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A Prototype of True Dawn Observation Automation System (Prototipe Sistem Otomatisasi Observasi Fajar)

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ABSTRAK

Dibutuhkan data pengamatan fajar yang memadai baik secara kualitas maupun kuantitas untuk mengoreksi atau memverifikasi kebenaran kriteria awal waktu subuh yang ditetapkan oleh Kemenag yang satu dekade terakhir ini diragukan kebenarannya oleh beberapa pihak. Namun, suhu dan kondisi lapangan yang kurang bersahabat menjadi tantangan tersendiri dalam pengamatan fajar. Dalam tulisan ini dideskripsikan pengembangan Sistem Otomatisasi Observasi Fajar (SOOF) yang meliputi kebutuhan *hardware*, *software* beserta instalasinya dan pengujian kinerja sistem di tiga lokasi yaitu Karimunjawa (-5,7S, 110,48T, 1 mdpl), Banyuwangi (-7,97S, 114,42T, 1 mdpl) dan Semarang (-6,97S, 110,29T, 15 mdpl). Sekilas tentang data yang dihasilkan juga disajikan dalam tulisan ini yang meliputi variabilitas karena cahaya Bulan dan polusi cahaya terhadap pendeteksian terbit fajar. Hasil uji coba menunjukkan bahwa secara umum sistem berjalan dengan baik, tetapi perlu *upgrade* modul GPS dan *Real Time Clock* sehingga sistem bisa bekerja dengan lebih baik. Sementara itu, analisis terhadap data yang direkam oleh sistem tersebut menunjukkan bahwa cahaya Bulan memiliki pengaruh yang cukup kuat terhadap waktu deteksi terbit fajar di lokasi dengan polusi cahaya rendah (Banyuwangi dan Karimunjawa), yaitu terpaut rata-rata sekitar 3,4° (13,6 menit) dibandingkan ketika saat tidak ada cahaya Bulan. Sementara itu, cahaya Bulan di daerah dengan polusi cahaya tinggi (Semarang) tidak memiliki pengaruh yang signifikan, yaitu terpaut rata-rata sekitar 0,25° (1 menit). Kajian ini juga mengusulkan bahwa fajar sidik terdeteksi pada saat posisi Matahari rata-rata -20 ± 0,2 derajat di bawah ufuk.

Kata kunci: prototipe, sistem otomatisasi, pengamatan fajar

ABSTRACT

It requires adequate true dawn observation data both in quality and quantity to correct or verify the accuracy of the early true dawn criteria set by the Ministry of Religious Affairs of the Republic of Indonesia, which in the last decade had been doubted by several parties. However, temperature and unfavorable field conditions present challenges in observing the true dawn. This paper describes the development of the True Dawn Observation Automation System which includes hardware and software requirements, system installation, and performance testing in three locations: Karimunjawa (-5.78S, 110.48E, 1 m above sea level, Banyuwangi (-7.97S, 114.42E, 1 masl) and Semarang (-6.97S, 110.29E, 15 masl). An analysis of the data is also presented in this paper which includes the variability due to moonlight and light pollution on true dawn detection. The test results show that the system is running well but it needs an upgraded GPS and Real-Time Clock module so the system can work better. Meanwhile, analysis of the data recorded by the system shows that moonlight has a strong effect on true dawn detection in locations with low light pollution (Banyuwangi and Karimunjawa), an average difference of around 3.4° (13.6 minutes) compared to when moonlight was absent. Meanwhile, in areas with high light pollution (Semarang), it does not have a significant effect, an average difference of around 0.25° (1 minute). This study also proposes that true dawn is detected when the Sun's position averages -20 ± 0.2 degrees below the horizon.

Keywords: prototype, automated system, true dawn observations

1. Introduction

Determination of Muslim prayer times is discussed in Islamic studies, namely *fiqh* which is the view of Islamic jurists, namely *fuqaha*. It is based on the Koran and Hadith which relates to Muslim prayer obligations and the specified times. *Fuqaha* have agreed that the *subuh* prayer time begins when the true dawn rises (Sabiq, 1987).

