AMBIENT LIGHT MONITORING SYSTEM USING INTERNET OF THINGS (IoT)

By

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18435

Dissertation submitted in partial fulfilment of

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CERTIFICATION OF APPROVAL

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Approved by,

____

(Dr. Micheal Drieberg)

UNIVERSITY TECHNOLOGY OF PETRONAS

BANDAR SERI ISKANDAR, PERAK

January 2017

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD HARIZ BIN ABDUL MANAB

ABSTRACT

Nowadays, the Internet of Things (IoT) technologies are ubiquitous and widely used by the users to solve their specific everyday life problems related with power usage consumption, environmental condition, automation and many more. An ambient light monitoring system is designed to measure the ambient light intensity or illuminance of particular indoor areas in UTP campus. This system is designed to take the light measurement autonomously and continuously without human involvement. The purpose of this project is to build a scalable IoT system to remotely monitor the ambient light level in real-time inside the indoor areas of the campus that supports multiple sensors with low power consumption. The system is a remote system which is using the concept of Internet of Things (IoT) where the integration of everyday devices and the Internet takes place to provide some specific information and do particular analytics. This project can be considered as a smart indoor environmental monitoring where the ambient light intensity of the indoor surrounding is measured autonomously or without human interference. The end-users are able to access the real-time information of the collected data via internet through a particular website specially for IoT development or cloud. The integrated system of the node is consisting of microcontroller board, second generation ambient light sensors, and communication device for wireless communication (IEEE 802.11). The measurement in SI unit of lux of the light intensity in certain indoor areas in UTP will be taken and the data will then be collected and shared to the internet via the Wi-Fi. The data samples collected by the IoT system are evaluated to justify the lighting conditions at the work areas and conclude the reliability of the system. This project will give significant benefits towards the society especially the students and staffs in UTP in term of creating better environment, productivity and better health condition.

ACKNOWLEDMENT

First and foremost, I would like to praise The Almighty God Allah SWT for His guidance and blessings throughout my final year project which ended successfully. I would like to express my deepest thankful to my parents, Mr Abdul Manab bin Mohamed Taib and Mrs Noraisah bte Abu Naib for giving me such a great motivation and support throughout the journey. My gratitude also goes to University Technology of Petronas, Electrical & Electronic Department for giving me the platform to enhance my skills and knowledge to become a better engineer. Via this project, I have understood the needs of the industrial demand in depth analysis on various task and also the importance of Internet of Things (IoT). The project also helped me with my problem-solving skills and writing skills as well.

Furthermore, a very special note of thanks to my dedicated supervisor, Dr Micheal Drieberg, who has always keep motivating me and been willing to spend his time in assisting me and provided good support since the start of the project to the end of the completion. Through the discussions with my supervisor, I have attained numerous share of insight and inspiration on the different aspects to be assessed for this project to become feasible. His excellent support, motivation, patience and effective guidance have brought a great impact to my project.

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CHAPTER 1

INTRODUCTION

1.1. Background of Study

The energy demand is increasing exponentially years by years yet the non-renewable energy sources are depleting and decreasing day by day. Without proper control and management of these valuable resources, these sources will be wasted and eventually depleted. Improvements of the energy usage should be executed in order to enhance the energy usage efficiency. Today, we are dealing with many new technologies which are able to solve the problem of these non-renewable energy sources.

This project is focusing on the Internet of Things (IoT) implementation to build a remote ambient light monitoring system inside UTP in order for the staff and students to be able to get access to the real-time indoor light conditions at particular areas inside the campus. The main objective is to create a smart environmental monitoring in the indoor.

Take an example on how we can control the ambient light illumination likes fluorescent, incandescent and LED in a closed room or space, what is the correct level of the illumination of these ambient lights in the room; is the room is under illumination or over illuminated? The correct level of ambient light is crucial for various human activities and environment to ensure good productivity and comfortability. Improper lighting control may result in energy wastage, loss of productivity or worse, adverse health, bad comfortability and psychological effects.

This types of questions can be answered by doing continuous and long-term monitoring of the ambient light in living and working spaces which can provide the important data, support the arguments and most interestingly we can investigate whether the source of the lighting has potential to be harvest to power up low power embedded devices such as sensor nodes, and single board computer (SBC) [1].

In order to present and proof the concept, an ambient light monitoring system using IoT will be designed and implemented in the University of Technology Petronas (UTP) campus. The data transmitted will be stored in the Cloud and from the Cloud, data of the real-time and long term trends of the lighting or illuminance can be assessed by building management and also researchers at any time for improvement in energy consumption in terms of energy and cost thereby ensuring comfortable and good environment to all staffs and students.

1.2. Problem Statement

UTP is a big campus and the lighting distributions are not exactly the same in all the campus indoor areas. The unknown conditions of the indoor lighting level may lead to energy wastage and unwanted health issues. Currently, the luminous data of the indoor ambient light is not easily attainable nor available. The application of light meter is not practical and can only provide limited readings due to its unreasonable cost and the need of manual operation, thus it can affect the luminous data acquisition in terms of real-time and long term monitoring. Therefore, a real-time and long term monitoring system is required and need to be developed in order to collect the respected data of the ambient light and most importantly the data is easily to be attained and assessed anytime and anywhere using Internet. With this system, the staffs and students are able to manage and control their lighting usage thus improve energy usage and ensure a comfortable and good environment.

1.3. Objectives

The purpose of this project is to build a low power embedded device to remotely monitor the ambient light level in real-time inside the indoor area of the campus that supports multiple light sensors with low power consumption. The objectives of this project are:

i. To design and develop a scalable ambient light monitoring system which is able to take measurement continuously and autonomously inside the campus areas in a real time and long term monitoring activity of indoor ambient light.

ii. To provide a real-time access of the indoor ambient light condition which easily to be monitored continuously and reliable to the end users by using Internet.

iii. To evaluate the data samples collected by the ambient light monitoring system in several indoor places in the campus.

1.4 Scope of Study

The ambient light monitoring system using IoT is designed and developed using wireless network modules from Arduino with several light sensors. The sensors used are TSL2561 of ambient light sensor connected with the microcontroller board platform interfacing with wireless communication module for interconnection between the sink node and the Internetwork. The wireless communication device will act as the communication network server connecting the IoT system to the internet via Wi-Fi to transmit the data of lux measurements calculated by the sensors to the internet. The measurements transferred in real-time by the monitoring system will be collected and broadcast via the web browser to the end user by leveraging an open-source data platform software dedicated for IoT project works.

1.5 Relevancy and Feasibility of the Project

Nowadays, the IoT systems become ubiquitous system which start happened to be everywhere to carry out human task and purposes. The IoT monitoring system presented in this project is relevant as it fulfilled the need to have a well lighting condition in respected indoor areas thus improve the society working environment. The duration of eight (8) months given to complete this project is sufficiently enough as the proposed design is a simple system design which is also understandable by the user. This simple IoT monitoring system able to give big impact towards creating a better working environment to the society.

CHAPTER 2

LITERATURE REVIEW

In this chapter, the general theory and technical review relevant with the project is explained comprising the project of real-time monitoring of ambient light using IoT. The related works related with this project are also discussed.

2.1 Internet of Things (IoT)

The introduction and existence of Internet of Things (IoT) nowadays realised the smart environment system in our daily life by the integration of several technologies into one system. IoT is a term invented by Kevin Ashton in 1999 [2]. The IoT is about assorted technologies that able to communicate with one another [3]. The Internet has significantly developed in the last few years in such a way billions of things are being connected worldwide. These things are different in sizes, capabilities, computational power and processing and support various of applications. This smart future Internet is the one called IoT which merges from the conventional Internet [4]. Figure 2.1 shows the various applications of IoT. The IoT connects real world objects and embeds the intelligence in the system in order to process the specific information received from the object and take useful action or decision automatically. Thereby, various useful applications and services that can go beyond our imagination before can be created with the presence of IoT nowadays.

Figure 2.1: Various applications of IoT [4]

Moreover, with today technology which is advancing, the performance of the processing devices can be upgraded to a better power and storage capability while having it with smaller sizes. Usually, these smart devices which are able to connect and communicate over the Internet are equipped with many type of sensors and/or actuators that can provide various opportunities. Figure 2.2 shows many types of applications and services using the basic IoT system. The things connect and communicate with other things in the same service type implementation. Besides, nowadays physical objects are happened to be increasingly equipped with RFID tags or other electronic bar codes in order for the smart device to able to do scanning. The objects will have their own unique identity and their particular information will be in the RFID tags embedded [4].

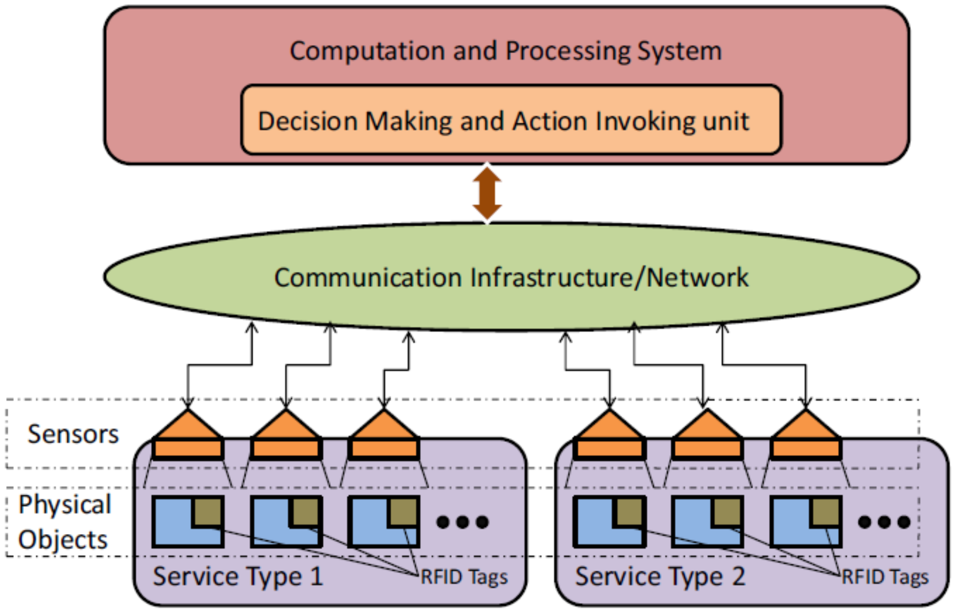

Figure 2.2: Basic IoT system [4].

The essential design behind IoT is it contains the "things" associated with the web with or without the nearby system channel and gives the information over the web open to the back-end administrations [5]. The "things" are the ordinary gadgets that will be sent the intel to and it comprises of three (3) primary parts to make the gadget intelligent; the sensors or actuators, the handling which is done by the microcontrollers or embedded board, and the communication to conveys the things either straightforwardly to the web or to local network as the sink.

The local network is going about as the sink to bring all the sensor hubs data or basically, the "things" data associated with it communicating to the web [6]. Ultimately, the back-end services are the place the data is being shown and analysed from the remote server, client get to and control, and for business information analysis [7]. Basically, the IoT structure consists of five (5) layers. Figure 2.3 and Table 2.1 briefly explained the layers for the structure of IoT.

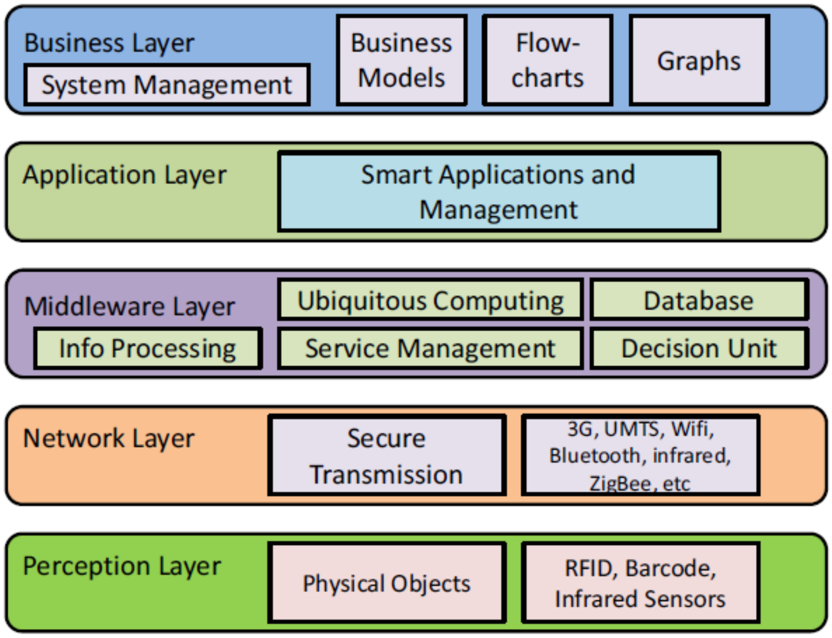

Figure 2.3: The IoT architecture layers[4].

Table 2.1: The IoT architecture

Layer Structure	**Description**
Perception Layer	Consists of the sensor devices and physical objects. Collection of information is happening here
Network Layer	Transmission of information from perception layer to the middleware layer via wired or wireless medium technology
Middleware Layer	Responsible for service management and has link to the database. Information processing and ubiquitous computation is performed here.
Application Layer	Provide management of the application based on the processed information in the Middleware layer
Business Layer	Responsible for the management of overall IoT system including the applications and services.

IoT offers a tremendous capability of uses to society that can enhance the nature of our lives in numerous viewpoints. IoT covers wide application in different spaces, for example, smart home, smart transportation, health monitoring, smart infrastructure and smart cities and each of the areas have various zones for canny organization [3]

Efficient energy consumption by the application of smart automation systems is trending nowadays in order to improve people's comfortability, security, convenience thereby result toward better environment factors. The evolution into IoT make the integrated technology system a realization. In order to reach to that application of smart automation system, sufficient and reliable real-time data is an extremely important requirement in context of data analysis thereby scalable wireless monitoring system is implemented [6, 8].

