Lux Meter Integrated with Internet of Things (IoT) and Data Storage (LMX20)

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***Abstract*—This project presents a prototype of lux meter integrated with Internet of Things (IoT) and data saving. Some commercial lux meters do not have data storage and cannot connect to the internet. Therefore, this project developed a prototype of a lux meter with additional features such as data logger and IoT. The prototype is using NodeMCU as its controller because it is cheap and easy to use. Besides, the sensor used for this prototype is BH1750 light sensor. It has a wide range sensor, and it could detect up to 65535lx value. Then, the data obtained also can be stored and saved in the Secure Digital (SD) card. These features will allow the user to secure the data and use it in the future. For IoT, there is a built-in WiFI module which is ESP8266 where it connects the prototype to the application in a smartphone which is the Blynk application. In the application, it will show the reading of the lux from the prototype, and there is a graph analysis of the lux measurement. Apart from measuring the lux, this prototype is also suitable for monitoring applications as the measurement can be monitored from a smartphone. However, the experimental test is done at home obeying Movement Control Oder (MCO) due to Covid-19 in this area.**

Keywords—Lux Meter, Data Storage, Internet of Things (IoT), Blynk Application, SD Module, Data Logging, Illuminance, Lighting.

I. Introduction

As an electrical engineer, designing, developing and testing devices and equipment, including the systems and machines, are the necessary job scope for an electrical engineer. Designing luminance is also one of the job scopes as an electrical engineer. Different locations required different room illumination levels by following the Malaysia Standard (MS) or "Panduan Teknik Jabatan Kerja Raya (JKR)". The Department of Occupational Safety Health (DOSH) has provided the guideline for lighting at the workplace [1].

The reason for the guideline is to guide for achieving visual environments that are relaxed and suitable for the function of the interior. Lux measurement is essential as it affects the performance, health and safety of a person. In January 2014, Stadium of Universiti Teknologi MARA (UiTM) Shah Alam was one of the stadiums that are not allowed to be used at night as it fails to follow the specification of the Football Association of Malaysia (FAM) [2]. The minimum lux value that allowed is 1000lx. Therefore, the team that playing at UiTM stadium needs to play in the evening. This situation will cause tiredness to the players because playing football in the evening, especially in Malaysia will consume more energy than playing football at night. The scientific reason is that Malaysia is located near to the equator line. Hence, the climate of Malaysia is categorised as equatorial, which is hot and humid throughout the year. Besides, the weather in Malaysia is hotter than ten years before [3]. So, it will cause the players to hydrate more and has a high risk to get injured easily. The scientific journal from the American College of Allergy, Asthma and Immunology (ACAAI) has stated that living in locations closest to the equator can put you at increased risk of developing allergy and asthma [4]. The health and safety of a player might be in danger if their fatigue is not monitored carefully.

This prototype is the combination of a few ideas which are the lux meter, Internet of Things (IoT) and data logger. Generally, this project is using NodeMCU as the controller. NodeMCU is a microcontroller that prevalent in developing the IoT project. It is an easy-to-use and low-cost controller. There is a built-in Wi-Fi module which is ESP8266, where it allows users to have a stable internet connection. With that, the user can monitor the value of lux from the application named Blynk. Besides, it also can be easily programmed with Arduino IDE, user-friendly and used widely all around the world. Then, the light sensor used for this project was BH1750, where it has a high range of the sensor. Besides, Secure Digital (SD) module is also available for the users to use the SD card to save the data. Lastly, there is a Liquid Crystal Display (LCD) to display the value of the lux. In conclusion, this prototype is a low-cost lux meter that has data saving and using IoT. The lux meter can display the value of the lux on LCD and in Blynk application, and the SD card store the data.

II. Lux Meter

In this technological era, various types of lux meter can be found. There is a lot of lux meter that has been commercialised in the market. Furthermore, there is also some prototype of a lux meter that has been developed by the researchers. Those projects are about the development of a lux meter but using different types of controllers or sensors. This section will explain about those projects and compare the other project with the proposed prototype.