Allah in al-Baqarah [2]: 187 describes the characteristics of dawn with a thin white thread as a sign of the start of fasting which is also a sign of the start of the *subuh* prayer time. Furthermore, the Prophet also explained that there are two types of dawn: (1) the dawn that vertically upwards like a wolf's tail which forbids eating and allows *subuh* prayers; and (2) the dawn that spreads over the horizon which permits the eating of *sahur* and prohibits *subuh* prayers (Narrated by Al-Bayhaqy; al-Bayhaqy, 1991).

Based on this, the term “true dawn” is used as a sign of entering the time of fasting and *subuh* prayers, and the opposite is the “false dawn” which appears before true dawn. In another word, the “true dawn” is a dawn that bodes an influx of dawn. It is named "true dawn" because dawn is the dawn of the “right” or the "true" dawn or the dawn "sadik" in Arabic. The rising of the true dawn begins with the emergence of white light that spreads along the eastern horizon then gradually brightening the sky.

Based on the Bortle scale[1], the appearance of zodiacal light is an indicator that the brightness of the night sky is very dark which has a value of more than 21 mpsas. Meanwhile, based on the above hadith (as well as several other hadiths) the dawn *kadzib* or the false dawn was quite easy to observe in the era of the Prophet. Thus, it can be said that the true dawn is the dawn detected in areas where the brightness of the night sky is more than 21 mpsas.

The term “true dawn” is also used by some scholars. Semeida & Hassan (2018) and Hassan *et al.* (2014) said that the true dawn is the beginning of twilight and the false dawn (pseudo dawn) as zodiacal light. Saksono & Fulazzaky (2020) also uses the term “true dawn” in determining the start of the *subuh* prayer time.

The Ministry of Religion of the Republic of Indonesia stipulates that the beginning of true dawn in Indonesia begins 80 minutes before sunrise or when the Sun is 20 degrees below the horizon. Lately, the truth of the criteria set by the Ministry of Religion of the Republic of Indonesia has begun to be doubted by several parties because it is only based on historical data on the opinion of ulama (Butar-Butar, 2018) and not based on adequate observations (Bahali *et al.*, 2018; Herdiwijaya, 2016).

To correct or verify the validity of these criteria is not enough based on observations of true dawn light in one or two locations only but long-term observations are needed in Indonesia by taking into account the variation and nature of each region. Based on these observational data, it will be known that the nature of true dawn light in Indonesia could be different from the theoretical true dawn that had been developed so far because the atmospheric conditions at the equator are higher than the other regions (Djamaluddin, n.d.-b).

True dawn research so far is still a snapshot observation and no long-term research has been carried out in several different locations. Each researcher tends to move independently in collecting research data in locations with limited area and time. With only a few data from that location, each of them concludes the results of their research. The conclusions of each researcher are often different from one another because the data is indeed taken at different locations and field conditions.

Herdiwijaya (2020), after analyzing the data for several days of observations at Bosscha Observatory, Cimahi, Bandung, Yogyakarta, and Kupang in the range of 2011 to 2018, proposed that the dawn rises in Indonesia when the Sun was at -18.5° with 1-sigma of error of sun’s depression angle obtained by assuming the darkest night sky brightness at 22.5 mpsas. Arumaningtyas *et al.* (2012) in their research in Bandung and

[1] John E. Bortle in his writing Gauging Light Pollution: The Bortle Dark-Sky Scale made measurements of several regions in the world based on the brightness of the night sky to 9 (nine) scales which was then called the Bortle scale. Bortle refers to the brightness limit that can be seen by the naked eye or naked-eye limiting magnitude (NELM) with the values of 8.0–4.0 or equal to 22.0~18.0 mag/arcsec^2. The higher the value shown will indicate the smallest level of light pollution or enter a scale of 1 (excellent dark-sky site) and so on up to scale 9 (inner-city sky) which shows the highest level of light pollution. (Bortle, n.d.)

Jombang for 10 days concluded that the dawn was detected about 40 minutes before the Sun rises or when the Sun was at -10°. In another location, Noor & Hamdani (2018) made observations on Tayu Pati Beach with the conclusion that dawn was detected when the Sun was at -17°. Meanwhile, Saksono & Fulazzaky (2020) concluded that dawn was detected when the Sun was at −14° ± 0.6 in Depok. Rohmah (2016) in his research for several days in Juwiring, Pati, Yogyakarta (Central Java), Kaibon (East Java), and Bandung (West Java) concluded that they were almost similar to Herdiwijaya's findings of around -18.5°.

