Sensor Technology for Night Sky Brightness Measurements in Malaysia

Ngadiman N. F., Shariff N. N. M., Hamidi Z. S.

Abstract*: *Artificial light at night is apparently showing to be a major contributor to the increase of sky brightness at night. The natural darkness in large regions of the world including Malaysia currently is at risk. Hence, some Night Sky Brightness (NSB) measurements in Malaysia were conducted by using several types of light sensors in order to serve quantitative data and spread awareness on this issue. This paper aims to analyze the sensor technology that have been used in night sky brightness measurement in Malaysia as well as to identify recent or significant advances and discoveries in this field of study. In this paper, the author adopted qualitative method through literature review from numerous conducted studies by other researchers in order to perceive better understanding on the use of dedicated light sensor in NSB related research. Starting from 2005 until now, it is noticeable that most of the light sensor used in the NSB studies in Malaysia was Sky Quality Meter (SQM) photometer, equipped with TSL237 sensor which has high irradiance responsivity 2.3kHz/(µW/cm2) @ λp = 524nm and 5 Milion:1 input dynamic range as well as able to sense down to 0.00002 Lux and has typical dark frequency down to 0.1 Hz. The result indicates the relative frequency of the SQM usage in NSB studies was 76% compared to PBM, APC, PMT and CDD of only 4% respectively. SQM has always been the choice of researchers in Malaysia to carry out their sky brightness measurements due to user-friendly implementation besides its reliable data obtained from TSL237 sensor which capable to convert the light directly to frequency without an amplifier or data converter. Thus, the nonlinearities and voltage offsets in the data can be circumvented. A fairly good development of sensor that have been utilized in NSB studies can be discerned patently besides NSB studies will always look forward for a better sensor to further enhance the efforts to map sky brightness for preserving the potential dark sky areas for the sake of astronomy.

Keywords: light sensor, night sky brightness, sensor technology

I. INTRODUCTION

Due to the spread of poorly designed outdoor lighting systems, nowadays, the natural darkness is at risk in large regions of the world including Malaysia. Artificial light at night has been shown to be a major contributor to the increase of sky brightness at night. This obtrusive and excessive light produced by human mainly electricity from residence areas, streetlamps or billboards. As consequence, some night sky brightness (NSB) measurement in Malaysia were conducted by using several types of sensors in order to serve quantitative data and spread awareness on this issue. Howbeit, most previous studies in this country have focused more on prayer time determination based on the measurement of sky brightness, the data obtained is still considered as a contribution to the quantitative data of night sky brightness readings in Malaysia.

Sensor is a device or subsystem whose purpose is to take input from the physical surrounding environment and send the information to other electronics. In NSB context, sensor technology can improve environmental monitoring by detecting the current ambient light level and portraying the night sky brightness pattern in certain locations. Commonly, in astronomy, the brightness was measured in magnitude unit – the brighter objects have lower magnitude.

In Malaysia, the NSB studies has been carried out since 2005 to date. This period exhibits the changing pattern of light sensor use among researchers. Initially, most of the light sensors used were self-made - a combination of several electronic devices, that usually derived from the electronics component supplier, RS Components. Zainuddin, Hamidi, Ahmad, & Latib, 2005 [1], built Pitch Black Meter (PBM) plus the light emitting diode (LED) as the sensor to detect light. Afterwards, a method using light dependent resistor (LDR) has been applied by Ahmad, Zainuddin, & Yahya, 2007 in the light detection technique and the device called *Alat Pengesan Cahaya* or Light Detector Tool (APC) [2]. Next, there is a study by Hamid & Aziz, 2009 [3] using the photometry technique that uses photomultiplier tube (PMT) as a light detector.

Starting in 2008, most NSB related studies such as Shariff, 2008, Hamidi, Abidin, Ibrahim, & Shariff, 2011, Niri et al., 2012, Nor & Zainuddin, 2012, Shukor & Zainuddin, 2015, Azhar, Gopir, Mohd Kamil, Mohamad, & Azmi, 2016, Tahar, 2017, Umar et al., 2018 and Aziz, Yusof, & Muhamad, 2018 [4]-[12], have shown a tendency to use commercial photometer, Sky Quality Meter (SQM) produced by the Canadian company Unihedron, which most of SQM model equipped with TSL237 sensor. Similarly, a recent study conducted by Islamic Astronomy and Solar Astrophysics, Universiti Teknologi MARA, Shah Alam, Malaysia which uses SQM-LU-DL and SQM-LE to make measurements of night sky brightness. Meanwhile, a study by Ngadiman, Ahmad, & Wahab, 2018 [13] has used charge-coupled device (CCD) device with KAF-1001 image sensor to implement the assessment.