2.2 Smart Environmental Monitoring

There are two types of environmental monitoring applications that can be classified into two (2) types which is indoor and outdoor monitoring. Indoor monitoring systems normally include buildings and workplaces monitoring. The sensors such as temperature, light, humidity, and air quality sensors are applied to do the sensing application. Besides, there are also fire detection/ smoke detection of indoor environment monitoring. For the outdoor monitoring systems, the monitoring is related with weather forecasting, habitat monitoring, traffic monitoring, and hazardous chemical detection [8]

The smart devices which used to create a smart environment are able to make individuals' lives more convenience. The smart environmental monitoring is also can be classified into three types of smart environment which are virtual computing environment, analysis of physical environment and human environments such as mobile devices or wearables or it could be a combination of the two groups.

In order to make it happen, the sensors really play an important role to implement a smart environmental monitoring systems. The application for monitoring proposed will decide what types of sensor need to be used. Several examples of the systems include water, air, soil, temperature monitoring and so on. Thus, the sensor used is depending on what applications need to be created.

Other than that, an ecosystem of interacting devices integrated using embedded system, sensors, and internet network is considered as smart environment [9]. Generally, a smart environmental system is a system that have capability to manage itself, administrating and could manipulate and analyse data.

2.3 Ambient Light Monitoring

Ambient light can be classified into two types; natural and artificial lights. The natural lights usually come from the Sun while artificial lights are such as LED, fluorescent and incandescent. The illumination of particular areas no matter outdoor or indoor is due to the presence of ambient lights. Light intensity is important parameter in applications such as to require an optimum lighting conditions in office or living areas, to have a good quality photography pictures, solar charging or sunlight harvesting, machine vision and many more related with light sensing applications.

In indoor encapsulated areas, the lighting load contribute most to the total domestic load [10]. Therefore, there is a rise of need to provide the indoor ambient light monitoring in order to save electrical energy. In the other hand, ambient light monitoring system also important for the study of light pollution, illumination engineering and agriculture[11]. There is a conventional work to collect or measure the light intensity which is by using a lux meter but due to its manual approach which only can provide limited readings and expensive in price, the ambient light monitoring system is the better solution due to its reliability to collect information regarding the light intensity. The system give more benefits once been implemented. Figure 2.4 illustrates an example of digital lux meter.

Figure 2.4: Digital Lux Meter

Besides, space rooms which are under illumination or over illumination may also contribute to adverse health issues such as headaches, fatigue, stress and also affect work performance [12]. Over illumination is a term used when the lighting intensity is beyond the required level needed for a particular activity while under illumination is vice versa. In [12], it is stated that an optimum lighting condition is crucial in order to have a good work performance thus creating a better work environment. Thus, monitoring system for ambient light is needed so we can get to know quickly the environmental changes so we can alert and decide the illumination level whether it is within the optimum level or not.

Figure 2.5 illustrates the light spectrum which for the visible light as perceived by human eyes, the wavelengths is between 380 and 760 nm as well as the other light spectrums. Basically, light sources emit visible, infrared (IR) and UV radiation regardless in indoor or outdoor areas. So, the right choice of light sensor is important for the ambient light monitoring system design.

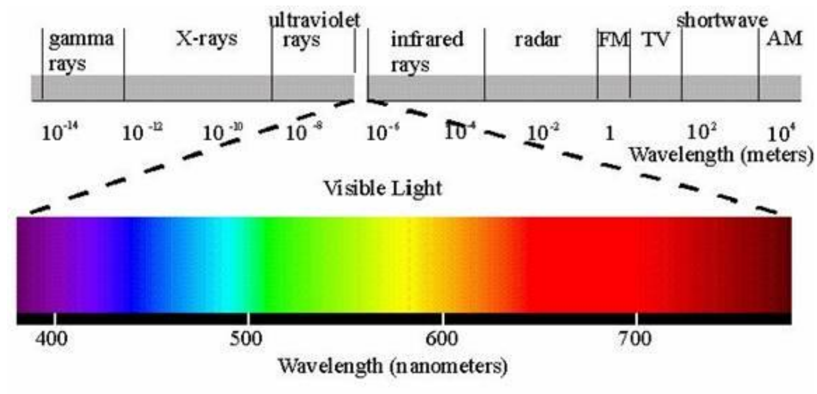

Figure 2.5: The light spectrum[13]

The light sensor chosen must match the luminosity curve so it can match with the spectral sensitivity of human eyes. Figure 2.6 illustrates the Commission Internationale de l'Éclairage luminosity (also known as the V (λ) which is a precise representation of the visual sensitivity of the human eyes to light of different wavelengths [13].

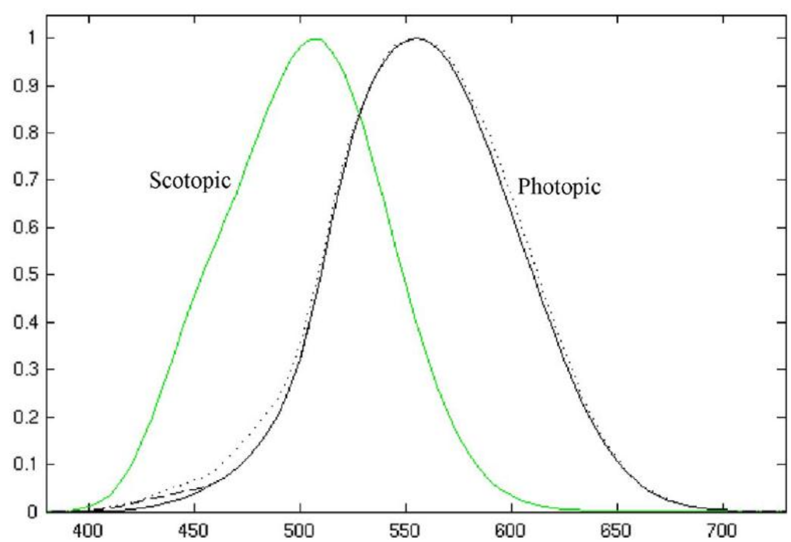

Figure 2.6: The Commission Internationale de l'Éclairage luminosity function curve [13]

Basically, there are two curves which are photopic (black curve) and scotopic (green curve). The black curve or photopic curve is a curve for the approximation of human eyes response under well lighting conditions while the green curve or scotopic curve is for low-light conditions. Normally, photopic curve will be used to match the response of the eye as the visual level is much better than well lighting condition in a typical working environment [13]. The sensor chosen will need to match the photopic curve. The wavelength range for the photometric measurement will be taken from 380nm – 710nm. This range of photometric unit is the approximation of human eyes response under photopic condition which is under bright lighting condition.

2.4 Related Work

In this part, the indoor and outdoor environmental monitoring using IoT are discussed. There has been many research been done for this smart monitoring system to be realised. Two of the researches will be discussed here as both of the researches' ideas will be implemented for this project proposed. Many researches were conducted to develop the smart environment system using IoT. The best research been implemented is from the [14]. In [14], an indoor monitoring system is build using Arduino Yun to monitor the air condition in terms of its humidity, temperature, VOCs concentration and dust particle density. The project is considered success as the monitoring system implemented is low in cost and consist of various of sensor to monitor the indoor air quality and the data can be accessed anywhere through Wi-Fi. However, the system is not scalable. Another approach of smart monitoring system is in [5]. The design approach is used to monitor three (3) types of parameters which are the attributes of a hot water system in home, power consumption in the house and the environmental conditions in the house. The internetworking of Zigbee communication with IP network or Internet is truly the best method in order to make the system scalable, remote accessible and reliable. All the data from the sensing units are able to be monitor anywhere everywhere through the IoT website as long as there is availability of Internet. However, most of the hardware used in the system is fabricated by his own thus limitations of hardware selections. Table 2.2 shows several examples of related work with this project.

Table 2.2: Examples of Comparison Works of Monitoring System

Title (year)	**Description**	**Advantages**	**Disadvantages**
Internet of Things based Smart Environmental Monitoring using the Raspberry-Pi Computer (2015)[15]	Using Raspberry Pi, a cost-effective environment monitoring (temperature, humidity, light level and CO harmful air pollutant) and earthquake detection is proposed	Cover many parameter of environmental sensing	No scalability. The system only considering one node
Design of Farm Environmental Monitoring System Based on the Internet of Things (2014)[16]	Implemented at Anhui Agriculture University, an environmental monitoring system is designed to measure soil temperature, soil moisture, air temperature, photosynthetic radiation and humidity	Cover many parameter of environmental sensing and has a stable and continuous data also using low-cost hardware.	Complex system in term of hardware and software used.
The Real-Time Monitoring of Water Quality in IoT Environment(2015)[17]	Raspberry-Pi is used as a sink node integrated with the sensors to monitor the water quality. Through Wi-Fi communication the information of the water quality can be accessed by the users on the Internet.	User friendly and low cost devices implementation yet have processing capabilities.	No scalability and not a low-powered monitoring system.

In this project, sensor nodes will not be implemented due to cost limitation and its complexity thus implementation of the nodes should be in the future work as improvement for the ambient light monitoring system. Other than that, more light sensors should be added as more areas can be monitored simultaneously and continuously at one particular time thus making the monitoring system more robust and reliable. Besides, the system is specially designed for indoor purpose only which make it not a versatile monitoring system.

CHAPTER 3

METHODOLOGY

This chapter present the methods and procedure that will be carried out throughout the project. Figure 3.1 briefly illustrates the methodology throughout the project work.

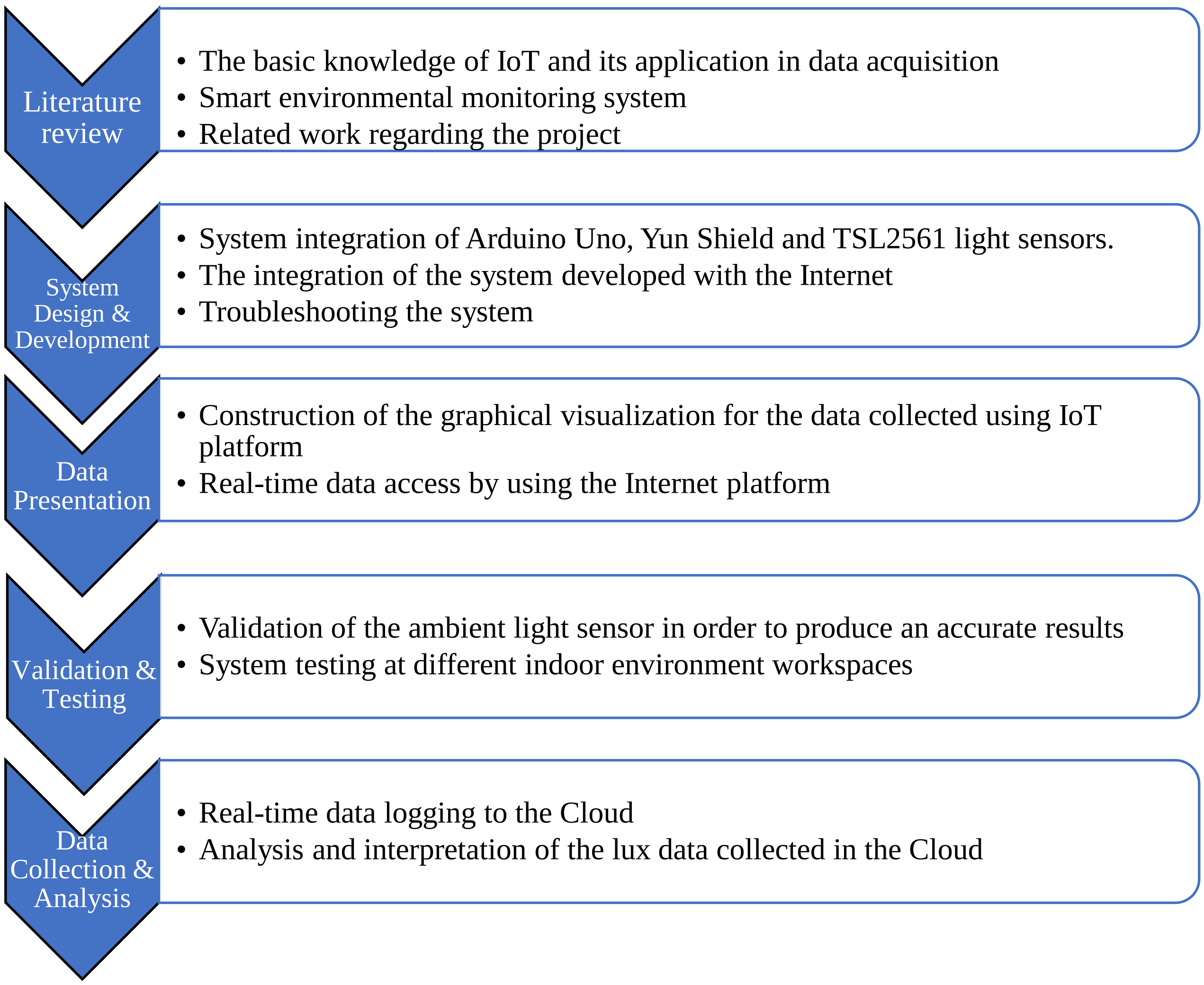

Figure 3.1: Project Methodology Flowchart

3.1 System Design & Development

There are two (2) main stages involved in the system design and development to build the ambient light monitoring system using IoT. The system focuses on monitoring the light intensity at certain indoor areas. Stage one of the system is to transfer the data collected from sensor to the sink node. The lux information retrieved to sink node coming from multiple sensors connected using the I2C communication protocol and placed at different position and distance in a fixed location. Lastly, the sink node will communicate and transfer the information collected to IoT data platform for data analysis and monitoring. Figure 3.2 shows the block diagram of network structure of the system architecture.

A comparison study also been done to analyse and decide the type of wireless sensor nodes (WSN) network architecture, embedded board for sink and sensor nodes, and the types of wireless communication. This to ensure the best choice of devices and technology that is suitable to be used for developing the remote ambient light monitoring system. Unfortunately, there is no availability and purpose to implement the sensor node wirelessly.

From the comparison study, the selected system architecture in this research project is designed and suitable to solve the problem statement thus come out with a solution for ambient light monitoring system using IoT in campus. The system development requires the integration of hardware and software component. The hardware is the physical devices used to develop the system while the software is used to make the system functioning.