The findings of these studies are certainly not enough to correct or verify the validity of the -20° criteria set by the Indonesian Ministry of Religious Affairs. Long-term observations in several regions in Indonesia are important to be done to find out the patterns of dawn occurrence in each location so that finally with a representative amount of data one can draw better conclusions.

However, observing the light of dawn requires greater effort than observing at other prayer times. Unfriendly temperatures and field conditions are often found in observations to get the best data in the best location away from urban light pollution. For example, the author's experience with the Lembaga Falakiyah Nahdlatul Ulama (LFNU) Gresik during the dawn observations on Bawean Island Gresik (+150 km north of Java) for one week in July 2019, 'only' obtained one of the best data. Another experience when observing dawn on Karimunjawa Island Jepara (+100 km north of Java) for several days in May and October 2019 was disturbed by cloudy conditions during the observation. Based on this we need a system that facilitates observers in observing the light of dawn.

The development of a night sky brightness monitoring system that utilizes the Sky Quality Meter (SQM) has been carried out in other studies. Hanel (2018) developed SQMDroid, an Android application that integrates reading of SQM-LU data from an Android phone. Dogan *et al.* (2016) designed the Rotational Sky Quality Meter (R-SQM) to measure changes in the quality of the night sky around the Eastern Anatolia Observatory area of Turkey at varying angles in data recording. Raspberry Pi used a system that controls R-SQM to record data automatically. Zamorano *et al.* (2017) designed the Telescope Encoder, Sky Sensor, and Wifi (TESS-W) for observing the brightness of the night sky under the Star4All Universidad Complutense Madrid project. In the TESS-W system, a custom PCB (Printed Circuit Board) is used as the main control and TSL237 photodiode sensor which is the same sensor used by Unihedron SQM.

Until now the use of SQM produced by Unihedron still dominates in observing the brightness of the night sky because it has good measurement accuracy and stability (Schnitt *et al.*, 2013). Falchi *et al.* (2016), for example, built a map of the sky brightness in the world manually using the Unihedron SQM which is directly linked in his observations. Based on this, in this paper, a true dawn observation system will be developed which automatically records the true dawn data whose results are automatically uploaded to cloud storage and can be accessed by the public for the next analysis process.

2. Methods

This paper will develop the celestial instrument for observing the dawn light. This study begins with the assembly of hardware needed, the installation of some software, and testing systems for observations of dawn in several locations (Table 1).

In general, the true dawn observation automation system is designed in Figure 1. Hardware requirements and system workflow are described in the following. The SQM used in this system is the SQM-LU-DL/SQM-LU version as the main sensor in recording the brightness of true dawn light. The SQM is connected to Raspberry pi Zero (as the main control) via a mini USB port or a standard USB port if we use Raspberry pi 2/3/4. This system is also designed to record true dawn images. The camera module is connected to the Raspberry pi through the camera module slot or via a USB port if we use an astronomical camera like the ZWO ASI series. A 5V 3A power adaptor is used as a power supply for Raspberry pi and USB 4G Wifi. After a true dawn light brightness data is recorded by SQM and a true dawn image recorded by the camera, the data is uploaded by Raspberry pi to Google Drive so that it can be accessed by the user for further analysis.

Data downloaded from the system are reduced by selecting data with clear weather and then categorized into several lunar

Table 1. Locations for testing the true dawn observation automation system.

Location	Coordinate	Elevation (m)	Time
Semarang	-6.97S, 110.29E	15	25/09/2020 – 25/10/2020
Karimunjawa	-5.78S, 110.48E	1	01/09/2020 – 28/10/2020
Banyuwangi	-7.97S, 114.42E	1	24/08/2020 – 25/10/2020

Figure 1. Flow chart of the true dawn observation system.

phases. In the next step, the selected data are analyzed by the gradient method per minute to determine the turning point of the curve which is an indication of true dawn obtained from the data with the formula:

$$m = \frac{y_2 - y_1}{x_2 - x_1} \quad (1)$$

where m is gradient, y_1 and y_2 are the average magnitude per minute at minute n and n + 1 respectively, while x_1 and x_2 are the average of sun depression angle at minute n and n + 1.