A. Commercial Lux Meter

A commercial lux meter is a lux meter that available in the market. The price range of the lux meter is from RM30 to more than RM10,000. The expensive the price, the more function and features are offered. So, people can choose to have either the basic lux meter or the high technology lux meter suitable with the user requirements. The critical part is the sensor on top of the body and the display. Different companies use different types of sensors. Therefore, the range of the sensor is different for each type of lux meter. Besides, there is also a lux meter that can separate the sensor and display; the display can be unlocked and connected to the cable provided by the developer [5].

B. Lux Meter Prototype

R. Hrbac, V. Kolar, T. Novak, and M. Bartłomiejczyk has developed a low-cost lux meter of usage in the automatic application for long-term measurement of illuminance [6]. The studies are about measuring the light to adjust the lighting system level of the artificial lighting on railways in the Czech Republic. The device is designed to transmit the measurement data to the FARCOM-ECO system where it is used to control the technological processes on the railways. A year later, the same team had built a prototype of a lux meter with high sensitivity suitable for long-term data recording [7]. The researcher [8] did the development and testing of HK-01 Data Logger lux meter, where it can operate automatically and record the data. The prototype measures illuminance and has a high range sensor from 10mlx to 100klx. The prototype also has an internal memory where all measured lux is saved. The recorded data can be either viewed on display or exported into a computer. The prototype can do the long-term evaluation of the state of obstructive light at night. The objective evaluation of obstructive light is to gather the data on its effect in different weather conditions and different locations.

C. Webcam-Based Lux Meter

In 2013, there is a study that uses a webcam as a lux meter [8]. A team from University Malaysia Perlis (UniMap) has developed a lux meter by using webcam where a series of controlled images are taken. Then, image processing is applied to the images. The results of the image are analysed statistically, and they have obtained a linear relationship between lux value and average grayscale with satisfactory R2. With the linear function that they calculated, the function is tested, and the results are justified. In the end, the algorithm for a low-cost webcam-based digital lux meter is developed. Then, from the previous study, the same researcher improvises the prototype by using the grid-based image processing [9]. The study is about an image processing-based technique by correlating the brightness level of an image with the actual lux value. From the results, the image is divided into four main grids, and the correlation is made prior to four light sources. The lighting mathematical model has been formulated concerning four grids. Hence, the lux value based on the mathematical model will be more accurate and more useful in manipulating the lux values.

D. Smartphone as Lux Meter

This section will explain the previous project that uses a smartphone as a lux meter. There is a study where an application for measuring lighting conditions was built with decision support systems [10]. This project is using the smartphone's camera to detect the light. With the measured value, there will be a comment based on the result. It is either

TABLE I. LUX METER THE SUMMARY OF LITERATURE REVIEW AND PROPOSED PROJECT

Project	Other prototypes	Smartphone	Web Cam	LMX20
Author	[7], [8]	[11], [12], [13], [14]	[16], [10]	Proposed research
Sensor	Photodiode, TLS 2561, MAX44009	Smartphone camera and sensor	Web cam	BH1570
Controller	DSP	Smartphone	Smartphone	NodeMCU
Software	DSP	Java	Java	Arduino IDE
Advantage	Low-cost, high range sensitivity, long term	Low-cost, provide decision, has application	Low-cost, capture image	Low-cost, high range sensitivity, using IoT, data storage
Limitation	Programme is complicated	Light scatter, need calibration, error up to 6%	Need calibration, error up to 11%	Need internet connection

the lighting is right or the lighting is insufficient. When the lighting is not following the specification, there will be a suggestion to change the bulb. However, since the project is using the phone's camera, the light might be scattered where it will affect the smartphone sensor reading, which will also affect the reading of the lux value. Hence, calibration is needed to reduce the error. Equation (1) is the equation of the calibration to reduce error.

$$(y-y1) / (y2-y1) = (x-x1) / (x2-x1) \tag{1}$$

Besides, there is also a project where it builds a low-cost cell-phone based digital lux meter [11]. The project is using a cell phone with a digital camera embedded and using JAVA to do the programming. Other than that, there is also a project where it is a low light detection for bioluminescence applications [12]. The study has proved that smartphones can be used as light measurement tools [13]. From the previous studies, a summary is made to compare each of the prototypes include the LMX20 prototype. The summary is based on the components used, the methodology, the advantages and the limitation of the project. Table I is the summary of the development of the lux meter prototype.

