR) is selected;it is basically selected due to the following characteristics: 1) it is more available in the market; 2) it is cheaper and 3) it is very easy to work with.

In previous years, many researchers have developed this meter using integrated circuits such as comparator as the core of their devices. For instance, in [3] and [5],the meter was developed using μA741 operational amplifier (Op-Amp)as controller with some other analog devices at high cost.

Concerning this issue, the increasing accessibility to microcontrollers has helped to develop a lux-meter at low price. In this way, one of the most common microcontroller devices used for electronic prototyping in the recent years is Arduino microcontroller.

The microcontroller constitutes an open-source electronic platform that allows monitoring and controlling of different analog and digital signals,as well as other specific electronic circuits.

It is arguably the easiest and least expensive microcontroller option for hobbyists, students and professionals to develop microcontrollerbased projects. Arduinos use either an Atmel AVR or Atmel ARM microcontroller chip. They have six or more analog input pins and fourteen or more digital input/output (I/O) pins that are used to connect sensors, actuators, and other peripheral.

There are many different types of Arduinos available, each with its own feature set. They differ with regard to processing speed, memory, I/O ports, and connectivity, but their basic functionality is the same [9].

In this work, a low cost Arduino microcontroller based lux-meter was developed to measure the level of light intensity falling on a surface area.The meter has been tested taking light measurements and compared with the convectional (standard)lux-meter. The obtained results demonstrate the suitability of the locally developed lux-meter to acquire measurements and this provide a low cost alternative to the standard oneavailable in the market.The meter is fully automated, easy to maintain and very comfortable to use. The power consumption is low and can be operated easily. Above all, the meter is very economical over the standard one.The entire project is designed using microcontroller based upon its reliability.

2. MATERIALS AND METHODS

The block diagram of the hardware scheme of the developed meter is shown in Figure1.Basically, it is composed of four majorunits: the input unit, control unit, display unit and the power unit.The four units are designed independently before being joined into one system. This ensures that if there are any errors, they are independently considered and corrected.

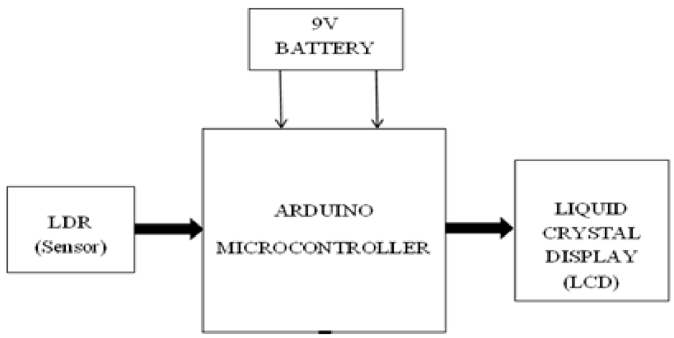

Figure 1: Block diagram of the locally developed

Input Unit

The input unit is the sensingsectionof the devicewhich comprises of photoresistor (light-dependent resistor, LDRORP12) and a complementary resistor with a value of 1kΩ arranged in a voltage divider configuration.The sensor, LDRis selected because it is readily more available in the market and cheaper than the other two types of photocells; photodiodes and phototransistors.The LDR is connected to the reference supply voltage obtained from 5V output pin of the microcontroller board and the1kΩ resistor is connected to the ground as indicated in Figure 2.With the resulting configuration, the 5V supply voltage splits between the LDR and the 1kΩ resistor to obtain anoutput voltage $V_o$corresponding to the value of the light intensity captured by the LDR. Thus, this allows high voltage across the LDR while in bright light and low voltage in darkness. The value of the complementary resistor is chosen such that the widest output range is achieved and not exceeds 5V, which is the highest voltage level that can be accepted by the microcontroller analogue input. Also, this enables the rate of variation in the conductivity of the LDR to be more visible.The picture of the light-dependent resistor used is indicated at the top left of the voltage divider circuit shown in Figure 2.

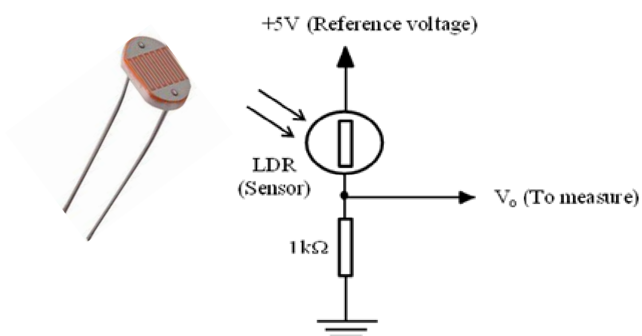

Figure 2: The input circuit that employs a

From the given relationship, the input-output relationship for the voltage divider circuit is given byEquation (1):

$$V_o = V_{cc}\left\{\frac{R}{LDR + R}\right\}, \qquad (1)$$

In this case,

V_o = Output voltage from the voltage divider (input circuit) as well as input voltage to the microcontroller