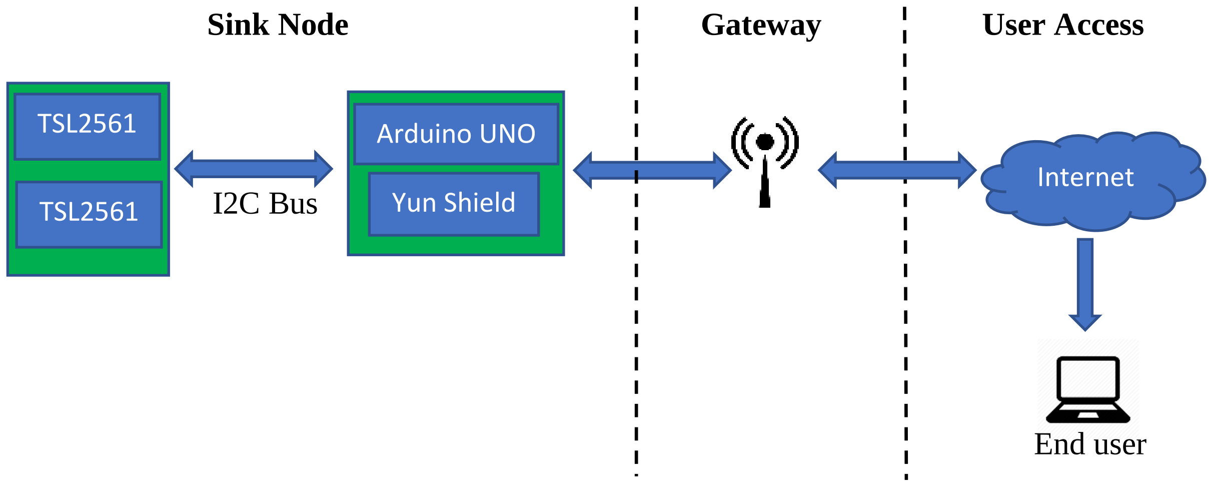

Figure 3.2: Block Diagram of Ambient Light Monitoring System Design

In this project, the modules architectures of the main hardware components are introduced. The Arduino Uno Board, Yun Shield and TSL2561 ambient light sensors will be implemented to build the monitoring system. Single Board Computer (SBCs) of Arduino Boards which based on Atmel microcontroller units (MCU) with shields and sensor make the IoT application a reality[18].

The factors that make variety of Arduino boards so demanding for different complexity level of the IoT applications are due to its reliability, robustness, open access, standard connections and low prices[18]. For Arduino Uno, it is based on Atmel MCU with AVR architecture of Atmega328. Table 3.1 shows the features of Arduino Uno board that is to be used.

Table 3.1: Arduino Uno specifications [18]

Board/features	**Uno details**
AI	6,10 bits
AO	6, PWM,8 bits
DIO	14,6 PWM, 8 bits
Processor	AtMega 328
Clock	16Mhz
Flash	32 KB
SRAM	2 KB
EEPROM	1 KB

Based on the Table 3.1, Arduino Uno is the best choice to be fully utilized as a microcontroller for the system. The Digital inputs (SCL and SDA) and the clock speed is just sufficient enough to design the monitoring system. Moreover, in order to make Arduino board or the system able to connect to the Internet, Yun Shield provide the functionalities extension and solve the problems of Internet connectivity like Wi-fi, Ethernet and storage like use of SD card. However, as all the data is stored in the Cloud, the storage extension provided by the Yun Shield is not to be used. Figure 3.3 shows the Yun Shield architecture block diagram and Figure 3.4 shows the Yun Shield module from Geeetech.

Based on the Figure 3.3, The Yun Shield module is a versatile module to deal with Internet connectivity and can solve storage issue for Arduino board. The core module of the Yun Shield is the Dragino HE. The HE module need only 200mA current when in full load, makes it a low power consume device. It is powered by the Arduino Vin pins which means that DC port (7V~15V) of Arduino board need to be used to power up the Yun Shield to prevent overheating of the hardware.

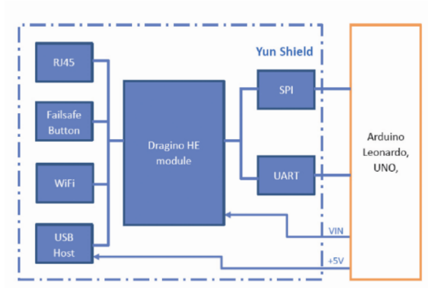

Figure 3.3: Yun Shield architecture block diagram

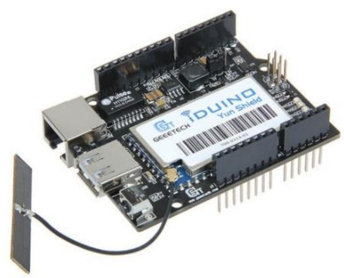

Figure 3.4: Yun Shield Module

The Wi-fi and RJ-45 (used for Internet cable) interface are connected directly to the HE module for Internetwork communication while SPI (Serial Peripheral Interface) and UART also can be used to communicate with the microcontroller. The sketches from the Arduino IDE can be upload using UART (universal asynchronous receiver/transmitter) interface, SPI or using Bridge class method by Wi-Fi interface. External wi-fi antenna also included for better connectivity in term of stability and adaptability. Table 3.2 shows the Yun Shield specifications. Based on Table 3.2, the specifications of the Yun Shield module able to provide Internet connection for the system.

Table 3.2: Yun Shield specifications

Processor speed	400MHz, 24K MIPS
RAM	64 MB
Flash	16 MB
Network	150M Wifi 802.11 b/g/n
OS	Linux Open Source OpenWrt
Peripherals	1 x 10M/100M RJ45 Connector 1 x USB 2.0 host connector

3.1.1 TSL2561 Light Sensors

The TSL2561 light sensors will sense the light intensity and convert it to digital output before being sent to the sink node via I2C (Inter-integrated Circuit) bus. The light sensors which read an analog input of light intensity measurement based on the empirical formula is converted to digital input before being sent to the microcontroller for data transmission. Each sensor has different addresses and unique ID in order to prevent address conflict during the data transmission to the sink node via the I2C bus. For the TSL2561 light sensor, the maximum sensors that can be integrated for one (1) microcontroller is three (3) sensors with different addresses and ID. In this project, only two (2) sensors are used to collect the lux measurement which each sensor is designed to be in different position and distance in a fixed indoor location.

3.1.2 Light Intensity Measurement

Light sensor TSL2561 is used by connecting it with the Arduino Uno to measure the intensity of the indoor light. Figure 3.3 illustrates the sensor and Uno board connection. The clock signal (SCL) pin and data signal (SDA) pin of the Uno Board is used for the data transmission between the TSL2561 and the Uno Board. In this context, the sensor s work as a “slave” and communicate with the “master” chip which is the sink node. The I2C communication protocol will allow multiple “slave” chips which are the sensor to communicate with the sink node respectively with the 3.3V power supply from the Uno Board. The TSL2561 must not exceed the supply of 3.3V or else it will damage the circuit.

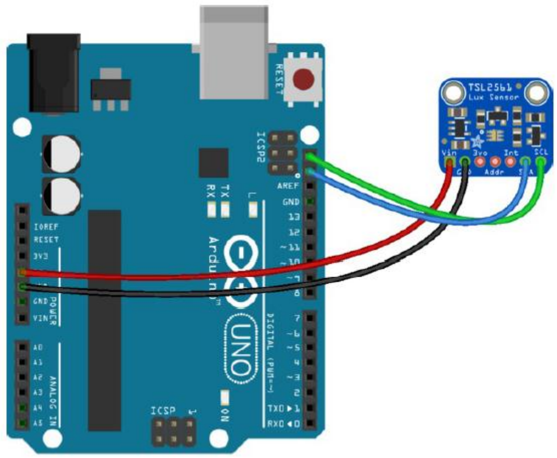

Figure 3.5: TSL2561 light sensor and Arduino Uno basic connection setup

For the light sensor, TSL2561 which has I2C interface is the chosen light sensor due to its accuracy in term of what exactly human eyes see or perceived and precise in measuring the lux thus allowing exact lux calculation. This choice is because of the different type of light energy spectrum will be received by the sensor and the conventional light sensor cannot differentiate the different wavelengths of light such as sunlight and artificial light thus will capture the entire energy spectrum produced by different light sources and transform the input into a current [19]. It is also the latest built of light sensor composed of photodiodes which the switching mechanism is less than 1ms. This sensor is better than Cadmium Sulfide (CdS) or Silicon.

This sensor is chosen because it is match with the Commission Internationale de l'Éclairage luminosity function, known as V (λ) curve [13]. Figure 3. illustrates the spectral response comparison between the ambient light sensor TSL2561 and later traditional light sensor for the photopic response measurement which the wavelength ranges from 390nm – 810nm.

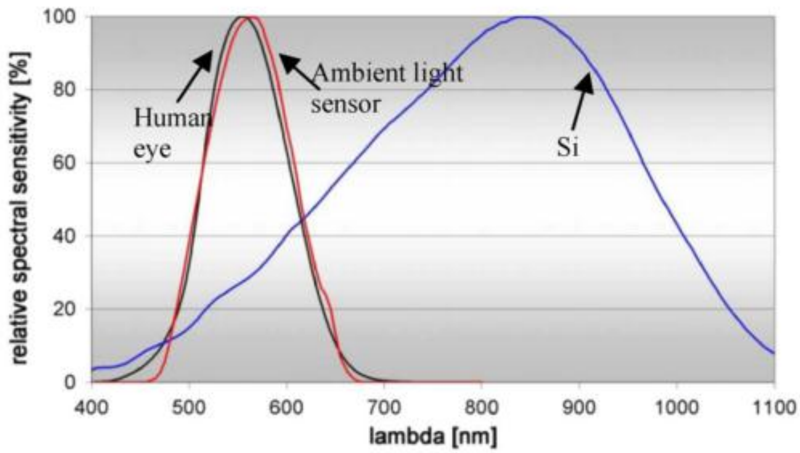

Figure 3.6: Comparison of spectral response between human eye, ambient light sensor and LDR Si-type [13]

Based on the Figure 3.5, the graph indicates that the relative spectral sensitivity between human eye and the ambient light sensor approximately the same while different with the Si light sensor, the sensitivity of the sensor is not the same with the human eye response. This is due to the characteristics of the traditional light sensor itself which only can measure and respond strongly to infrared (IR) light, which the human eye can't see rather than visible light. Once as the intensity of the IR light is high, a significant error of measurement will happen due to the different responsive of the silicon light sensor and the human eye. Thus, taking the traditional light sensor as a device to measure illuminance (lux) is not a good choice in this project.

The V (λ) curve is a very precise representation of the visual sensitivity comparison between the two types of light sensors and the human eyes to light of different wavelengths. Table 3.3 describe the specifications of TSL2561 ambient light sensor. However, this TSL2561 is only suitable to be used for indoor monitoring as the maximum light range detection is about 40klx and for an indoor lighting environment, the maximum light range will not exceeding 40klx.

Table 3.3: TSL2561 features[20]

Features	Details
Light range detection	0.1 - 40,000+ Lux
Diodes	Infrared and full spectrum
Voltage range	2.7 – 3.6V

The ambient light is said to have potential in energy harvesting. The lux is directly proportional with the voltage level. As the intensity is lower the voltage will be lower and vice versa [11]. The currents produced by the photodiodes of Channel 0 and Channel 1 are converted in form of illuminance measured in SI unit of lux. The value produced from Channel 0 and Channel 1 will be used in the empirical formula to obtain the value in lux. The responsivity of the photodiodes of Channel 0 and Channel 1 are different. For Channel 0, the photodiode is sensitive to both visible and infrared light (IR) while Channel 1 is strongly responsive to IR light.

Figure 3.6 shows the TSL2561 light sensor that will be used in this project while Figure 3.7 shows the spectral responsivity graph of TSL2561 light sensor. The significant characteristics of this sensor able to mimic or approximates the human eye response towards light, commonly interpreted as illuminance measured in lux.

Figure 3.7: TSL2561 Light Sensor

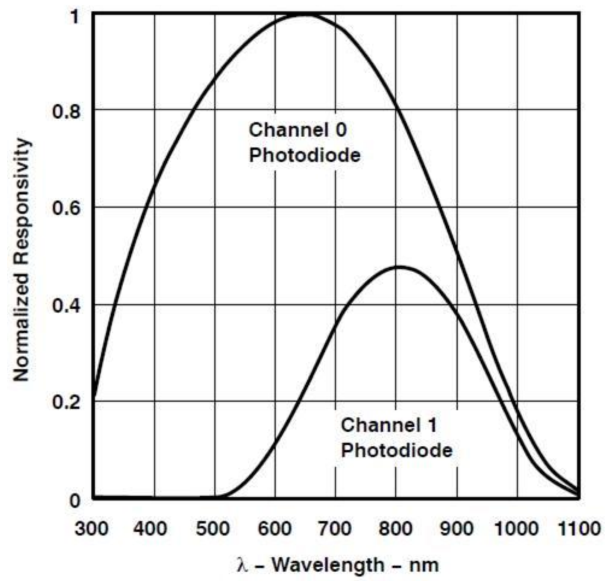

Figure 3.8: Spectral Responsivity of TSL2561 sensor[20]

TSL2561 is programmable light-to-digital converters that convert the light intensity to a digital signal output by using two (2) integrating ADCs. It is manufactured by United States TAOS company [21]. This chip can be used for various applications related with optical engineering. As the sensor consisted of two types of photodiodes, the currents produced by the photodiodes will be converted to a digital output (16-Bit Digital Output) that indicates the irradiance measured on each channel. The output from the sensor will be the input to the microprocessor to do the derivation using specific calculation in order to get the illuminance or ambient light intensity in lux SI unit.