III. METHODOLOGY

This chapter will explain the prototype LMX20 in detail. It will include the components and software used for the project, the flowchart of the prototype operation and the circuit diagram.

A. Proposed Prototype

The prototype LMX20 is the development of a lux meter with a high range sensor and using IoT. This project is using NodeMCU as the microcontroller. The reason for using this controller is because of the simple working principle, cheap, user-friendly and has a built-in Wi-Fi module which is ESP8266. Hence, the prototype can be connected to the internet. The measured value can also be monitored through the phone via Blynk application and sent directly to the user's email. Besides, this prototype is using BH1750 as the light sensor. This light sensor can sense up to 65535 lux. With the wide sensor range, it is one of the best cheap light sensors that can be found. Then, this prototype also has a 2x16 LCD to show the measured lux value. So, the user can see the value on the spot. Last but not least, the SD module is attached to the controller. Hence, the user can save the data recorded on the SD card.

B. Hardware

NodeMCU ESP8266 is an open-source microcontroller what widely used for IoT project. The reason it is chosen for this project is because of the interesting features which are low cost, interactive, simple, smart and Wi-Fi enabled. Even there is a study that using NodeMCU to monitor flood [14]. This microcontroller contains a built-in Wi-Fi chip which is ESP8266 Wi-Fi SoC from Espressif Systems. With 128KB RAM and 4MB of flash memory, it is enough to store data and program of the prototype. NodeMCU can be powered up by any source that has USB port such as power bank and laptop since it is a low power battery operated application.

BH1750 is one of the ambient light sensors that have a wide range sensor. This sensor can measure the lux value precisely up to 65535lx. BH1750 is commonly used in smartphones where it senses the environment lighting and adjusts the brightness of the screen display. There is a study using this sensor to adjust the LCD screen brightness [15]. The sensor has five pins, and it uses the I2C communication protocol (SCL and SDA pins), so it is easy to use with NodeMCU. BH1750 light sensor measures the intensity based on the amount of light hitting on it and directly gives the lux value. The error for this sensor is low because the variation in measurement is as low as 20%.

One of the objectives of this project is to design a prototype with data recording and saving. Therefore, a micro SD card is needed for data logging. Hence, the micro SD card module is used in this project because it is easy to use, and the pinout is directly compatible with the microcontroller. The input voltage of the module for this project is 5V and only uses four input/output pins on the NodeMCU. The push-pop socket with a card is over the edge, so it is easy to insert or remove the SD card.

The LMX20 has Liquid Crystal Display (LCD) on it to show the value of the lux to the user. The LCD size is 16x2, and it has an I2C module attach to it. With the I2C module, the connection is much easier. Besides, it has a built-in potentiometer for contrast adjustment. The I2C is placed behind the screen.

C. Software

The development of the prototype employs two software: Arduino IDE and Blynk. Arduino IDE is used to write the program while Blynk is used for the smartphone application (Internet of Things).

Arduino Integrated Development Environment (IDE) is a cross-platform application for Windows, Mac OS X, and Linux. It is open-source software that is used to write and upload programs to boards such as Arduino boards and NodeMCU. The Arduino IDE can supports languages C and C++. The coding is simple and straightforward.