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The objective of this paper is to analyze the sensor technology that have been used in measuring brightness of night sky in Malaysia besides to identify recent or significant advances and discoveries in this field of study.

II. METHODOLOGY

Qualitative method was adopted in this paper through literature review from numerous conducted studies by other researchers in order to perceive better understanding on the use of dedicated light sensor in NSB related research that will add on the body of knowledge. The following is the list and brief description about sensor technology that have been used in Malaysia.

A. Pitch Black Meter (PBM)

PBM is an optical device which can provides precise measurement of sky brightness by comparing the brightness of light source with the given area of night sky and the current value readings will be obtained off the multimeter. PBM has been built by constructing three components: (1) Sighting tube – using Polyvinylchloride (PVC) plumbing tubing material, (2) Variable power supply – using arching process to create the circuit base, and (3) Ordinary digital multimeter. For sighting tube, with several modification on length of tubing, the green LED which centered in the sky end of the tube, the green filter holder and tripod have been made. Fig. 1 shows the picture of sighting tube with the green filter. All the main electronic components have been gathered in the power supply control box. Fig. 2 and Fig. 3 portray the picture and schematic diagram for the variable power supply.

Fig. 1.Sighting tube with the green filter.

Fig. 2.Picture of variable power supply.

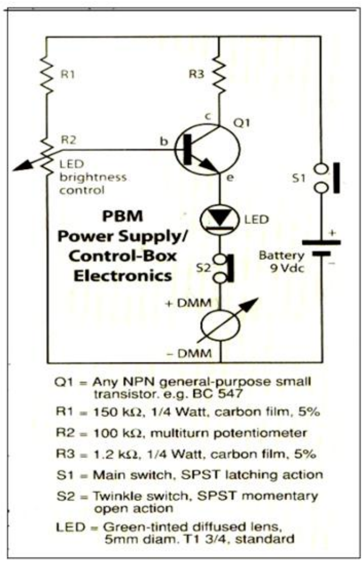

Fig. 3.Schematic diagram for the variable power supply.

B. Light Detector Tool (APC)

APC is made up of several electronic components i.e. operation amplifier 741, NPN transistor NTE128 or 2N3035, resistor 470 Ω, 10 Ω and 1 Ω, and variable resistor 10 Ω. Light dependent resistor (LDR) is an electronic device that works against changes in light intensity. The LDR surface which is sensitive when exposed to light with a certain intensity, will reduce resistance to the LDR and hence the current will be allowed to pass through it. Op-amp 741 is a device that works to strengthen the voltage passing through it. While NPN transistors is a device used to convert the voltage generated by op-amp to the current. Output from transistors is measured using a multimeter. APC has 2 circuits, one for measuring current and other for measuring voltage. 12 - 15 V batteries are required in this circuit for turning on the op-amp 741.

The APC is designed to have 2 main parts. First part consists light sensitive boxes, green light filters and LDR as shown in Fig. 4. While second part is circuit box, 12 V battery and multimeter digital (Fig. 5). Fig. 6 illustrates the fully installed APC.

(a) Light Sensitive Boxes **(b) Green Light Filters** **(c) LDR**

Fig. 4.First part of APC.

Fig. 5.Second part of APC.

Fig. 6.APC is fully installed.

C. Photomultiplier Tube (PMT)

PMT is commonly used as the photodetectors due to their high signal-to-noise ratio, high responsivity in A/W and high gain as well as lower in dark current and transport delay. Previous study has used the SSP7 photometer (Fig. 7) that uses PMT as a light detector. This photometer has good temperature stability, able to measure relatively small amounts of electromagnetic radiation and exhibit a high detection bandwidth. Due to the avalanche process, the responsivity of PMT can be orders of larger magnitudes. Thus, this sensor is suitable for photon counting because the current pulse created by a single photoelectron is large enough to be simply detected. The light will be collected through the telescope, then through the Johnson filters U (ultraviolet), B (blue), V (green) and R (red), then the light will be detected by the PMT and produce numerical readings of the sky brightness values (Fig. 8).

Fig. 7.SSP-7 Precision Photometer mounted on telescope.