The lux calculated will approximately same as the human eye response. This TSL2561 light sensor will using both of its diodes which are infrared (IR) and full spectrum. Figure 3.8 shows the functional block diagram of TSL2561 light sensor. As the two of the photodiodes (Channel 0 and Channel 1) received input in a form of light, the current produced by the photodiodes will be converted into a digital signal by the two of the ADCs simultaneously. After conversion cycle is done, the result is transferred to the Channel 0 and Channel 1 data registers. The data transfer is double buffered to ensure no invalid data is registered or read. After the transfer is completely done, new conversion cycle will begin [21]

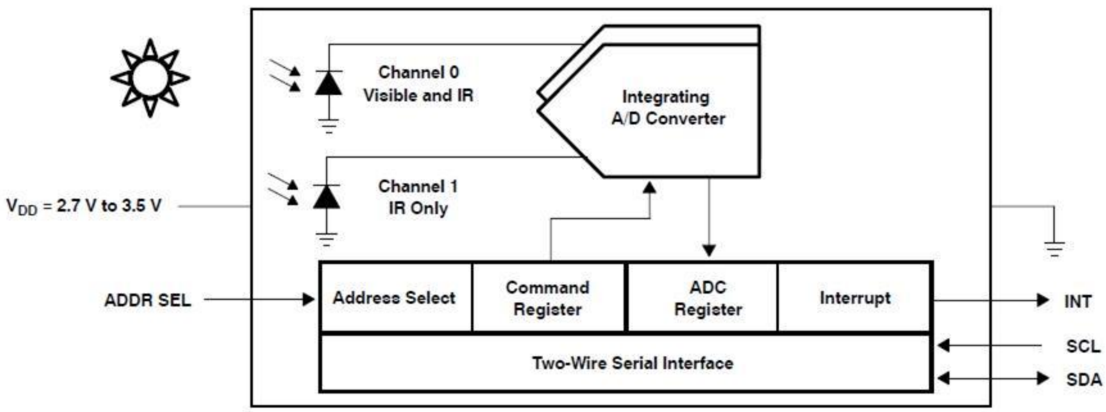

Figure 3.9: TSL2561 Functional Block Diagram[21]

The way the sensor approximates the human eye response towards light is by using the ADC digital outputs from the two channels in a formula to obtain a value in lux unit. Channel 1 digital output will compensate the effect of the IR component of light on the Channel 0 digital output. Table 3.4 shows the formula to obtain the value in lux unit. The formula is obtained by optical testing with fluorescent and incandescent light sources.

Table 3.4: Empirical formula of illuminance of TSL2561 light sensor [21]

For 0 < CH1/CH0 <= 0.52	Lux = 0.0315 x CH0 − 0.0593 x CH0 x ((CH1/CH0)1.4)
For 0.52 < CH1/CH0 <= 0.65	Lux = 0.0229 x CH0 − 0.0291 x CH1
For 0.65 < CH1/CH0 <= 0.80	Lux = 0.0157 x CH0 − 0.0180 x CH1
For 0.80 < CH1/CH0 <= 1.30	Lux = 0.00338 x CH0 − 0.00260 x CH1
For CH1/CH0 > 1.30	Lux = 0

Basically, the modules will be integrated and link to the Internet via Wi-fi for data transmission to the webserver. The exchange of analogue data will occur using I2C communication before the data channelled to Internet via Wi-Fi then being analysed in the cloud. The strength of this simple IoT monitoring system is on the sensor used which is reliable and its simple connectivity mechanism. Even with its simple design, the IoT system is robust and able to give significant impact towards achieving better working environment and productivity.

3.2 Data Presentation

For the last part of the system, graphical visualization for the data collected by the device will be constructed using the IoT platform provided in the Internet. There are a lot of open IoT platform provided in the Internet for the purpose of IoT project related. The data collected will be in real-time based in order to make the data collected is reliable thus creating a trustworthy IoT monitoring system. The visualization of the data collected will be in pointy graphical form as it is easier to do the evaluation on the lighting trends in the indoor workspaces. There are two (2) pointy graphs that representing the two (2) TSL2561 sensors of the ambient light monitoring system constructed in the IoT platform used in this project.

3.3 Validation & Testing

Proceed to next step of realizing the ambient light monitoring system using IoT, validation and testing is done for the system in order to make sure the data collected by the light sensors is accurate. The accuracy of the light sensors used in the system design is based on the datasheet provided by the manufacturer, Texas Advanced Optoelectronic Solution (TAOS). Besides that, a conventional digital luxmeter is also used to compare the measurement results produced by the TSL2561 light sensors. This digital luxmeter need to be operated manually by human. Figure 3.9 show the physical of the digital luxmeter and Table 3.5 shows the electrical specification of the digital luxmeter which is used for this project. The manual for the operation is attached at the appendix section.

Figure 3.10: Conventional LX1010B digital luxmeter

Table 3.5: LX1010B conventional digital luxmeter electrical specifications[22]

Range	Resolution	Accuracy (23 ± 5 ℃)
0 – 2000 Lux	1 Lux	±(5%+2d)
2000 – 19990 Lux	10 Lux	±(5%+2d)
20000 – 50000 Lux	100 Lux	±(5%+2d)

3.4 Data Collection & Analysis

Once the validation and testing of the sensors is done, the wireless connection mechanism is implemented to complete the system as an IoT monitoring system. In this project work, a simple connectivity to the Internet is implemented by using the Wi-Fi interface of the Yun Shield to make the connection to the Internet wirelessly. An Access Point (AP) is to be setup by the user first in order for the Yun Shield to connect with it as to be connected to the Internet. In this project, a software named Connectify is used for the computer to create the Wi-Fi hotspot as to be the AP for the ambient light monitoring system. After the Internet integration with the IoT ambient light monitoring system, the data collection can directly be done. The collection of the light data is stored in the Cloud in order to make the access of the data to be easier to the users anytime, anywhere using the Internet. Several data samples will be taken in order to evaluate the trends of the lighting condition in several indoor workspaces thus prove the reliability of the IoT monitoring system in terms of its data transmission and the accuracy. Figure 3.10 shows the wireless connection mechanism using the Internet.

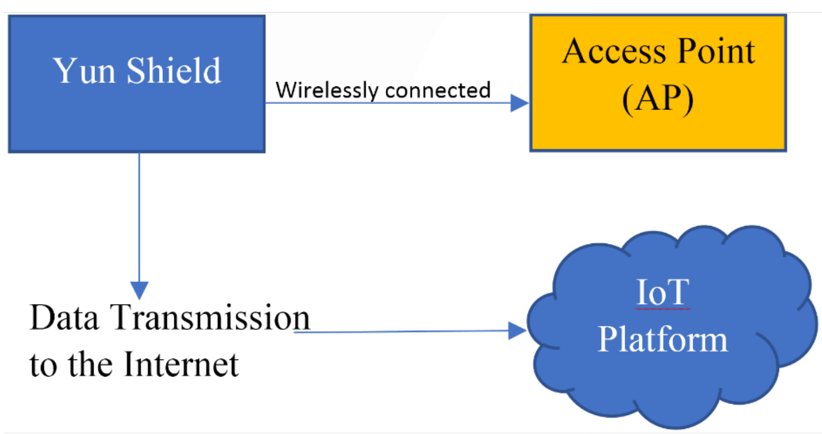

Figure 3.11: Wireless connection mechanism

3.5 Project Timeline / Gantt Chart

Table 3.6: Gantt Chart

Year		2016				2017				
No	Activities	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
1	Literature Review & preparatory work to build the respective system.									
2	Setup & development of the ambient light monitoring system.									
3	System integration with the Internet using wireless connection mechanism.									
4	Comprehensive construction of the graphical visualization of the real-time data collected using the open IoT platform provided in the Internet.									
5	Validation of the light sensors & testing of the IoT monitoring system with the indoor lighting condition in several working spaces.									
6	Running the IoT monitoring system perfectly in context of real-time data logging; autonomously and continuously.									
7	Documentation									

Based on Table 3.6, the project is feasible and realizable in the duration of eight (8) months period.

3.6 Project Key Milestones

Table 3.7: Project Key Milestones

No	Milestone	Completion (%)
1	Comprehensible knowledge on the ambient monitoring system & Internet of Things (IoT)	10
2	Full setup & development of the ambient monitoring system using IoT	40
3	Friendly-user visualization of the collected data	60
4	Full running of the system for real-time data logging	80
5	Project completion	100

Based on Table 3.7, the project is considered done within the time limit given which is about eight (8) months period as the prototype of the ambient light monitoring system using IoT were able to be design and developed successfully.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 System Design and Development

The results of the design and development of the ambient light monitoring system and the system integration with the Internet using wireless connection mechanism is discussed briefly in this section.

The testing of the light sensor was done to check whether it can take measurements of the lux. Fluorescent light is used as an input to the light sensor. The sensor need to be configured first whether it need to be used in bright light or low light to avoid sensor saturation or to boost sensitivity.

For this project, the sensor is configured to switch automatically to be in low light or bright light condition. This is because the monitoring activities will be conducted in 24hour time period respected to different location of workplaces. Besides, for a best sensor resolution, the integration time is set to 402ms which make the conversion from analog to digital to be the slowest as it is 16-bit of data resolution. However, the integration time can be set to 13ms for a low resolution but fastest conversion while 101ms for a medium resolution and conversion speed. Figure 4.1 and 4.2 shows the readings are taken every 250ms for the sensor. Based on the result obtained, the sensor is functioning as expected.

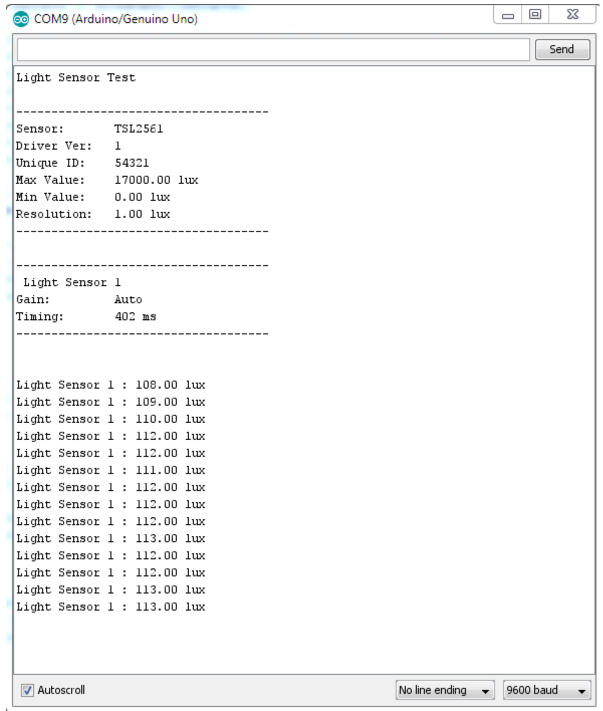

Figure 4.1: Light sensor test during high brightness

The TSL2561 light sensor is tested with different lighting intensity to measure its lux changes. Based on Figure 4.1, the sensor able to give out the readings at high brightness when 4 tubes of fluorescent lamps are used as the sensor is fixed at 7ft or approximately 2.10m. Figure 4.2 shows the measurement when the sensor is responding towards the two sources of fluorescent lamp to simulate low light intensity. During this test, there is no presence of natural light which is the sunlight. The reading is taken at fixed distance of 7ft or 2.10m and with the use of two fluorescent lamps facing directly the sensor from upward position.

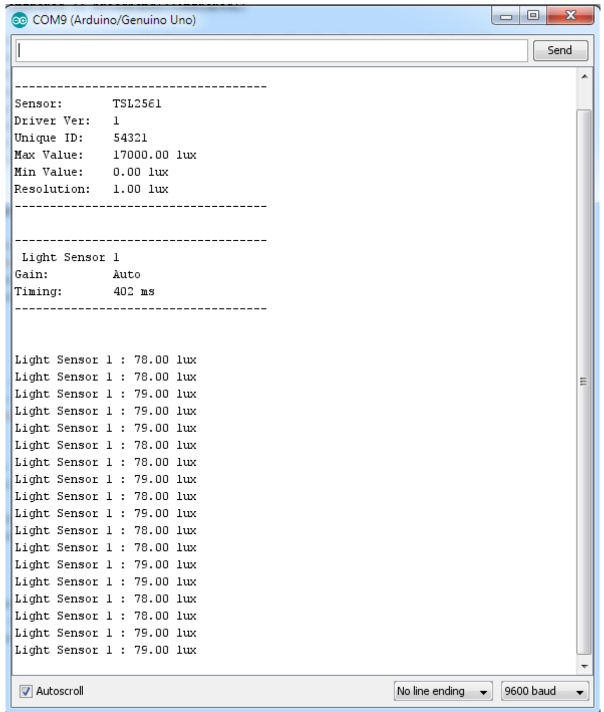

Figure 4.2: Light sensor test during low brightness

4.1.1 Data Transmission Via I2C Communication

To enable I2C communication, the sensors need to be connected with the Uno Board using the SCL and SDA pins on the board. Figure 4.4 shows the connection of the sensors with the Uno Board. Basically, the sensors used only allocated with three (3) addresses currently and each of the sensor will have a unique ID respectively. The address allocation is to prevent conflict during the data transmission between the sensors and sink node. The allocation of the address also need to be declared in the code in order to make the sensors work. Figure 4.5 shows the results of the lux from both the sensors integrated using the I2C bus. The value produced by the sensors is from the fluorescent lamps fixed at 7ft or 2.10m facing upward. The setup is considered successful as the serial monitor able to print the result produced by the light sensors.