Blynk is the most popular IoT platform that connects devices to cloud, design application to control devices and analyse telemetry data. It supports both iOS and Android smartphones, and it can fit with any microcontroller such as Arduino, Raspberry Pi and NodeMCU. The reason it is chosen is that the application is free, it is customisable and user-

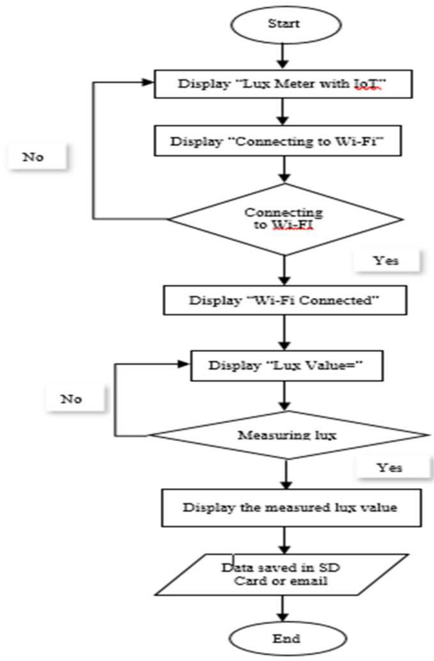

Fig. 1. Flowchart of the prototype

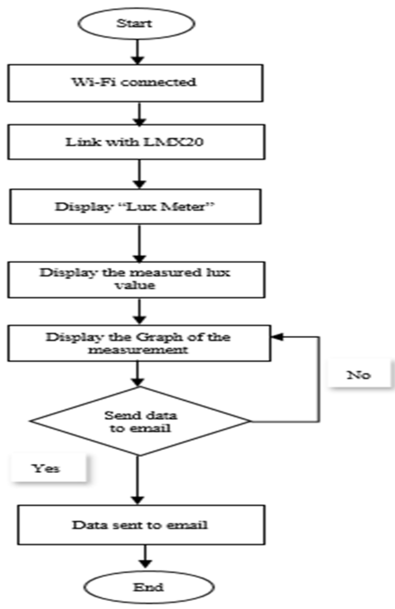

Fig. 2. Flowchart of the Blynk Application

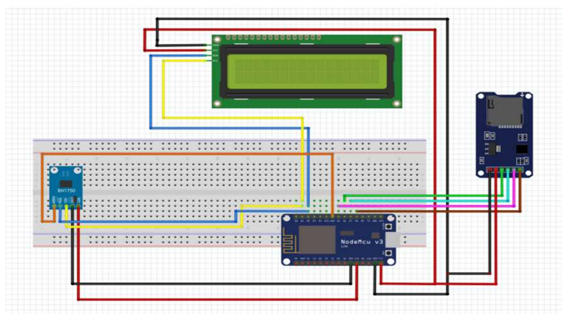

Fig. 3. The ciircuit diagram of the prototype.

friendly. The Blynk Library can connect any hardware over Wi-Fi, Ethernet, LTE, and many more. Many things can be developed, such as controlling devices, monitoring value and notification systems. For example, this application can be used to monitor the farm or garden [16][17]. With this application, the farmer can be more aware and alert to the farm condition. For this project, a monitoring system is used where the value from LMX20 is showed directly in the smartphone. After that, the measurement data can be sent to the user's email.

D. Operation

Since this project is applying IoT as its main objective, the project can be divided into two major parts which are the hardware and software. The hardware is the prototype LMX20 and the software is the Blynk Application.

Prototype LMX20 flowchart. The flowchart in Fig. 1 explains the whole operation of the LMX20. So, when the prototype is supplied with 5V - 6V source, it will start working. At first, the LCD will show the title "Lux Meter with IoT", then delay for a few seconds before it shows "Connecting to Wi-Fi". If the connection is successful, "Wi-Fi connected" will be displayed, but if not, it will reset. Then after successfully connected to the internet, the LMX20 will measure the lux and display the lux value. Then the data will be saved in the SD card if the user inserts the SD card. The data also can be sent to email by using a smartphone via Blynk Application.