Furthermore, the formula is applied in Python with the criteria to determine early dawn rises to be tried in the range of 0.01 – 0.05 magnitude/minute gradient values. If the gradient is found to match the specified criteria and the data gradient thereafter is consistently greater than the criterion, then the beginning of the gradient of which the value is greater than the criterion is indicated as the dawn.

This paper will also present the effect of moonlight to determine the rising of true dawn in several observation locations as listed in Table 1.

2.1. Software Requirement

Software used in the system are:

a. *Raspbian Operating System*
Raspbian is a free Debian-based Linux operating system that has been optimized for Raspberry Pi hardware, including the Python programming language installed[2].

b. *Python Sky Quality Meter* (PySQM)
PySQM is a Python language-based software designed by Nievas & Zamorano (2014) for reading, storing, and plotting data from SQM-LU and SQM-LE. This software will connect to SQM and perform several tests to connect to SQM to ensure it is ready for retrieval of sky brightness data. This program will automatically save data in two formats: .dat file and curve plotting image[3].

c. *Raspistill* and *Mencoder*
Raspistill is a CLI (command-line interface) based program that functions to capture images by the camera module, while *Mencoder* is a complementary code of MPlayer application that can encode audio files, images, and videos into a video that is compatible with MPlayer applications and several other video player applications[4].

d. *AllSky*
AllSky is a Raspberry Pi operated Wireless Allsky Camera[5]. We use this software when we use the Raspberry Pi HQ camera or ZWO ASI series in this system.

e. *RClone*

[2] https://www.raspberrypi.org/software/operating-systems
[3] https://guaix.fis.ucm.es/PySQM
[4] https://help.ubuntu.com/community/MEncoder
[5] https://github.com/thomasjacquin/allsky

RClone (Rsync for Cloud Storage) is a CLI-based program that functions to synchronize files and local directories to and from some online storage (cloud storage), for example, Google Drive, Box, and so on[6].

2.2. System Installation

There are six steps to install the system: (1) installation of the Raspbian operating system on an SD Card; (2) the configuration of the Raspbian operating system wifi so that it can be connected with USB 4G Wifi for the installation and configuration of the required software; (3) installation of Remote.It program to maintain the system remotely; (4) installation of the PySQM program in the Raspbian operating system; (5) installation of the *raspistill* and *mencoder* or *AllSky* program; and (6) installation of the *RClone* program. More details are described below.

The installation process of the Raspbian operating system is the following steps:

a. Download the Raspbian image from The Raspberry Foundation website[7];
b. Flash the image to SD Card with one of the imager programs (*balenaEtcher*, *Win32DiskImager*, *imgFlasher,* or others).

Before installing other programs, we need to configure the WiFi network from Raspbian because the installation process for the next programs is done remotely via a WiFi network emitted by USB 4G Wifi. For this purpose, two files need to be made in the SD Card root directory which has been installed by Raspbian. The two files are empty files with the name *ssh* which functions to activate the ssh (secure shell connection) feature on the Raspbian OS. The second file is the *wpa_supplicant.conf* file with the following contents:

```
country=ID
ctrl_interface=DIR=/var/run/wpa_supplican
t GROUP=netdev
update_config=1

network={
ssid="NETWORK-NAME"
psk="NETWORK-PASSWORD"
key_mgmt=WPA-PSK
}
```

Where *ssid* data is replaced with the name of the wifi network used and the *psk* is filled with the wifi network password (Michael, n.d.).

The maintenance process or installation of any software to the system can be done remotely by installing *Remote.It* program with the following command (Remote.It, n.d.):

```
$>sudo apt update
$>sudo apt install remoteit
```

After the network configuration has been done, the Raspbian system can be accessed via the *ssh* with applications such as *Bitvise SSH Client*. Via *ssh* connection, the PySQM program can be downloaded with the command:

```
$> wget http://guaix.fis.ucm.es/
sites/default/files/luminica_
files/PySQM.tar.gz
```

and extract it with the command:

```
$> tar -xvzf PySQM.tar.gz
```

Before the execution of the PySQM program, it is necessary to adjust the data in the configuration file located in the pysqm/confiq.py file. Data that needs to be adjusted include (1) name and coordinates of the observation location; (2) the name of the SQM identification; (3) the connection port used by SQM with the Raspbian system; (4) location of observation data storage folder; and (5) axis boundaries for plotting curves from observational data (Lázaro, 2020; Nievas & Zamorano, 2014).