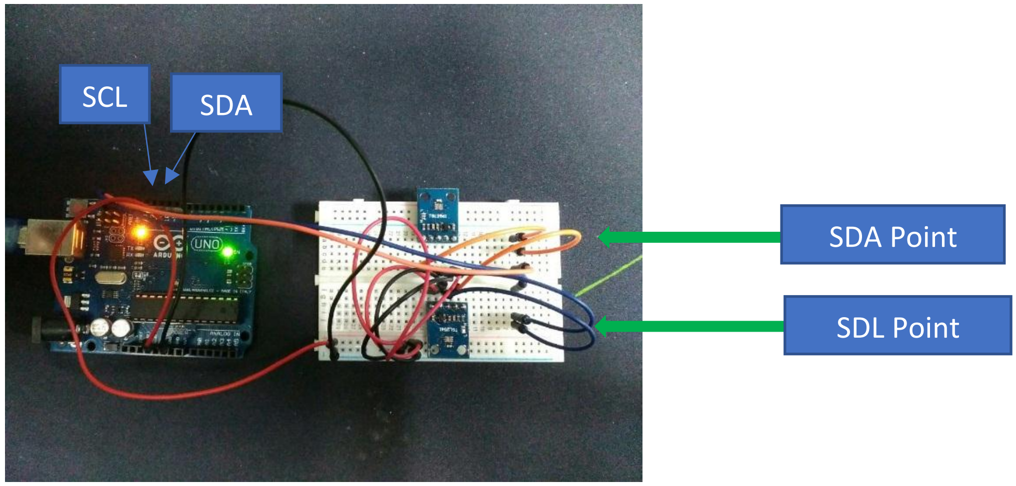

Figure 4.3: Configuration setup of TSL2561 Sensors and Arduino Uno

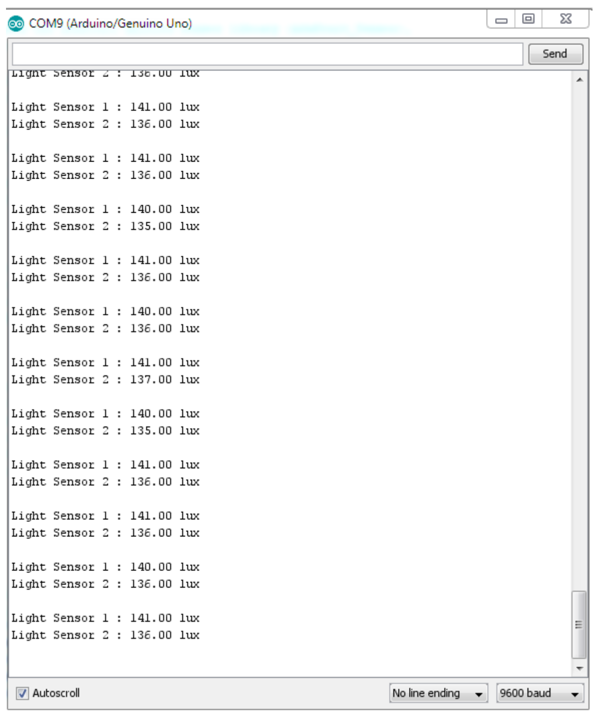

Figure 4.4: TSL2561 sensors measurement reading from serial monitor using I2C bus

4.1.2 Data Transmission to the Cloud

The data transmission from the monitoring system to the Cloud is performed by using the open IoT platform provided in the Internet which is Thingspeak platform. In order to transfer the data collected by the light sensors to the thingspeak, Yun Shield is used as a Wi-Fi platform for the Uno Board to connect to the Internet wirelessly. The data will be sent over the internet via Wi-Fi connection to the IoT platform. An Access Point (AP) is setup first in order to connect the Yun Shield with the Internet wirelessly. The configuration setup of Yun Shield is different based on what Arduino Board is used. For this case, Arduino Uno is used as is it more convenient to be used. Figure 4.5 shows the connection between the Yun Shield and Arduino Uno while Figure 4.6 shows the integration with the TSL2561 light sensors. The integrated system is powered up using the AC/DC adapter of 6V/300mA to make sure there is no depletion of energy occur as if a battery is used because the monitoring activity is running continuously in a 24hours time period.

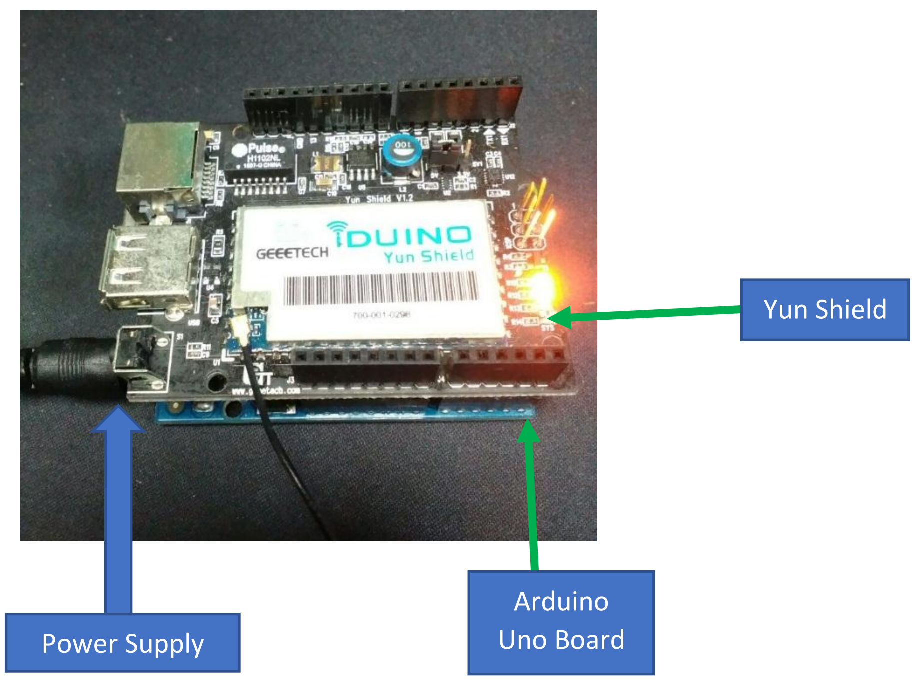

Figure 4.5: Yun Shield and Arduino Uno Board connection

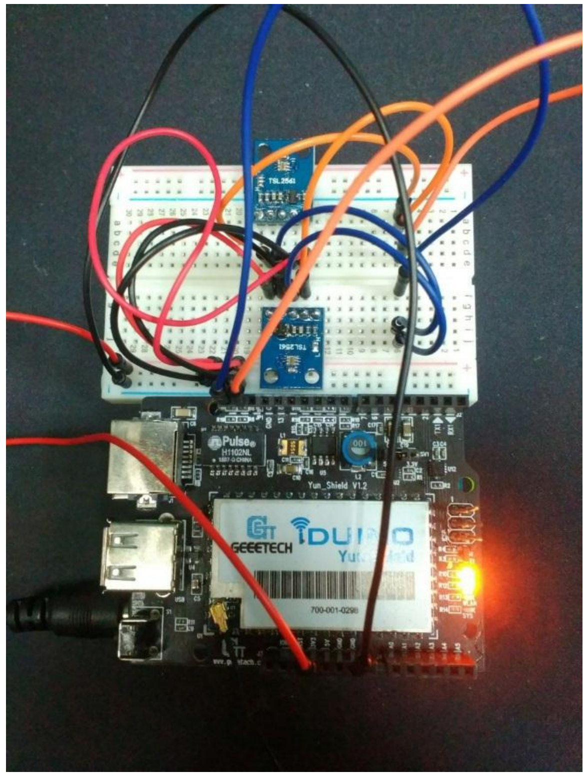

Figure 4.6: Integration of sink node with the TSL2561 light sensors

Based on the Figure 4.6, the light sensors are connected with the sink node to complete the system design using the I2C communication protocol which make the system to be robust and scalable as addition of sensors is not an issue for I2C communication protocol.

4.2 Data Presentation

In this section, a comprehensive construction of the graphical visualization of the real-time data collected using the open IoT platform provided in the Internet is elaborated.

4.2.1 Open IoT Platform: Thingspeak

After the hardware and software setup and configuration has been made, the data can be transfer to the Cloud. In this project, Thingspeak platform is used as it is an open platform provided in the Internet for IoT project purpose. Thingspeak platform is simple to be used and user friendly thus it is chosen to be used in this project.

In order to use the Thingspeak, user account is created and a channel is also created to record the value sent which is measured by the TSL2561 sensors. Figure 4.7 shows the channel created by the user. The data logging is running in the created channel during the monitoring activities.

For this project, the Ambient Light Monitoring Channel will be used for the monitoring activity of indoor ambient light. After channel is created, the API key shown by Figure 4.8 will be given as verification key to access the channel. The API key is used in the coding for the transmission of data to the respected channel to be happened. The transmission time of the data collected by the system to the Thingspeak channel will be precisely at 15s. The data will be presented in the form of pointy line graph as shown by Figure 4.9. The monitoring activity can be accessed via site: https://thingspeak.com/channels/233615.

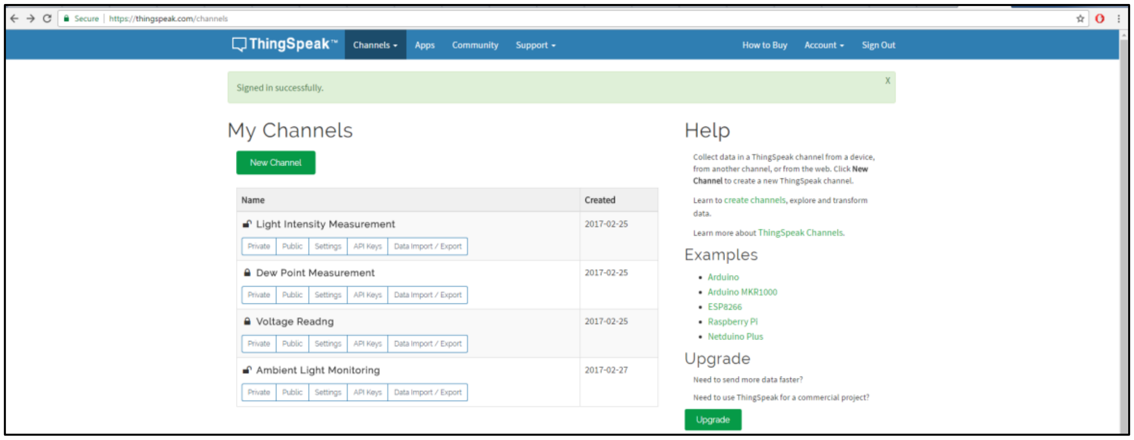

Figure 4.7: User Thingspeak channels

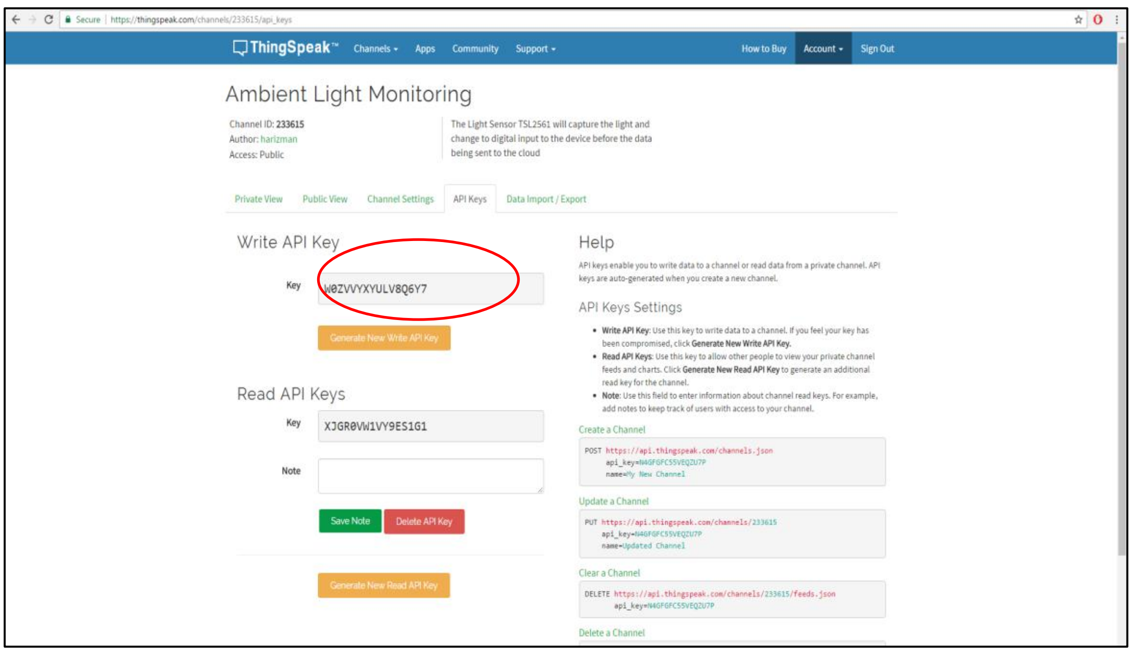

Figure 4.8: API key of the Thingspeak channel

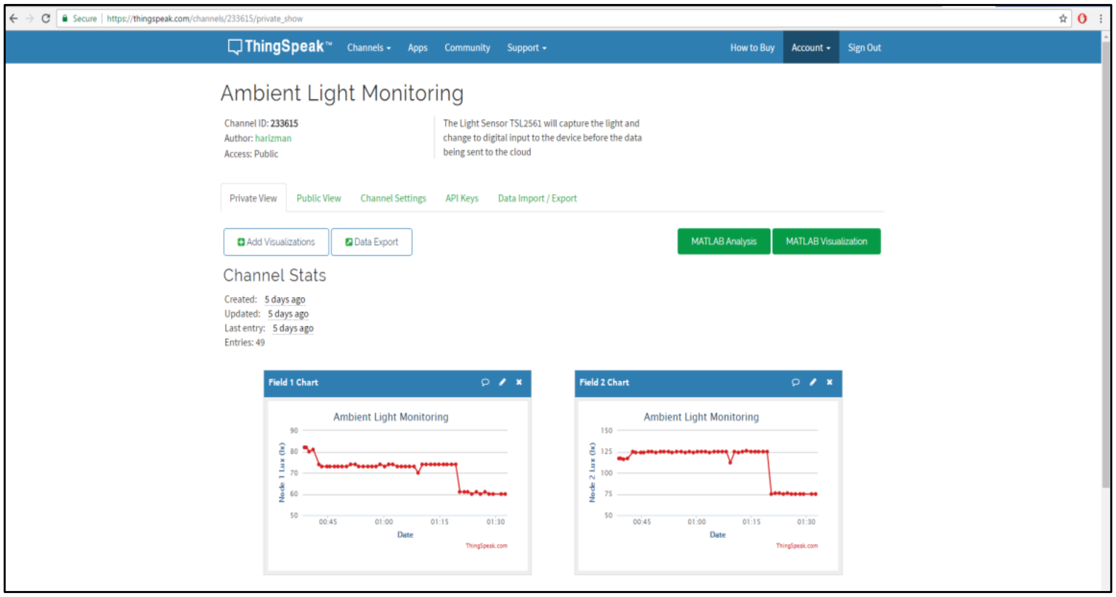

Figure 4.9: Display of data on the Thingspeak Channel.