In the Blynk application, there is an LCD widget to show the lux value and a Super Chart widget to show the live data. So, the consistency of the value can be monitored via a smartphone. The application starts when the LMX20 is connected to the internet, so it is also connected to the Blynk. Then, the value of the lux will be shown on the LCD widget. Every change from LMX20 LCD will also change the value in the Blynk LCD widget. Below the LCD widget, the Super Chart will visualise the live data. From that, a conclusion can be made for the sensor performance based on the line graph shown. Then, the value measured is saved and can be sent to the user via email. Therefore, the user does not need to memorise the value of the lux anymore. The flowchart of the application is shown in Fig. 2.

E. Circuit Diagram

The connection of the prototype is shown in Fig. 3. At first, connect the BH1750 light sensor with NodeMCU. The light sensor is using 3.3V, and then the SCL will connect to D1, SDA connects to D2 and ADDR will connect to the ground. Next, LCD will be supplied with 5V, SCL to D1 and SDA to D2 just like the BH1750. Lastly, the SD Card module, also get the 5V supply from Vin NodeMCU, the CS pin connect to D8, SCK pin connect to D5, MOSI connects to D7, and MISO connects to D6.

IV. Result and Analysis

For analysis, the LMX20 has been tested to measure the light intensity in the living room, kitchen, bedroom and bathroom. A commercial lux meter and a smartphone are also being used to compare the measurement with the prototype. The measurement is taken during night time to avoid Sunlight. Furthermore, the sensor of each piece of equipment is located at the same place and the same height, which is 4cm above the ground. Then, the results are analysed by calculating the percentage difference using (2).

$$\frac{\text{Other equipment} - \text{commercial lux meter}}{\text{commercial lux meter}} * 100\% \qquad (2)$$

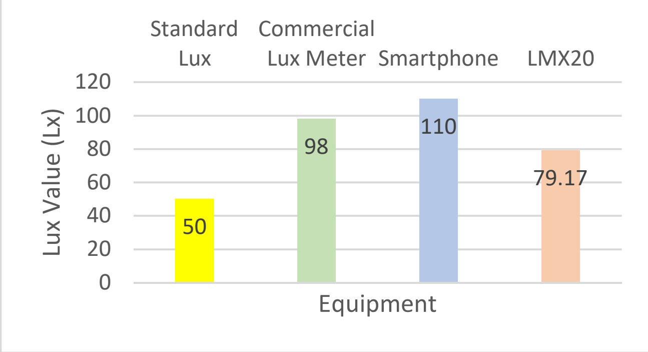

Fig. 4. The chart for the living room

TABLE II. THE PERCENTAGE DIFFERENCE IN THE EQUIPMENT FOR THE LIVING ROOM

[redacted]	LMX20	Smartphone
Commercial Lux Meter	19.21%	12.24%

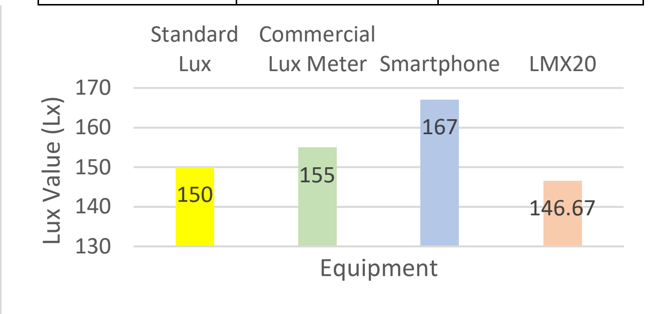

Fig. 5. The chart for the kitchen

TABLE III. THE PERCENTAGE DIFFERENCE IN THE EQUIPMENT FOR THE KITCHEN

[redacted]	LMX20	Smartphone
Commercial Lux Meter	5.37%	7.74%

A. Living Room

In the living room, the lux value measured by LMX20 was 79.17lx, commercial lux meter was 98lx, and the smartphone was 110lx, as shown in Fig. 4. However, the standard lux from Jabatan Kerja Raya (JKR) is 50lx only. The percentage difference is shown in Table II where the difference between LMX20 and commercial lux meter is less than 20%. The considerable gap difference is maybe caused by the bulb used in the living room.