Up to this point, when the system is running, it automatically records the dawn light data detected by SQM. To complete the observation data, an application is needed to capture the image of dawn light so that it can be used as a comparison data for the SQM data. In this case, the application used is a *mencoder* and *raspistill* application that has a successive installation process as follows (Shaw, n.d.):

```
$>sudo apt-get install mencoder
```

The *raspistill* application does not need to be installed because it is already included in the Raspbian operating system. The camera module can be activated in the system via the command:

```
$>raspi-config
```

[6] https://rclone.org
[7] https://www.raspberrypi.org/ downloads

If we use Raspberry Pi HQ camera or ZWO ASI series in this system we need to install the *AllSky* program via the command:

```
$>sudo apt-get install git
$>git clone --recursive
  https://github.com/thomasjacquin/allsk
  y.git
$>cd allsky
$>sudo ./install.sh
```

Observation data that is automatically recorded by PySQM, *raspistill*, *mencoder,* and *AllSky* will be stored on the local drive. To facilitate access to the data, the data will be uploaded automatically to cloud storage by the *RClone* application with the following installation steps:

```
$>curl https://rclone.org/ install.sh |
sudo bash
```

The *RClone* and Google Drive configuration process continues with the following commands and configurations:

```
$>rclone config

n/s/q> n          # choose n (new)
name>gdrive       # fill with free
                    caption, for
                    example, Gdrive
Storage>          # Select the number that
                    matches the Google
                    Drive number
client_id>        # can be left empty
client_secret>    # can be left empty
scope>            # select scope, for
                    example 1
root_folder_id>   # can be left empty
service_account_file>
                    /home/bas/myfile.jso
                    n # This is where
                    the JSON file goes!
y/n>              # choose y for automatic
                    configuration
```

Furthermore, the PySQM program, *mencoder*, *raspistill, AllSky,* and *RClone* are set up so that it will run automatically when the system boots and automatically records data at the desired time. For this purpose, an additional configuration is needed in the rc.local file (Dexter Industries, n.d.; The Raspberry Pi Foundation, n.d.).

3. Result and Discussion

The first step in testing the system started with the assembly of the system hardware as shown in Figure 1 and position-

Figure 2. System installation at Banyuwangi.

ing the system in a location where the eastern horizon is unobstructed as shown in Figure 2. The second step is to access the system via the *ssh* connection with the *Bitvise SSH Client*. After the *hostname* and *port* (provided by Remote.It) had been entered, now we are connecting to the system and then the user is asked to enter a username and password which by default are *pi* and *raspberry*, respectively.

The next step is to check that PySQM is running properly in the background with the command:

```
$>ps –aux | grep "pysqm"
```

Then, PySQM runs correctly in the background with the process ID (PID)1104.

The next step to run the PySQM program is not necessarily done because it is set to run automatically when the system boots, as well as the *mencoder*, *raspistill*, *AllSky,* and *RClone* programs.

The results of reading the data generate photo data, *.dat* files, and SQM data plotting curves (Figures 3 and 4) and the data is automatically uploaded to the Google Drive account.

Data analysis using the gradient method shows that the Karimunjawa and Banyuwangi areas are categorized as dark areas or category 1 (excellent dark-sky) on the Bortle scale with a Night Sky Brightness (NSB) value of more than 21 mpsas while Semarang is a bright area or category 8 (city sky) with an NSB value less than 18 mpsas. Also, moonlight has a strong influence on the detection of true dawn in dark areas and less in bright areas.

Table 2. Comparison of average measurements at three locations in the several Moon phases and clear weather. NSB columns are the average night sky brightness while the Twilight columns summarize the Sun's depression angle during which true dawn lights are observed.

Location	New Moon & First Quarter		Full Moon		Last Quarter	
	NSB	Twilight	NSB	Twilight	NSB	Twilight
Karimunjawa	22.6 ± 0.9	-20.0 ± 0.1	19.5 ± 0.6	-15.8 ± 1.3	20.3 ± 0.2	-17.5 ± 0.6
Banyuwangi	21.4 ± 0.2	-19.9 ± 0.2	19.2 ± 0.8	-16.7 ± 0.9	20.0 ± 0.1	-17.5 ± 0.7
Semarang	17.1 ± 0.2	-13.7 ± 0.7	17.1 ± 0.2	-14.4 ± 0.6	17.1 ± 0.1	-14.0 ± 1.0

Figure 3. One of the true dawn images recorded.