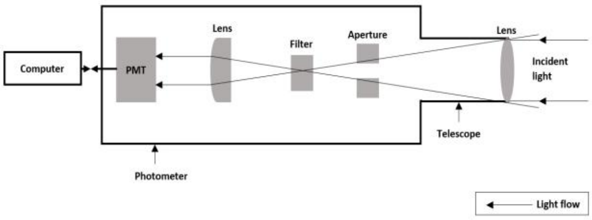

Fig. 8.Diagram of the SSP7 photometer.

D. Sky Quality Meter (SQM)

SQM is a photometer produced by the Canadian company, Unihedron. The first SQM released in 2007 was a typical SQM. The manufacturer then made improvements to this product to the SQM-L or Lens type, followed by SQM-LE (Ethernet Lens), SQM-LR (Lens RS232) and the latest instrument used is the SQM-LU type Lens Universal Serial Bus (USB) and SQM-LU-DL type USB Data Logging. The types of SQMs and their features are summarized in Table 1.

integrated circuit which has capability to convert the light directly to frequency without an amplifier or data converter. Thus, the nonlinearities and voltage offsets in the data can be circumvented.

Moreover, has high irradiance responsivity 2.3kHz / (µW / cm2) @ λp = 524nm, enabling this sensor to sense ultra-low light levels where most silicon-based sensors are unable to detect. It means TSL237 sensor designed for high sensitivity to detect a small change in light. Among other features of this sensor is that it has 5 Milion:1 input dynamic range that can detecting light intensity at a high resolution. This SQM was invented to provides low light level operation down to 0.00002 Lux because it has typical dark frequency down to 0.1 Hz. On top of that, the method of using SQM is very easy to apply when conducting the measurement by simply directing the light detector to the night sky. The output is a square wave with 16-bit resolution and frequency which directly proportional to light intensity on the photodiode (Fig. 9).

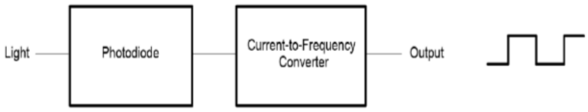

Fig. 9.Functional block diagram for TSL237 sensor.

Table- I: Types of SQM and its features

						
Model	**SQM**	**SQM-L**	**SQM-LE**	**SQM-LR**	**SQM-LU**	**SQM-LU-DL**
Interface	Handheld/ Display	Handheld/ Display	Ethernet	RS232	USB	USB
FOV	Wide (60^o)	Narrow (20^o)	Narrow (20^o)	Narrow (20^o)	Narrow (20^o)	Narrow (20^o)
Reach	Handheld	Handheld	Global	100m (300')	5m (15')	Autonomous
Readings	Single reading	Single reading	Single/ Continuous	Single/ Continuous	Single/ Continuous	Single/ Continuous

The SQM and SQM-L are manual type which the user needs to press the button to turn on the photometer and the readings are displayed on the instrument as well. Howbeit, the light detector in SQM-L is more sensitive than the SQM type. Then, the company made improvements by introducing SQM-LE, SQM-LR, SQM-LU and SQM-LU-DL. These types of SQMs are automatic so that the user does not have to press a button. The data obtained continues to be entered into the computer. In addition, these types of SQM equipped with TSL237 sensor. This sensor is light-to-frequency converter that designed from combination of a silicon photodiode and a current-to-frequency converter on a single monolithic CMOS

This photometer provides logarithmic measurement and will give numerical readings in magnitude per square arc second (MPSAS) unit. The relation between MPSAS and candela per square meter (cd/m^2) unit, which commonly used by lighting engineer, can be define in following equation:

$$cd/m^2 = 10.8 \times 10^4 \times 10^{(-0.4\times[mag/arcsec2])} \quad (1)$$

E. Charge-Coupled Device (CCD)

Fundamentally, CCD is a device which designed as light-sensitive integrated circuit that captures light, accumulates and converts it into electrical charge or digital data. The CCD type used in the NSB study in Malaysia is SBIG STL 1001 E which using the KAF-1001 as an image sensor (Fig. 10). This image sensor is a high-performance CCD created for a wide range of image sensing applications. It also utilizes the TRUESENSE Transparent Gate Electrode in order to improve sensitivity compared to the use of a standard front side illuminated polysilicon electrode. This sensor chip has a full capacity of 650 keÀ which can store more electrons due to its larger pixel. The working principle for this sensor in collecting NSB data is same as the PMT sensor which the telescope will collect the light, then it will pass through the Johnson filters UBVR, then the sensor will detect it. Afterwards, photometry technique will be applied to the recorded image of night sky to obtain the brightness readings.