B. Kitchen

For the kitchen, the standard lux that recommended by JKR is 150lx. Meanwhile, the value measured by a commercial lux meter was 155lx, the smartphone was 167lx, and LMX20 was 146.67lx as shown in Fig. 5. The percentage difference is shown in Table III where the difference is less than 10%. From the measurement, a conclusion can be made where the lighting condition in the kitchen is good.

C. Bedroom

In the bedroom, 50lx is the recommended lux value. Fig. 6 shows the reading for each equipment is 82.5lx for LMX20, 92lx for commercial lux meter and 103lx for the smartphone. The percentage difference between LMX20 and a commercial

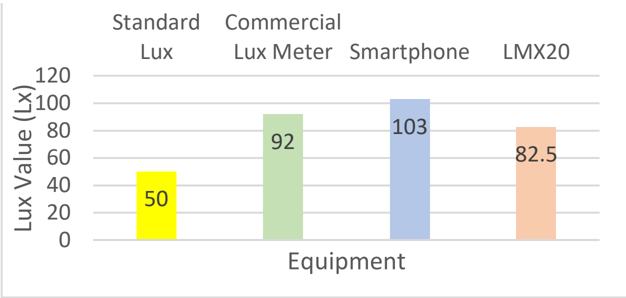

Fig. 6. The chart for the bedroom

TABLE IV. THE PERCENTAGE DIFFERENCE IN THE EQUIPMENT FOR THE BEDROOM

	LMX20	Smartphone
Commercial Lux Meter	10.33%	11.96%

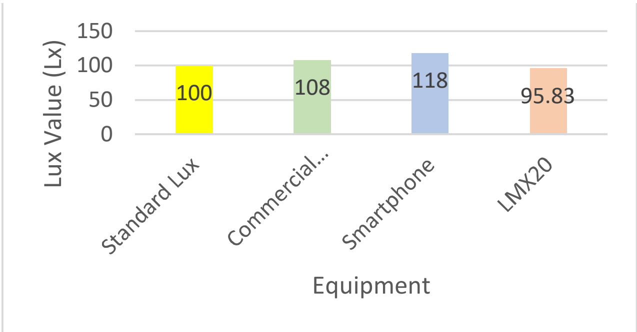

Fig. 7. The chart for the bathroom

TABLE V. THE PERCENTAGE DIFFERENCE IN THE EQUIPMENT FOR THE BATHROOM

	LMX20	Smartphone
Commercial Lux Meter	11.27%	9.26%

lux meter is shown in Table IV. From the results, the light condition in the bedroom is good.

D. Bathroom

The recommended lux value by JKR for the bathroom is 100lx. The value measured by the LMX20 was 95.83lx, commercial lux meter was 108lx, and smartphone was 118lx. The chart of the value measured is shown in Fig. 7. The percentage difference between the LMX20 and a commercial lux meter is shown in Table V where the difference is 11.27%. From the result obtained, a conclusion can be made where the bathroom has a good lighting condition.

For the discussion, the commercial lux meter is used as the reference for the LMX20. The reading obtained from the equipment are compared with each other, and the percentage difference is calculated. However, the accuracy of the tested commercial lux meter is unproven. In addition the accuracy for all used equipment varies based on sensor and system algorithm. The standard accuracy of lux meter should be ±5% of reading ±10 digits (<10,000 lux) or ±10% of reading ±10 digits (>10,000 lux).

V. CONCLUSION

For this project, the measurement obtained by the LMX20 has a slight difference from the commercial lux meter. The difference between the commercial lux meter and LMX20 is less than 20%. With additional features such as data saving and Internet of Things (IoT), it made the prototype more valuable. From the results and analysis, the low cost LMX20 is acceptable to measure the light. Besides, the user can use their smartphone to monitor the reading and save the data obtained by using SD card for future use.

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