R = Resistance of the resistor which is 1kΩ

V_{cc} = Supply voltage to the LDR (this is the 5 V reference supply)

Control circuit

This section of the device is accomplished using arduinounomicrocontroller board, a device that can be programmed for various purposes. The device helps to eliminate the use of integrated circuits such as comparator as the controller of the meter. Figure 3shows the picture of the microcontroller board. The board consists of Atmega 328P microcontroller chip with 6 analog inputs and 14 digital input/output (I/O) pins, 6 of which are pulse width modulator (PWM) outputs and 10bits inbuilt analog-to-digital converter (ADC).

The microcontroller is programmed using C language to read the output voltage $V_o$from the input circuit via one of its analogueinput pin A0. Withthe additionof some codes and calculations, the microcontroller with its 10bits inbuilt analogue-to-digital converter (ADC), then converts the output voltage $V_o$into corresponding digital values in the range of 0-1023.

The digital values obtained are further processed into a readable form corresponding to the light intensity values detected by the LDR in Lux.The conversion is done using Equation (2).

$$\text{LDR Output} = \frac{\text{Equivalent Digital Output} * 5}{1023}\,\text{Volts}, \quad (2)$$

Figure 3: Arduinouno

Display unit

The display unit of the meter is achieved using 16x2 Hitachi's HD44780 liquid crystal display (LCD)module; the module is a thin flat screenthat can display a total of 32 characters, which are divided into two lines of sixteen characters to produceoutput readings over itsscreen.

The LCD is interfaced with the microcontroller through pins 2, 3, 4, 5, 11 and 12 of the digital pins on the microcontroller board to display the values of the light intensity detected by the meter over its screen. The picture of the LCD is shown in

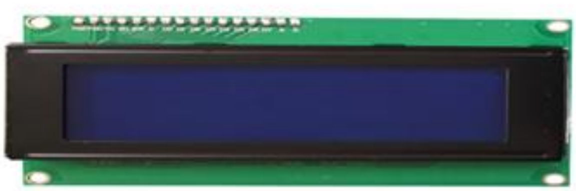

Figure 4: 16 x 2 Liquid crystal display

Power unit

The entire systemwaspowered using a 9V Can battery via pin V_{in} of the microcontroller board, while the other units of the meter were powered with 5Vacquired from the voltage output pin on the microcontroller board as indicated in the circuit diagram of the device shown in Figure 5. The complete assembly of the locally developed lux-meter is shown in Figure 7, while the convectional lux-meter is indicated in Figure 8.

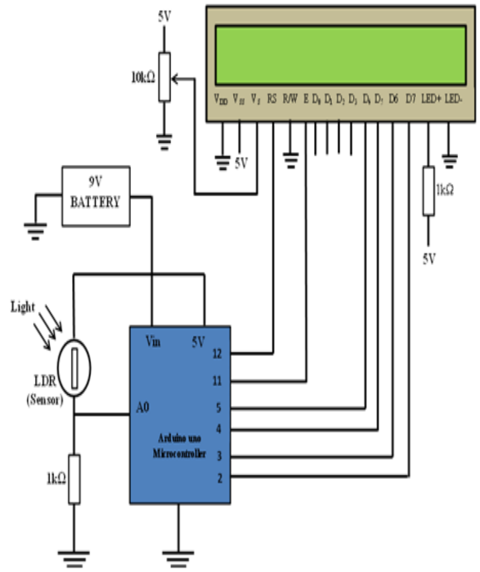

Figure 5: Circuit diagram of the locally developed lux-meter

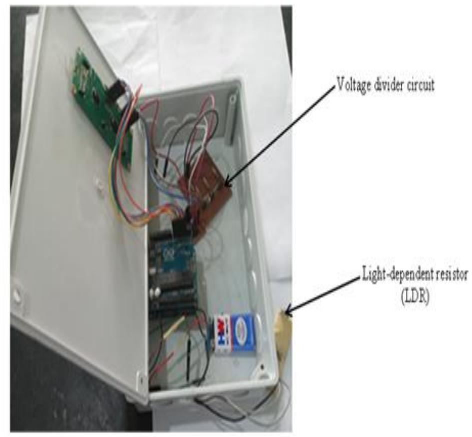

Figure 6: The internal circuitry of the locally developed lux-meter

Figure 7: The complete assembly of the locally developed lux-meter

Figure 8: The convectional (standard) lux-meter

3. CALIBRATION AND PERFORMANCE TESTS

Each unit of the developed lux-meter described above was coupled together using flexible wires as shown in Figure 6. The LDR resistance is measured under bright light, average light and dark conditions to determine its maximum resistance value and the results are presented in the Table 1.