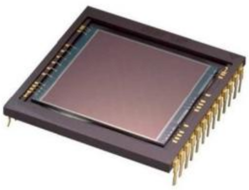

Fig. 10.KAF−1001 CCD image sensor.

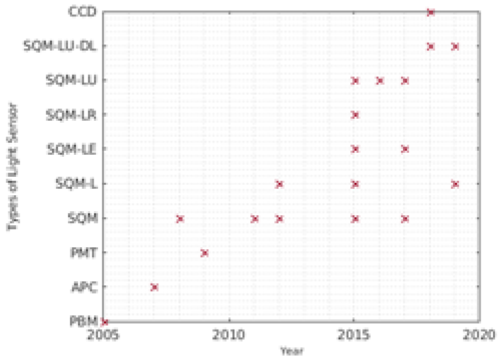

Fig. 11.Use of sensor technology for NSB studies in Malaysia

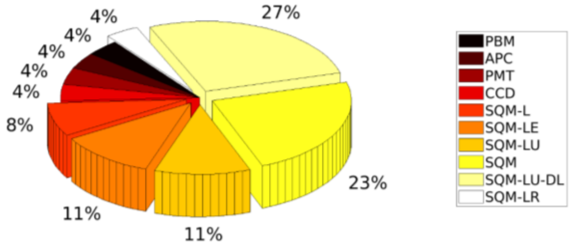

Fig. 12.Percentage for the use of different types of sensor in NSB studies.

III. RESULT AND DISCUSSION

Based on an in-depth review of the literature, starting from 2005 to date, it is noticeable that most of the light sensor used in the NSB studies in Malaysia was Sky Quality Meter (SQM) photometer (Table II and Fig. 11). The result indicates that since the SQM was launched in 2007, researchers in Malaysia have begun to use this commercial photometer to make measurements. The percentage in Fig. 12 showed that the use of SQM in NSB studies was 76% compared to PBM, APC, PMT and CDD of only 4% respectively.

Table- II: Frequency and relative frequency for the different sensors that have been used.

Sensor	Frequency	Relative Frequency
PBM	1	0.05
APC	1	0.05
PMT	1	0.05
SQM	5	0.25
SQM-L	3	0.15
SQM-LE	2	0.1
SQM-LR	1	0.05
SQM-LU	3	0.15
SQM-LU-DL	2	0.1
CCD	1	0.05
Total	20	1

SQM is a user-friendly instrument which is very easy, simple and uncomplicated to apply when conducting research. Moreover, the latest types of SQM which equipped with TSL237 sensor, provide for high resolution and high sensitivity to detect very lower light levels and excellent for measurement of NSB into the bargain. These advantages are due to this type of sensor equipped with high irradiance responsivity 2.3kHz/(μW/cm2) @ λp = 524nm, 5 Milion:1 input dynamic range and low dark frequency (0.1Hz typical) feature. SQM is a felicitous equipment and has always been the choice of researchers in Malaysia to carry out their sky brightness measurements compared to other light sensors such as CCD, PMT, APC and PBM.

Based on previous studies, for PBM, the circuit need to be improved by replacing the LED with more sensitive light detector. For APC, some performed test concluded that the APC is not suitable due to the lack of sensitivity to brightness changes. The application of LDR limits when the light signal varies rapidly besides highly inaccurate with a response time of about tens or hundreds of milliseconds. This sensor also gives inaccurate readings as the working temperature changes. Somehow, both of this tool still relevant to measure light pollution by improving in terms of its circuit.

Meanwhile, the study that use PMT to measure sky brightness indicate that this sensor is suitable to be applied in NSB studies since the results show that the green filter resembles human eye's response. Similarly, the use of CCD with KAF-1001 sensor, it is seen as suitable to measure sky brightness readings.

Nonetheless, because of both sensors i.e. PMT and KAF-1001 are extreme low-light sensitivity, there are many things such as the star's magnitude, reduction and calibration processes and more, need to be considered during observation as mistakes in these things may cause errors in brightness readings. The author concludes that even PMT and CCD are good for NSB studies, but due to the complicated implementation method, most researchers in Malaysia are more likely to use SQM than both these tools.