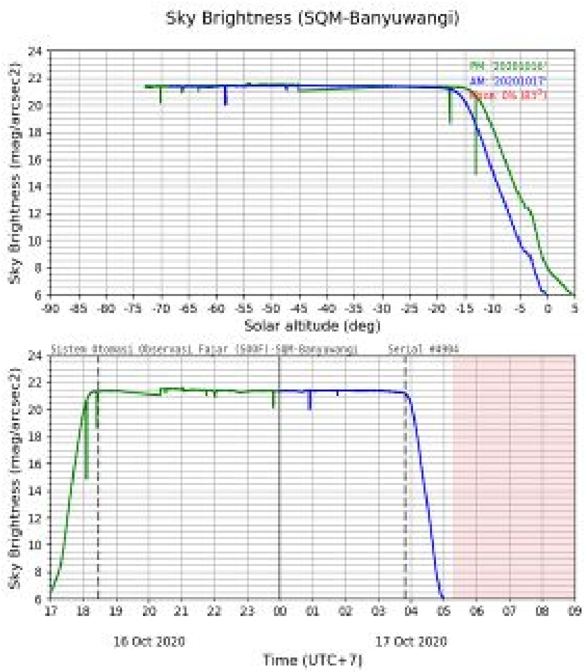

Figure 4. The sky brightness plot produced from a .dat file recorded by the system.

Table 2 shows that in dark areas (Karimunjawa and Banyuwangi) and no moonlight disturbance (new moon and first quarter), the true dawn light is detected when the Sun is -20.0 ± 0.1 degrees in Karimunjawa and -19.9 ± 0.2 degrees in Banyuwangi. Meanwhile, in the full Moon phase, dawn was detected at -15.8 ± 1.3 degrees in Karimunjawa and -16.7 ± 0.9 degrees in Banyuwangi or a difference of around 4.2 degrees (16.8 minutes) and around 3.2 degrees (12.8 minutes). Meanwhile, in the last quarter phase, dawn was detected at -17.5 ± 0.6 degrees and -17.5 ± 0.7 degrees or a difference of around 3.9 degrees (15.6 minutes) in Banyuwangi and Karimunjawa.

Meanwhile, in bright areas (Semarang) when there is no moonlight, the dawn light is detected when the Sun is located at -13.7 ± 0.7 degrees. Meanwhile, in the full Moon phase and the last quarter phase, the dawn was detected at -14.4 ± 0.6 degrees and -14.0 ± 1.0 degrees, or a difference of around 0.7 degrees (2.8 minutes) and around 0.3 degrees (1.2 minutes).

The results in this paper also show that the suggestion of Saksono (n.d.) which stated that moonlight does not have a significant effect on the true dawn is correct when observations are made in locations with high light pollution. However, the results are different if the observations are made in areas with low light pollution or dark areas, such as Karimunjawa and Banyuwangi.

Based on the Bortle scale and the explanation of the Hadith above, the results in Karimunjawa and Banyuwangi (in clear weather and when there is no disturbance of moonlight and the night sky brightness is more than 21 mpsas) can be accepted as true dawn, when the position of the Sun in average is about -20 ± 0.2 degrees below the horizon.

The observations in Karimunjawa and Banyuwangi confirm the findings of previous studies which stated that true dawn is detected in Labuan Bajo when the Sun is located -20 degrees below the horizon (Djamaluddin, n.d.-b), but it is different from the findings of Noor (2019) who observed in 5 locations (Imah Noong Lembang, Tayu Pati, Branta Madura, Pengkol Pasuruan and e-Maya Observatory Subang) and found that the deepest solar depression angle was -21.81 degrees with 1-sigma of error at Tayu site.

There is still a lot of data needed to correct or verify the criteria for the Ministry of Religion. However, the results in this paper can be used as a reference for future research and it can be one of the references and evidence that the system built in this study can work well. Further trials are still needed in several other locations so that sufficient representative data is obtained for further analysis to obtain better conclusions.