The complete arrangement of the lux-meter was calibrated with theconvectional (standard)lux-meteravailable in our departmental laboratory. The convectional meter has photodiode as sensor. The two meters weresubjected to various light sourcesat the same time to take the measurements of light intensity in order to test for its accuracy and precision;the results of the measurement are presentedin Table 2.

Table 1: Light-dependent resistor(LDR)Resistance Testing Data

Measured Resistance	Lighting Conditions
1000kΩ	Dark condition (the LDR was placed inside container)
4.75 kΩ	Average light condition (normal room lighting level)
158 Ω	Bright light condition (20 LED bulbs Hand torch pointed directly in front of the LDR)

Table 2:
Readings of light intensity taken with the convectional (standard) lux-meter and the locally developed lux-meter.

Light Conditions	Convectional (Standard) Meter Light level (lux)	Locally Developed Meter Light level (lux)
Total Darkness	0.00	0.00
No moon	0.17	0.18
Mid-Night Full moon	121.24	122.18
Sunset	135.63	136.15
Sunrise	513.97	515.01
Mid-day sunlight	1305.01	1306.32
20 LED bulbs Hand torch	1516.03	1517.08
30watts Florescent bulb	1713.80	1824.20
60watts Filament bulb	2523.01	2651.14
75watts Florescent bulb	2702.12	2721.10
120watts Filament bulb	3411.03	3421.14
Car headlamp	5332.24	5344.10

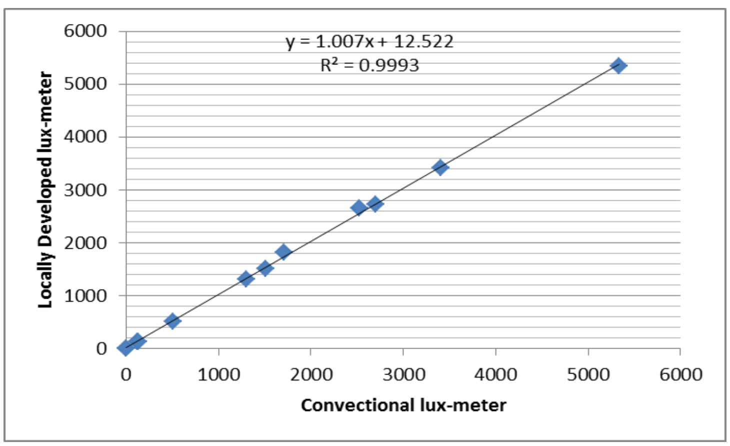

Figure 9: Graph of convectional lux-meter versus locally

4. RESULTS AND DISCUSSION

The readings from Table 1 clearly confirm the relationship between the light intensity and resistance of the sensor (LDR). It was observed that the LDR display high resistance value while in darkness and low resistance value while in bright light. This shows that the resistance of the LDR varies inversely as the light intensity changes.

The measurements of the light intensity obtained by our locally developed lux-meter and that of thestandard meter shown inTable 2 werecompared in order to determine its reliability.

In this case, the light intensity values obtained from the standard lux-meter were plotted in agraph against the values obtained from the locally developed lux-meter as shown in Figure 9; this is carried outto check the instruments correlation.

As in the graph, the slope of the graph was 1.007and $R^2$was calculated to be 0.9993;which shows that the correlation between the locally developed lux-meter and standard lux-meter was found to be very close to unity, thissuggests that the values from the locally developed lux-meter washighly reliable. Also, from thereadings of the two meters presented in Table 2, the standard deviation valueswere calculated to be 1651.794 and 1663.859 respectively. From these values the developed lux-meter was found to be capable of measuring light intensity with an accuracy of 99.27% and a tolerance value of ±0.73%.Differences in the measured values of the two meters as illustrated in Table 2 are probably a result of different sensors used in their circuits.

5. CONCLUSION

This paper has presented the developmentof a low cost microcontroller based light intensity measurement instrument (lux-meter). The result demonstrated in the graph shown in Figure 9has indicated that the locally developed lux-meter has a good correlation with the standard type and thishas proven that the meter work satisfactorily by using light-dependent resistor (LDR)as a light sensor andarduino microcontroller as the core of the device.The meter was found capable of measuring light intensity with an accuracy of 99.27% and a tolerance value of ±0.73% at high intensity. Therefore, thiscan be proposed as a better replacement for the high cost light intensity lux-meter available in the market.Technicians and lighting solution engineers who intend not to spend much money on a lux-meter can purchase this low cost designed meter and get their work done easily. For low cost operations,this design is perfect and more feasible to buy and use because of its simple design.

6. ACKNOWLEDGMENTS

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