IV. CONCLUSION

In conclusion, it is noticeable that SQM, the felicitous equipment, has been the choice among researchers in NSB studies due to the user-friendly implementation and affordable price as well as the good aftersale service and support which attended by the inventor themselves for troubleshooting or tool maintenance. Furthermore, SQM equipped with TSL237 sensor, which has high irradiance responsivity 2.3kHz/(μW/cm2) @ λp = 524nm, 5 Milion:1 input dynamic range and low dark frequency (0.1Hz typical) feature to produce reliable data in the measurement. Its capability to convert the light directly to frequency without an amplifier or data converter, can circumvents the nonlinearities and voltage offsets in the data. We can see clearly a fairly good development of sensor that have been utilized in NSB studies definitely, NSB studies will always look forward for a better sensor to further enhance our efforts to map sky brightness for preserving the potential dark sky areas for the sake of astronomy.

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REFERENCES

1. Zainuddin, M. Z., Hamidi, Z. S., Ahmad, N., & Latib, A. A. (2005). *Pitch Black Meter – Determining the accurate time of Isha and Syuruk.*
2. Ahmad, N., Zainuddin, M. Z., & Yahya, M. S. (2007). Kajian Kecerahan Langit Di Ufuk Senja dan Fajar.
3. Hamid, C. A., & Aziz, A. H. A. (2009). "Penentuan Syarat Mula dan Akhir Senja Astronomi Menggunakan Kaedah Fotometri Langit dalam Menentukan Permulaan Waktu Fajar dan Isyak. In M. Z. M. Jafri, K. Abdullah, H. S. Lim, & N. M. Saleh (Eds.), Astronomi: Pelestarian di Malaysia (p. 88). Pulau Pinang: Universiti Sains Malaysia.
4. Shariff, N. N. M. (2008). Sky Brightness at Twilight: Detectors Comparison between Human Eyes and Electronic Device For Isha' and Subh from Islamic and Astronomical Considerations. University of Malaya.
5. Hamidi, Z. S., Abidin, Z. Z., Ibrahim, Z. A., & Shariff, N. N. M. (2011). Effect of light pollution on night sky limiting magnitude and sky quality in selected areas in Malaysia. *3rd ISESEE 2011 - International Symposium and Exhibition in Sustainable Energy and Environment*, (June), 233–235. https://doi.org/10.1109/ISESEE.2011.5977095
6. Niri, M. A., Zainuddin, M. Z., Man, S., Anwar, M. S., Nawawi, M., Wahab, R. A., … Lokman, A. (2012). Astronomical Determinations for the Beginning Prayer Time of Isha'. *Middle-East Journal of Scientific Research*, *12*(1), 101–107. https://doi.org/10.5829/idosi.mejsr.2012.12.1.1673
7. Nor, S. A. M., & Zainuddin, M. Z. (2012). Sky Brightness for Determination of Fajr and Isha Prayer by Using Sky Quality Meter. *International Journal of Scientific & Engineering Research*, *3*(8), 3–5. Retrieved from http://www.ijser.org/paper/Sky-Brightness-for-Determination-of-Fajr-and-Isha-Prayer-by-Using-Sky-Quality-Meter.html
8. Shukor, M. S., & Zainuddin, M. Z. (2015). Perbandingan Metodologi Kajian Penentuan Masuknya Fajar Sadiq dan Hilangnya Syafaq Ahmar: Kajian Kecerahan Langit. Jurnal Falak, 1, 133–139.
9. Azhar, A. D., Gopir, G., Mohd Kamil, W. M. A. W., Mohamad, N. S., & Azmi, N. C. (2016). Night sky brightness measurement at PERMATApintar observatory. AIP Conference Proceedings, 1784, 1–5. https://doi.org/10.1063/1.4966789
10. Tahar, M. R. et al. (2017). Spatial Model of Sky Brightness Magnitude in Langkawi Island, Malaysia. 17(4), 1–10. https://doi.org/10.1088/1674
11. Umar, R., Jannah Awang, W., Nadhirah Berzanji, S., Farhana Abd Majed, N., Khairul Amri Kamarudin, M., & Garba Abdullahi, M. (2018). Spatial Model of Sky Brightness Magnitude in KUSZA Observatory, UniSZA. International Journal of Engineering & Technology, 7(2.15), 13. https://doi.org/10.14419/ijet.v7i2.15.11189
12. Aziz, A. H. A., Yusof, M. Z. M., & Muhamad, M. N. (2018). Kajian Bermulanya Waktu Fajar. Jurnal Falak, (4).
13. Ngadiman, N. F., Ahmad, N., & Wahab, R. A. (2018). Atmospheric Extinction and Night Sky Brightness at Langkawi National Observatory. Jurnal Falak, (4), 163–176.

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