4.3 Validation and Testing

Validation of the light sensors & testing of the ambient light monitoring system using IoT with the indoor lighting condition in several working spaces is discussed here.

4.3.1 Illuminance

Illuminance is the radiant flux density from visible radiation measured in lux. In this context, the visible radiation or visible light is ranges from 390nm – 810nm of wavelengths. Basically, the illuminance from the light source will be varies depending on the distance the sensor is fixed. As the distance between the sensor and the light source increases, the illuminance or lux will be decreases or simply to say, the light will be dimmer. Regarding the sensor TSL2561, the accuracy and reliability can be compared using lux meter to make sure that the illuminance value produced by the sensor when compared with the value produced with the lux meter will not produce a big deviation. Based on the TSL2561 datasheet we can also conclude that the sensor is accurate and reliable for light measurement.

4.3.2 TSL2561 Light Sensor Sensitivity Test

In order to have the accurate results using the ambient light monitoring system, the values measured by the TSL2561 light sensors are compared with the value measured by the LX1010B digital luxmeter. This procedure is done to ensure the IoT monitoring system to become a reliable system and the data collected is to be trustworthy during the monitoring activities or when the data logging is running. Table 4.1 shows the results of the TSL2561 light sensors sensitivity test.

Table 4.1: TSL2561 light sensor sensitivity test

Distance, ft.	Actual, lx	S1, lx	S2, lx	S1 Difference, lx	S2 Difference, lx	S1 Percentage error, %	S2 Percentage error, %
1	1238	1297	1276	59	38	4.77	3.07
2	577	590	605	13	28	2.25	4.85
3	253	264	266	11	13	4.35	5.14
4	179	188	185	9	6	5.03	3.35
5	138	143	145	5	7	3.62	5.07
6	119	125	122	6	3	5.04	2.52
7	94	95	99	1	3	1.06	5.32

Based on the Table 4.1 above, the illuminance is produced directionally by two (2) tubes of fluorescent lamps length of 2ft.The results of the actual measurements is the average when three (3) times of measurement is taken by the LX1010B digital luxmeter. Sensor1 (S1) and Sensor2 (S2) is the TSL2561 light sensor used to measure the illuminance produced by the luminaires (fluorescent lamps). The values measured by S1 and S2 is compared with the actual values measured by the digital luxmeter to test its sensitivity towards the illuminance of the luminaires used in the indoor work place. The illuminance is observed to be decreasing as the distance of the measurement taken is increasing thus it shows that illuminance is depending on the distance. As the distance between the light source and the surface/object (in this context, we are referring the sensors and luxmeter as the object) increasing, the illuminance produced by the light source will decreasing. This relationship is stated as an Inverse square law in the study of illumination[23]:

$$Ev = Iv/d^2 \qquad (1)$$

Ev = illuminance produced by the luminaire.

Iv = Luminous intensity produced by the luminaire.

d = distance from the luminaire.

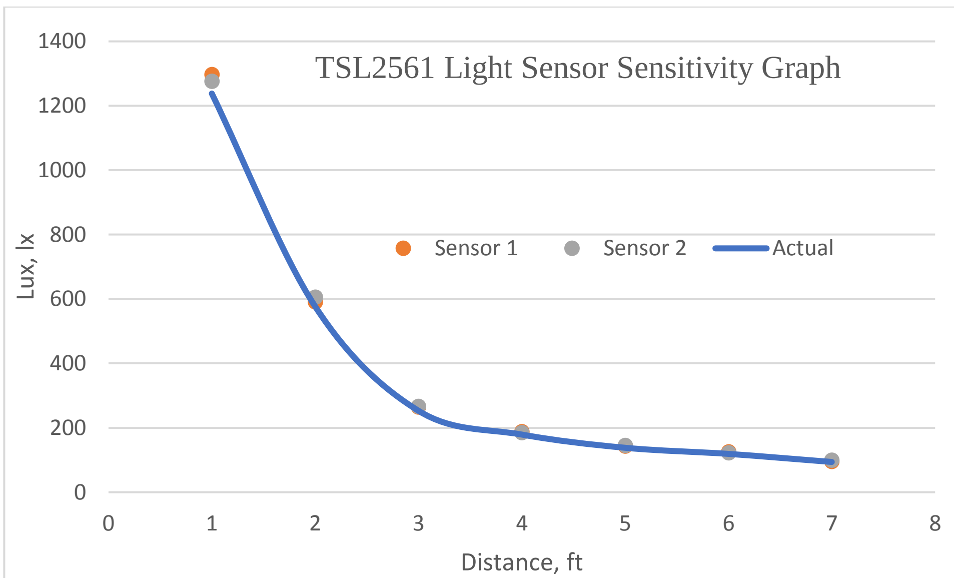

Figure 4.10: TSL2561 Light Sensor Sensitivity Graph.

Based on Figure 4.10, the deviation produced by the light sensors is small when compared with the actual readings by the digital luxmeter shown by the actual line graph produced thus the readings from the light sensors is accurate and precise. The illuminance produced by the luminaires also decreases as the distance where the measurements taken increases. The tolerances of the light sensors should be below 6% based on the results in Table 4.1 obtained from the light sensor S1 and light sensor S2 measurements. Thus, the TSL2561 light sensors can be used to monitor the lighting conditions in the indoor area workplaces in the campus because of its accuracy to compare with the actual line graph (LX1010B digital luxmeter used).

However, different quality and quantity of luminaires will give different readings of illuminance[23]. In this project, only the illuminance produced by the fluorescent lamp is studied as most of luminaires of the indoor workplaces in the campus used are the fluorescent lamps.

4.4 Ambient Light Monitoring System Testing

The ambient light monitoring system was tested at different indoor environment workspaces. In this project, only two (2) work areas with same specifications of different indoor location is used to do the monitoring activity. The two (2) work areas is denoted as Area 1 and Area 2. The collected data by the monitoring system is extracted from the Thingspeak channel. The evaluation and analysis of the collected data samples is discussed in this section. Figure 4.11 shows the proposed prototype of the ambient light monitoring system while Figure 4.12 shows the settings of the sensors made to run the experiments at the work areas.

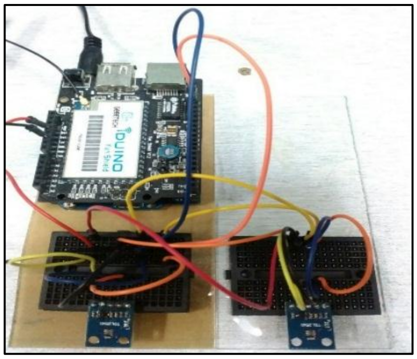

Figure 4.11: The prototype of Ambient Light Monitoring System

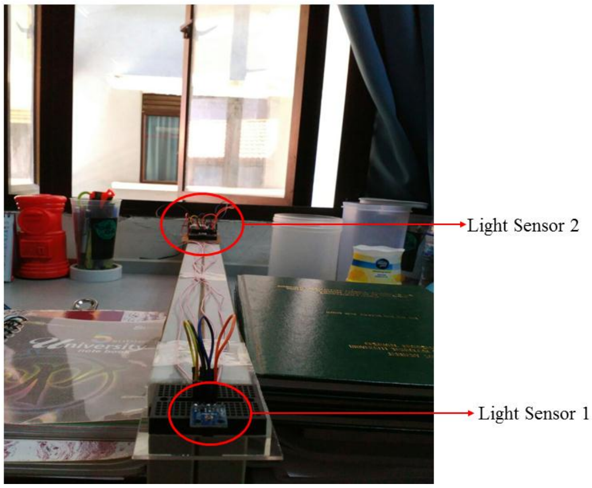

Figure 4.12: The Sensors positioning during experiments conducted.

In order to verify the reliability of the ambient light monitoring system, the system was tested. The monitoring system was fixed directionally at 7ft or 2.10m from the artificial light sources which illuminate the indoor working area. Figure 4.13 illustrate the positioning of the light sensors in the indoor workspaces.

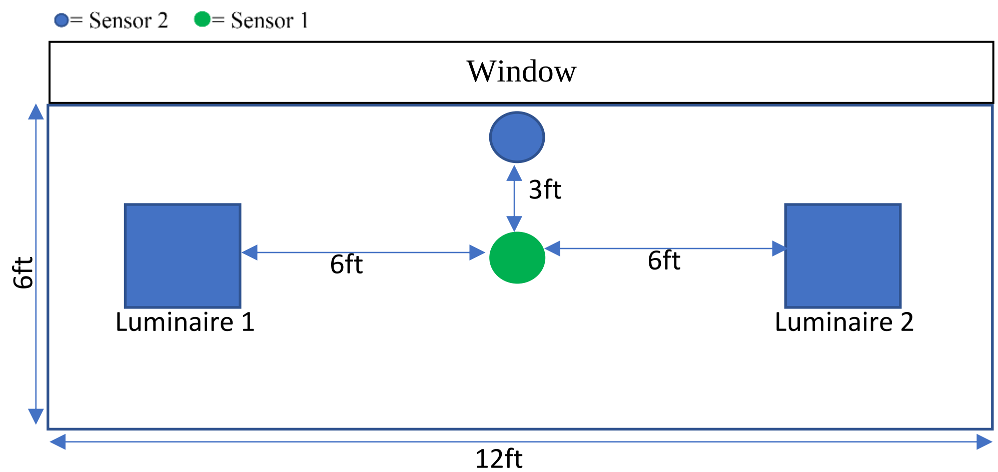

Figure 4.13: TSL2561 Light Sensor Positioning

Based on Figure 4.13, the indoor work area is of 12ft by 6ft. The indoor work area is the area where all the work task is done. The illumination or the light distribution of the work area is analysed here. The Luminaire 1 and Luminaire 2 are composed of two (2) tubes of fluorescent lamps with length of 2ft. The technical specifications of Luminaire 1 and Luminaire 2 is also equal. The positioning of the light sensors is based on the grid method [24]. Sensor 1 is represented by the green round shape while Sensor 2 is represented by the blue round shape. The distance between the sensors is fixed at 3ft with Sensor 2 is positioned beside the window of the indoor work area. The reason Sensor 2 is fixed beside the window is because to differ or compensate the illuminance measured by the Sensor 1 as the measurement taken by Sensor 1 is greatly affected by the Luminaire 1 and Luminaire 2 while the measurement taken by Sensor 2 is greatly affected by the natural light which is from the sunlight. Sensor 1 is positioned at the middle of the work area which is about 6ft between Luminaire 1 and Luminaire 2. This setting is to make sure the measurement taken by Sensor 1 is a true measurement value of the illuminance or lighting condition in the work area. Table 4.2 shows the settings of the work areas.

Table 4.2: Setting of the work areas

Work Area	Area, ft	Luminaires	Location	Orientation,	Monitoring date	Monitoring interval, s	Data Transmission delay, s
Area 1	12ft x 6ft	Two tubes of fluorescent lamp	V5D-L1.1.4	250° from North	1.4.2017	60	15
Area 2	12ft x 6ft	Two tubes of fluorescent lamp	V5D-L1.1.6	135° from North	2.4.2017	60	15

The monitoring activity at Area 1 and Area 2 were conducted at different day as the monitoring was done in 24 hour of time period and at different location. The data collected by the monitoring system in taken every 60 seconds to ensure the measurements taken are numerous and better in terms of accuracy and reliability of the system itself. However, due to 15s transmission delay from the monitoring system to Thingspeak, there will be several time points missing during the data logging.

4.4.1 Area 1 Illumination

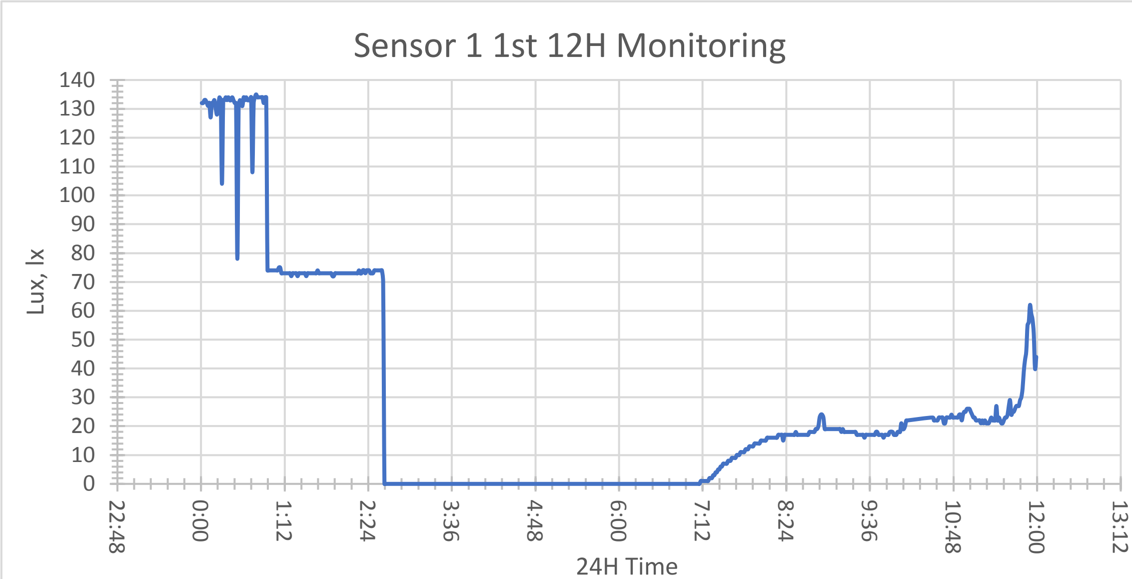

Figure 4.14: Sensor 1 1st 12Hour Monitoring Graph

Based on the Figure 4.14, the readings of the lux recorded is from Sensor 1. The lux recorded between 00:00 till 02:27 is in the range of 70lx – 140lx due to the luminaires used to light the area while between 07:12 till 12:00, the lux recorded is in the range of 1lx – 70 lx which due to the sunlight only. During this 1st 12Hour monitoring, the luminaires are only used or switched on at 00:00 till 02:27. We can see at the time between 00:00 and 01:12, there are points where only one luminaire is used either Luminaire 1 or Luminaire 2.