4. Conclusion

Based on the testing of this system in Semarang, Banyuwangi, and Karimunjawa for several days, the true dawn observation automation system can work well. Data recorded by the system is automatically uploaded to the cloud storage so that it can then be accessed by other users for further analysis.

Moonlight in dark areas has a strong effect on the detection of the rising of true dawn or causes the true dawn to rise later than when there is no moonlight in an average of around 3.4 degrees (13.7 minutes). Whereas in bright areas there is no significant effect or an average difference of around 0.25 degrees (1 minute). This study also proposes that true dawn is detected when the Sun's position averages -20 ± 0.2 degrees below the horizon.

There are some limitations in this system that need to be developed for the perfection and improvement of the system. It would be better if the system was integrated with a GPS module that automatically reads the observation position and stores it in the system configuration file. Besides, the installation of the Real-Time Clock module is also quite important to anticipate the failure of time synchronization performed by the NTP server used in this system.

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References

Al-Bayhaqy, A. bin al-H. bin A. (1991). *as-Sunan al-Kubro*. Dar al-Kutub al-'Ilmiyah.

Arumaningtyas, E.P., Raharto, M., & Herdiwijaya, D. (2012). Morning twilight measured at Bandung and Jombang. *AIP Conference Proceedings*, *1454*(1), 29-31. DOI: 10.1063/1.4730680

Bahali, K., Samian, A.L., Muslim, N., & Hamid, N.S.A. (2018). Measuring the Sun Depression Angle of Dawn with a DSLR Camera. *Sains Malaysiana*, *47*(11), 2877-2885. DOI: 10.17576/jsm-2018-4711-31

Bortle, J.E. (n.d.). *Gauging Light Pollution: The Bortle Dark-Sky Scale*. Retrieved 8 March 2020, from https://www.skyandtelescope.com/astronomy-resources/light-pollution-and-astronomy-the-bortle-dark-sky-scale/

Butar-Butar, A.J.R. (2018). *Fajar & Syafak dalam Kesarjanaan Astronomi Muslim dan Ulama Nusantara*. LKiS.

Dexter Industries. (n.d.). *Run a Program On Your Raspberry Pi At Startup*. Retrieved 5 March 2020, from https://www.dexterindustries.com/howto/run-a-program-on-your-raspberry-pi-at-startup/

Djamaluddin, T. (n.d.-a). *Benarkah Waktu Subuh di Indonesia Terlalu Cepat?* Retrieved 5 December 2019, from https://tdjamaluddin.wordpress.com/2017/09/13/benarkah-waktu-subuh-di-indonesia-terlalu-cepat/

Djamaluddin, T. (n.d.-b). *Penentuan Waktu Shubuh: Pengamatan dan Pengukuran Fajar di Labuan Bajo*. Retrieved 1 October 2020, from https://tdjamaluddin.wordpress.com/2018/04/30/penentuan-waktu-shubuh-pengamatan-dan-pengukuran-fajar-di-labuan-bajo/

Dogan, E., Ozbaldan, E.E., Shameoni, N.M., & Yesilyaprak, C. (2016). Automatic Rotational Sky Quality Meter (R-SQM) Design and Software for Astronomical Observatories. *Revista Mexicana Astronomia y Astrofisica (Serie de Conferencias)*, *48*, 31–32.

Falchi, F., Cinzano, P., Duriscoe, D., Kyba, C. C. M., Elvidge, C. D., Baugh, K., Portnov, B. A., Rybnikova, N. A., &

Furgoni, R. (2016). The new world atlas of artificial night sky brightness. *Science Advances*, 2(6), e1600377. DOI: 10.1126/sciadv.1600377
Hanel, A. & T. (2018). *SQMDroid - A universal SQM measurement device*. http://unihedron.com/projects/darksky/cd/SQM-LU/SQMDroid/Poster_ALAN2-2.1.pdf
Hassan, A.H., Abdel-Hadi, Y.A., Issa, I.A., & Hassanin, N.Y. (2014). Naked eye observations for morning twilight at different sites in Egypt. *NRIAG Journal of Astronomy and Geophysics*, *3*(1), 23–26. DOI: 10.1016/j.nrjag.2014.02.002
Herdiwijaya, D. (2016). Sky brightness and twilight measurements at Jogyakarta city, Indonesia. *Journal of Physics: Conference Series*, *771*(1), 012033. DOI: 10.1088/1742-6596/771/1/012033
Herdiwijaya, D. (2020). On the beginning of the morning twilight based on sky brightness measurements. *Journal of Physics: Conference Series*, *1523*(1), 012007. DOI: 10.1088/1742-6596/1523/1/012007
Lázaro, R.D. (n.d.). *OBSOLETE Unattended Sky Quality Meter Station*. Retrieved 14 January 2020, from http://rdlazaro.info/20-COMPU/80-RASPBERRY_PI/32-unattended_SQM_OLD.html
Michael. (n.d.). *How To Setup Raspberry Pi Zero W Headless WiFi*. Retrieved 20 February 2020, from https://core-electronics.com.au/tutorials/raspberry-pi-zerow-headless-wifi-setup.html
Nievas, M. & Zamorano, J. (2014). *PySQM the UCM open source software to read, plot and store data from SQM photometers*. http://eprints.ucm.es/25900/1/LICA_PySQM_v2.pdf
Noor, L.A.H. (2019). *Analisis Perubahan Kecerahan Langit Waktu Fajar dengan Sky Quality Meter* [Institut Teknologi Bandung]. https://repo.science.itb.ac.id/3597/
Noor, L.A.H. & Hamdani, F.F.R.S. (2018). The dawn sky brightness observations in the preliminary shubuh prayer time determination. *Qudus International Journal of Islamic Studies*, *6*(1), 25–37. DOI: 10.21043/qijis.v1i1.2870
Remote.It. (n.d.). *Installing remoteit on a Raspberry Pi running Raspbian or Raspberry Pi OS*. Retrieved 1 October 2020, from https://support.remote.it/hc/en-us/articles/360045375151-Raspberry-Pi-Quick-Start-remote-itPi-SD-Card-image-
Rohmah, N. (2016). The Effect of atmospheric humidity level to the determination of Islamic Fajr/morning prayer time and twilight appearance. *Journal of Physics: Conference Series*, *771*(1), 012048. DOI: 10.1088/1742-6596/771/1/012048
Sabiq, S. (1987). *Fiqh al-Sunnah*. Dar al-Kitab al-‘Araby.
Saksono, T. (n.d.). *Fajar Di Hari Dengan Polusi Cahaya Tertinggi*. Retrieved 10 October 2020, from https://www.saksono.org/2020/08/fajar-di-hari-dengan-polusi-cahaya.html
Saksono, T. & Fulazzaky, M.A. (2020). Predicting the accurate period of true dawn using a third-degree polynomial model. *NRIAG Journal of Astronomy and Geophysics*, *9*(1), 238–244. DOI: 10.1080/20909977.2020.1738106
Schnitt, S., Ruhtz, T., Fischer, J., Hölker, F., & Kyba, C. (2013). Temperature Stability of the Sky Quality Meter. *Sensors*, *13*(9), 12166–12174. DOI: 10.3390/s130912166
Semeida, M.A. & Hassan, A.H. (2018). Pseudo dawn and true dawn observations by naked eye in Egypt. *Beni-Suef University Journal of Basic and Applied Sciences*, *7*(3), 286–290. DOI: 10.1016/j.bjbas.2018.03.005
Shaw, A. (n.d.). *Working with the Raspberry Pi camera module*. Retrieved 5 March 2020, from https://www.raspberry-pi-geek.com/Archive/2013/02/Working-with-the-Raspberry-Pi-camera-module
The Raspberry Pi Foundation. (n.d.). *rc-local*. Retrieved 5 March 2020, from https://www.raspberrypi.org/documentation/linux/usage/rc-local.md
Universidad Complutense de Madrid. (n.d.). *PySQM*. Retrieved 10 February 2020, from https://guaix.fis.ucm.es/PySQM
Zamorano, J., García, C., Tapia, C., Sánchez de Miguel, A., Pascual, S., & Gallego, J. (2017). STARS4ALL Night Sky Brightness Photometer. *International Journal of Sustainable Lighting*, *18*(35), 49–54. DOI: 10.26607/ijsl.v18i0.21