Based on Figure 4.15, at time 12:00 till 18:14, the lux recorded by Sensor 1 is in the range of 1 lx – 420 lx. The trend is increasing until 15:58 (maximum of 416 lx was recorded) which indicated the sunlight illuminance is increasing over time. During this time period, neither Luminaire 1 nor Luminaire 2 is switched on. The illuminance is truly from the natural light, sunlight. At 18:14 till 18:43, either Luminaire 1 or Luminaire 2 is switched on as the lux recorded is between 70 lx – 80 lx while between the time 18:43 till 20:03 the lux recorded is between 130 lx – 140 lx which is when both Luminaire 1 and Luminaire 2 is used.

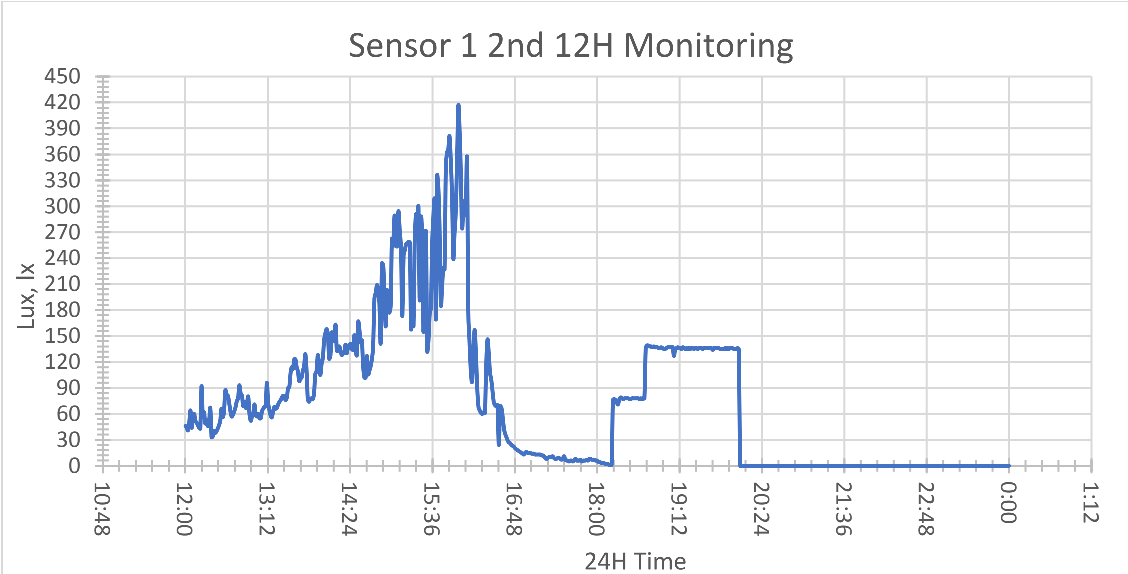

Figure 4.15: Sensor 1 2^nd^ 12Hour Monitoring Graph

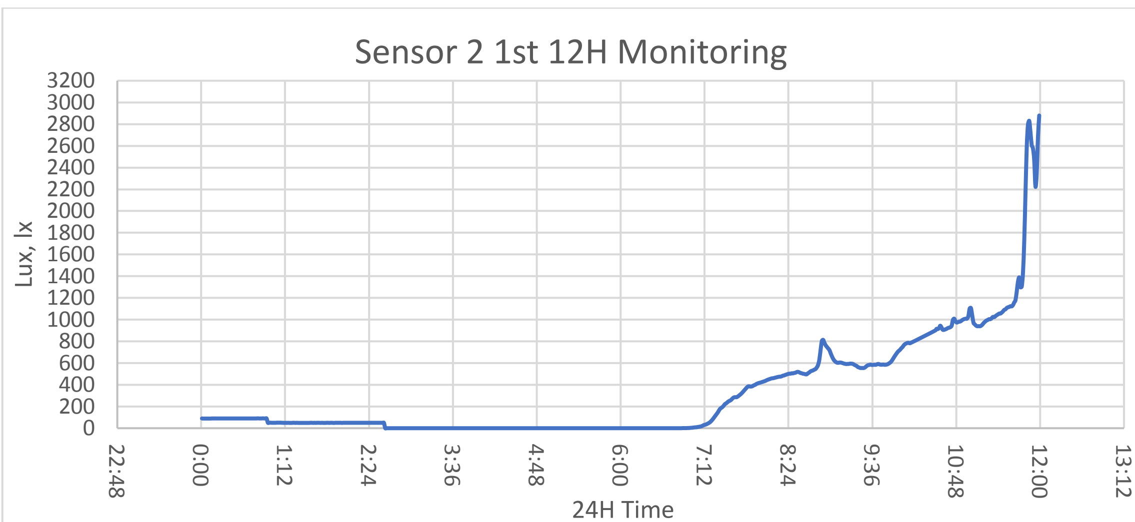

Figure 4.16: Sensor 2 1^st^ 12Hour Monitoring Graph

Based on Figure 4.16 and Figure 4.17, the readings recorded was taken by Sensor 2. Referring at Figure 4.16, the lux values recorded at 0712 till 1200 is bigger as Sensor 2 is placed beside the window. Based on Figure 4.17, at the time between 1507 and 1604 there were points where the lux values recorded were 0 lx. At that several points, the light sensor is saturated thus recorded 0 lx values. This is because the light sensor already achieved its maximum limit range to measure the illuminance of the area as the maximum lux can be measured was set in the coding to be at highest of 20 klx.

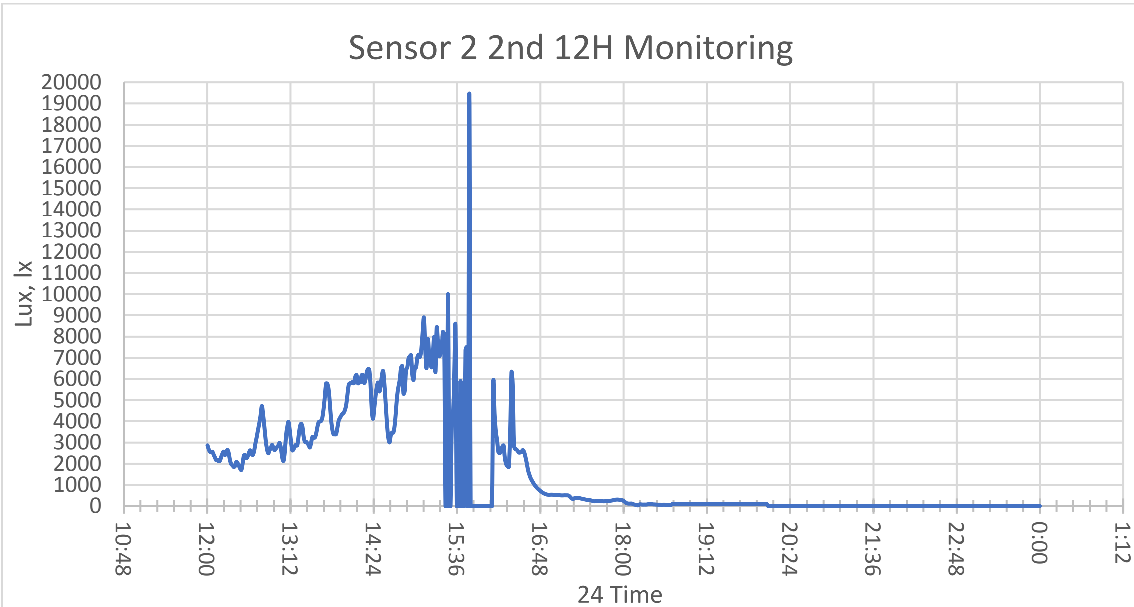

Figure 4.17: Sensor 2 2nd 12Hour Monitoring Graph

Basically, the room orientation of the area give great effect to its illumination. The lighting condition of Area 1 is greatly affected by the sunlight rather than the luminaires during the day and the usage of luminaires only can be seen at the time 18:43 till 20:03 as the lux recorded is between 130 lx – 140 lx (we can observe this condition at Figure 4.15) which is when both Luminaire 1 and Luminaire 2 is used. Other points that recorded value of 0 lx by the Sensor 1 and Sensor 2 indicated that the work area is under scotopic light condition or low light condition.

4.4.2 Area 2 Illumination

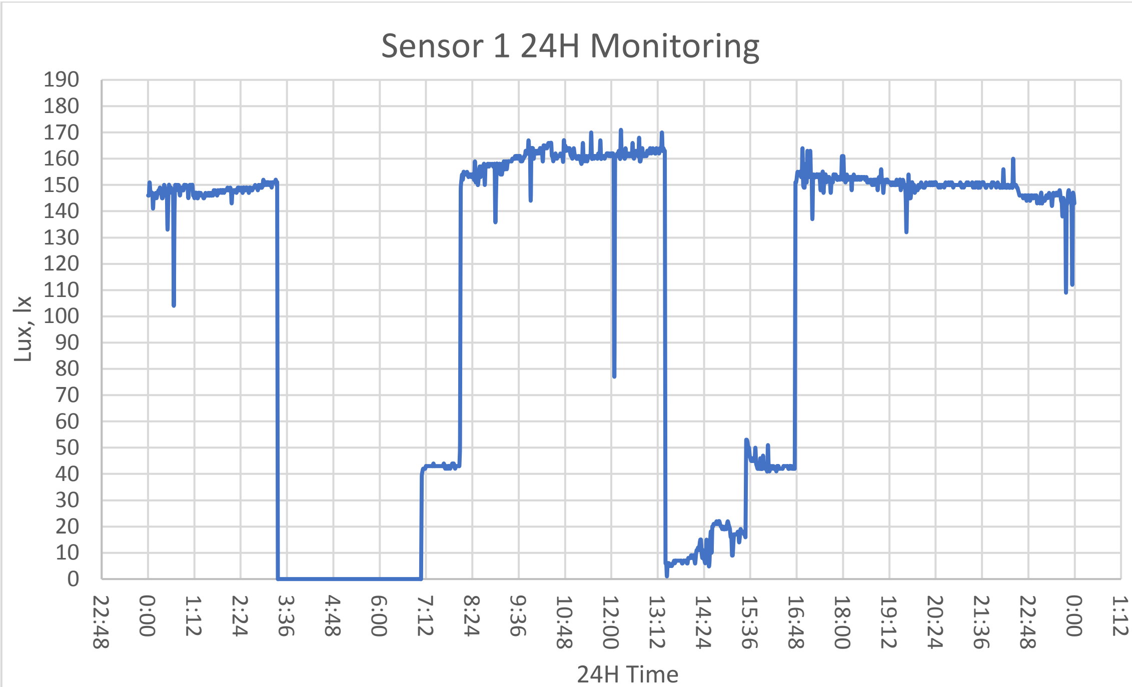

Figure 4.18: Sensor 1 24Hour Monitoring Graph

Based on Figure 4.18, the usage of luminaires can be seen, at time 00:00 till 03:20, 08:08 till 13:20 and at time 16:54 till 23:59 as the values recorded was steady at the range of 140 lx – 170 lx. The luminaires were not switched on at time 13:30 till 16:45 and the values of lux 1 lx – 60 lx recorded is due to the presence of sunlight. Normally, the values in the range of 140 lx – 170 lx recorded when both Luminaire 1 and Luminaire 2 is used. However, there were points which shows discrete spikes due to the to the luminaire used which is fluorescent lamp that has a low-level continuum of spectral power distribution (SPD) at specific wavelength. Based on Figure 4.19, the illumination recorded by Sensor 2 increasing in the range of 27 lx – 231 lx at time 07:12 till 10:41 and in the range of 66 lx – 167 lx at time 13:34 till 15:00 due to the increasing of illuminance of the sunlight at the area.

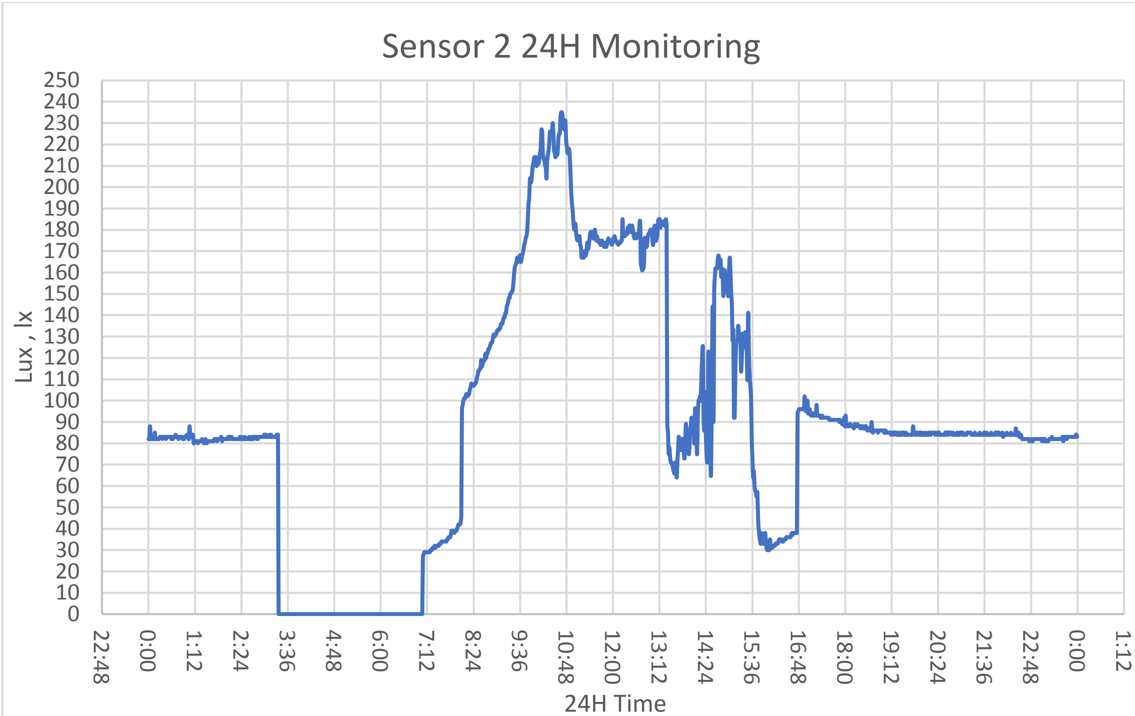

Figure 4.19: Sensor 2 24Hour Monitoring Graph

Generally, the illumination of Area 1 is greatly due to the presence of sunlight as the values recorded was approximately exceeding 160 lx at several points while the illumination of Area 2 is greatly due to the usage of both/either Luminaire 1 and/or Luminaire 2. However, the illumination of both Area 1 and Area 2 is still under well lighting condition as the values recorded by Sensor 1 was below 3000 lx and in the range of 100 lx – 3000 lx. The orientation of the room of both Area 1 and Area 2 is greatly affect the illumination or lighting condition of the work areas. The average of the illuminance from the luminaires (both Luminaire 1 and Luminaire 2) used is between the range of 130 lx-160 lx after the values recorded by Sensor 2 and Sensor 1 was compensated. Based on the result, the ambient light monitoring system which is reliable and scalable is successfully designed and developed.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

As a conclusion, the design and development of the ambient light monitoring system using Internet of Things (IoT) discussed in this project is a simple IoT monitoring system yet reliable and scalable that can take measurement of the illuminance autonomously in a real-time without human involvement and continuously able to do the long-term monitoring of the indoor ambient light remotely. The prototype which consist of several main components able to proof the concept of using IoT in environmental monitoring activity. Besides, the system also provides access of the collected ambient light data anywhere to the users using the Internet platform for any intervention work. The system that will be implemented in the campus able to promote a smart environment around the campus as well as giving the society an awareness in terms to use energy efficiently and practice a good health conditions. The system able to give an impact towards human productivity, comfortability and mood. Other than that, the data samples taken automatically and continuously for several days at several indoor workplaces around campus able to show different trends of lighting conditions and usage which are due to the artificial lights and natural light thus prove the reliability of the ambient light monitoring system using IoT. However, the lighting demands is subjective as it is changeable because it depends on the user's specific visual task. The TSL2561 light sensor, Arduino Uno, Yun Shield module and used IoT platform chosen are absolutely the best choice due to its simplicity, robustness, open source, reliable, scalable, trustworthy and low power usage. The data acquisition by the advanced light sensor is extremely important for future intervention works such as to have a well lighting condition, or about energy harvesting purpose and most importantly to create better environment in terms of energy efficiency and better working environment.

Recommendations for future work can be in terms of improvisation and enhancement of the monitoring system which related with the system modules such as to do implementation of sensor nodes and to have better data transmission with IoT platforms used. Besides that, the use of diffusive cover on the TSL2561 light sensors to prevent saturation due to the direct sunlight during daytime should be implemented as the monitoring activities is run continuously every day in 24hours time period so there will be presence of sunlight. We can also do the addition of light sensors for better monitoring activities as more data samples could be taken in the same time and different position of the light sensors. In spite of that, addition of actuators that can automatically control the lighting condition based on the data collected from the sensors which are transferred and stored in the cloud. These future improvements can be implemented in the future in order to build the best IoT system.

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APPENDICES

Appendix I

```
#include "ThingSpeak.h"
#include <Wire.h>
#include <Bridge.h>
#include <Console.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_TSL2561_U.h>
#include "BridgeClient.h"

// The sensor address is defined here (more TSL2561 light sensors added means more address needed)
Adafruit_TSL2561_Unified tsl = Adafruit_TSL2561_Unified(TSL2561_ADDR_FLOAT, 12345);
Adafruit_TSL2561_Unified tsl1 = Adafruit_TSL2561_Unified(TSL2561_ADDR_LOW, 54321);
//Store the 16-bit value
int calibrated=0;
int calibrated1=0;

//The type of client used to exchange the data is define here
BridgeClient client;

//The Channel ID and the APIKey to write the data to Thingspeak channel captured by the sensor is define
here
unsigned long myChannelNumber = 233615;
const char * myWriteAPIKey = "W0ZVVYXYULV8Q6Y7";

void setup() {
Bridge.begin();
// Console.begin(9600); // Is used to print the output on the serial monitor
Console.println("Light Sensor Test"); Console.println("");
```

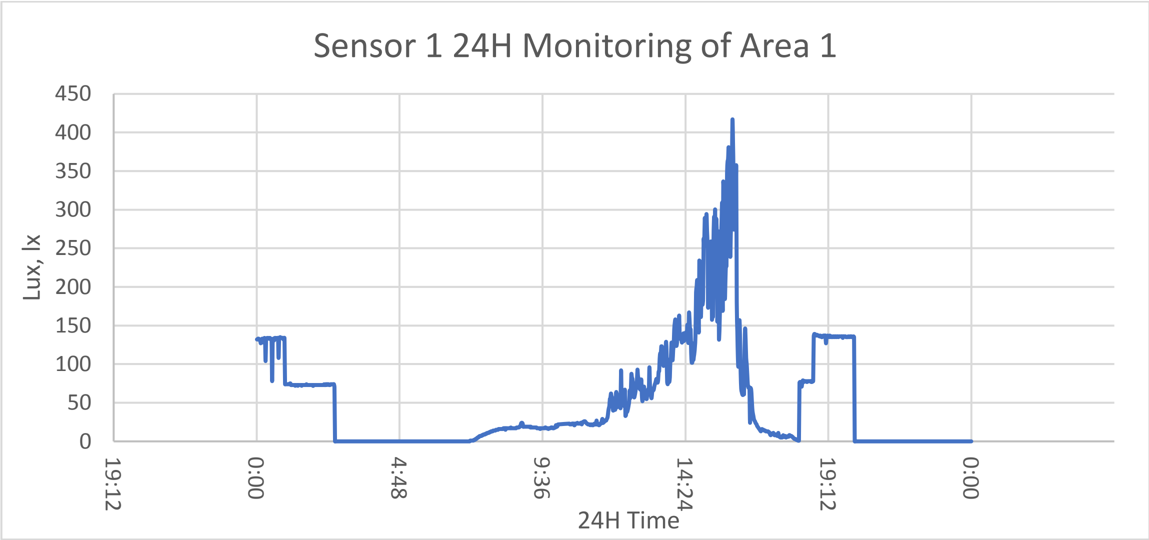
```
/* Initialise the sensor */
if(!tsl.begin())
{
/* There was a problem to detect the TSL2561 light sensor ... check again the connections */
Console.print("Ooops, no TSL2561 detected ... Check your wiring or I2C ADDR!");
while(1);
}

/* Display some basic information on this sensor */
displaySensorDetails();

/* Setup the sensor gain and integration time */
configureSensor();

/* We're ready to go! */
Console.println("");
ThingSpeak.begin(client);
}
void displaySensorDetails(void)  // Serial Monitor is used here
{
sensor_t sensor;
tsl.getSensor(&sensor);
Console.println("------------------------------------");
Console.print  ("Sensor:       "); Console.println(sensor.name);
Console.print  ("Driver Ver:   "); Console.println(sensor.version);
Console.print  ("Unique ID:    "); Console.println(sensor.sensor_id);
Console.print  ("Max Value:    "); Console.print(sensor.max_value); Console.println(" lux");
Console.print  ("Min Value:    "); Console.print(sensor.min_value); Console.println(" lux");
Console.print  ("Resolution:   "); Console.print(sensor.resolution); Console.println(" lux");
Console.println("------------------------------------");
Console.println("");
delay(500);
```

```
sensor_t sensor1;
tsl1.getSensor(&sensor1);
Console.println("------------------------------------");
Console.print  ("Sensor:       "); Console.println(sensor1.name);
Serial.print  ("Driver Ver:   "); Console.println(sensor1.version);
Console.print  ("Unique ID:    "); Console.println(sensor1.sensor_id);
Console.print  ("Max Value:    "); Console.print(sensor1.max_value); Console.println(" lux");
Console.print  ("Min Value:    "); Console.print(sensor1.min_value); Console.println(" lux");
Console.print  ("Resolution:   "); Console.print(sensor1.resolution); Console.println(" lux");
Console.println("------------------------------------");
Console.println("");
delay(500);
}

void configureSensor(void) /* To montitor the light condition in a 24-hour time. The limit will be set at 20 klx max.*/
{
/* You can also manually set the gain or enable auto-gain support */
// tsl.setGain(TSL2561_GAIN_1X);      /* No gain ... use in bright light to avoid sensor saturation */
// tsl.setGain(TSL2561_GAIN_16X);     /* 16x gain ... use in low light to boost sensitivity */
tsl.enableAutoRange(true);            /* Auto-gain ... switches automatically between 1x and 16x */
tsl1.enableAutoRange(true);            /* Auto-gain ... switches automatically between 1x and 16x */

/* Changing the integration time gives you better sensor resolution (402ms = 16-bit data) */
//tsl.setIntegrationTime(TSL2561_INTEGRATIONTIME_13MS);      /* fast but low resolution */
// tsl.setIntegrationTime(TSL2561_INTEGRATIONTIME_101MS);  /* medium resolution and speed   */
tsl.setIntegrationTime(TSL2561_INTEGRATIONTIME_402MS);  /* 16-bit data but slowest conversions */
tsl1.setIntegrationTime(TSL2561_INTEGRATIONTIME_402MS);  /* 16-bit data but slowest conversions */

/* Update these values depending on what you've set above! */
Console.println("------------------------------------");
```

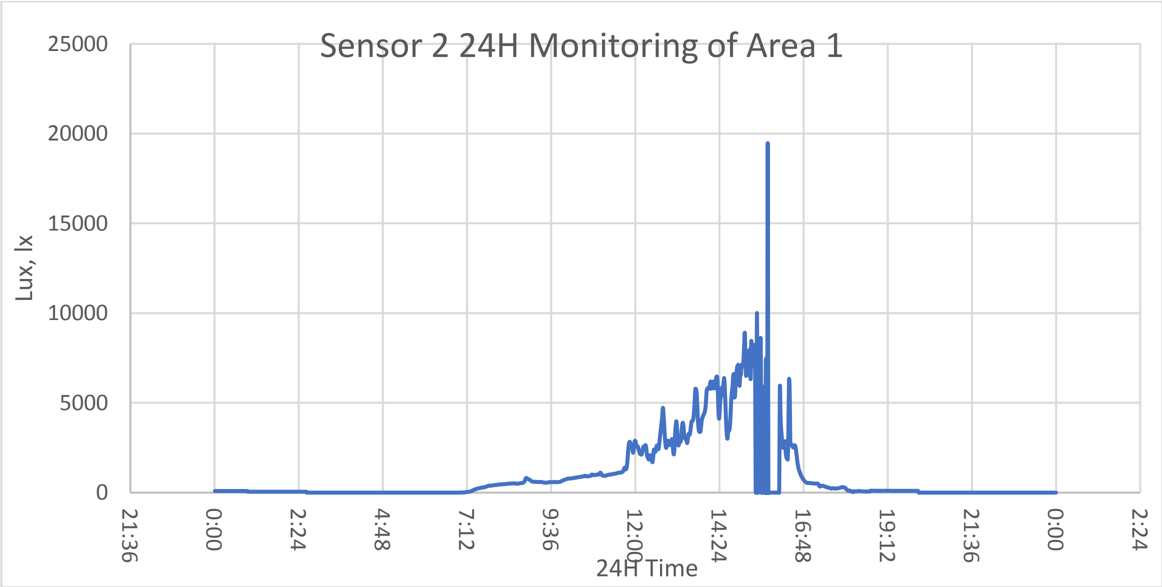
```
Console.println(" Light Sensor 1");
Console.print  ("Gain:         "); Console.println("Auto");
Console.print  ("Timing:       "); Console.println("402 ms");
Console.println("------------------------------------");
Console.println("");
Console.println("------------------------------------");
Console.println(" Light Sensor 2");
Console.print  ("Gain:         "); Console.println("Auto");
Console.print  ("Timing:       "); Console.println("402 ms");
Console.println("------------------------------------");
}

void loop() {
/* Get a new sensor event */
sensors_event_t event;
tsl.getEvent(&event);
sensors_event_t event1;
tsl1.getEvent(&event1);

/* Display the results (light is measured in lux) */
// if (event.light && event1.light)
//{
calibrated=event.light;
calibrated1=event1.light;
Console.print("Light Sensor 1 : "); Console.print( calibrated); Console.println(" lux");
Console.print("Light Sensor 2 : "); Console.print(calibrated1); Console.println(" lux");
Console.println (millis());
Console.println("");
//int sensorValue = event.light;
float lux =  calibrated;
ThingSpeak.setField(1,lux);
// int sensor1Value = event1.light;
float lux1 = calibrated1;
```

```
ThingSpeak.setField(2,lux1);


// Write the fields that were set all at once.

ThingSpeak.writeFields(myChannelNumber, myWriteAPIKey);


delay(60000);

}

else

 {

/* If event.light or event1.light = 0 lux the sensor is probably saturated or the light condition is in scotopic condition

and no reliable data could be generated! */

Console.println("Sensor overload"); }

delay(250);

}
```

Appendix II



Appendix III



Appendix IV

RECOMMENDED ILLUMINATON

OFFICE	Conference, reception room	200～750Lux
	Clerical work	700～1,500Lux
	Typing drafting	1,000～2,000Lux
FACTORY	Packing work, entrance passage	150～300Lux
	Visual work at production line	300～750Lux
	Inspection work	750～1,500Lux
	Electronic parts assembly line	1,500～3,000Lux
HOTEL	Public room, cloakroom	100～200Lux
	Reception, cashier	220～1,000Lux
STORE	Indoors stairs corridor	150～200Lux
	Show window, packing table	750～1,500
	Forefront of show window	1,500～3,000
HOSPITAL	Sickroom, warehouse	100～200Lux
	Medical examination room	300～750Lux
	Operation room, emergency treatment	750～1,500Lux
SCHOOL	Auditorium, indoor gymnasium	100～300Lux
	Class room	200～750Lux
	Laboratory, library, drafting room	500～1,500Lux