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Development of Graphical Interface Software for Solar Flare Monitoring System

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ABSTRACT

Solar activity such as solar flares causes increased X-ray and ultraviolet ray flux. This event will cause sudden ionospheric disturbances (SID) and disrupts the communication systems as well as the space-based equipment on Earth. Public awareness especially to school students on the effects of solar activities towards humans on Earth is very important as the dependency of human daily life on space technology is increasing. The awareness has been conducted by the Space Science Center, Institute of Climate Change, UKM using UKM-SID™ system. Based on the program, it was found that school student experienced constraints in the process of analyzing data due to the absence of computers in schools. Therefore, UKM-SID™ system, with portable kit equipped with an interactive software to produce an easy-to-understand figure, was proposed. An algorithm was also developed to transfer the observed data onto the server in near real time. The developed Graphical Interface software showed a visualized sunrise and sunset patterns which is in agreement with the previous study. A solar flare was detected on 1 December 2020. The observed data is also successfully uploaded onto the server in near real time. Result shows that this new UKM-SID™ system is able to capture the solar flare occurrence. This new system is also at an optimal and sophisticated level compared to the technology that has been used. Hence, the researchers believe the UKM-SID™ is able to help educators, students and the general public in the learning of space science more effectively.

Keywords: Solar flare; UKM-SID™; GUI; Python; Very Low Frequency (VLF)

INTRODUCTION

Solar flare is a large explosion that occurs in the sunspot region when the magnetic energy that has been built up is suddenly released. This event involves the release of charged particles such as protons and electrons into the solar atmosphere (Seaton & Darnel 2017). The rays produced by solar flare are in the form of X-ray or Extreme Ultraviolet (EUV) ray. Both can propagate at the speed of light and take approximately eight minutes to reach and affect the Earth's ionospheric layer dramatically (Papaioannou et al. 2016).

The Earth's ionosphere layer contains free electrons that affect the propagation of radio waves. During the occurrence of solar flares, large amounts of EUV and X-rays penetrate the D-layer and increase the rate of ionization. The changes in the ionosphere is known as sudden ionospheric disturbances (SID) (Nina et al. 2017). SID can be detected by monitoring interference at the amplitude of a very low frequency (VLF) signal using a VLF receiver (Šulić et al. 2016). A VLF receiver is a radio frequency in the range of 3–30 kHz (Saccuan et al. 2018).

One of the equipment that has been used to detect the occurrence of SID is Atmospheric Weather Electromagnetic System for Observation, Modeling and Education (AWESOME). While AWESOME is a more sensitive monitor, a researcher from Stanford University has developed a smaller version of AWESOME known as SuperSID, which can be used for learning and research purposes (Abdullah et al. 2013). The differences between AWESOME and SuperSID system are shown in Table 1.

TABLE 1. The difference between AWESOME and SuperSID

No.	system	Hardware	Operation	User
1.	AWESOME	Complex and expensive	More sensitive and accurate timing via GPS	Researcher in space, telecommunications and energy sectors
2.	SuperSID	Concise and cheaper	Smaller sampling rate depending on the sound card used and less sensitive	Educators, students and the general public

Since the occurrence of SID can disrupt radio communication and navigations, it is important to create awareness to the public on the effects of solar activities towards humans on the Earth (Nagem et al. 2018). In line with the Malaysian government vision to create space weather awareness among the public, UKM's researcher has started to develop their own portable SID detection known as UKM-SID™ since 2011 (Abdullah et al. 2014). This system was developed based on the Super SID schematic owned by the Stanford University (Abdullah et al. 2018).

The first system that has been developed in 2011 consists of loop antenna, preamplifier and a computer (Wong et al. 2012). Table 2 shows the past literature which focused on the development of SID system from year 2015 to 2019. The existing system requires a desktop PC to run the SuperSID software. This is the limiting factor for educators to attract young students towards Science, Technology, Engineering and Mathematics (STEM) education in Malaysia due to energy consumption, cost and also the size of the computer (Soon et al. 2015).

The system then has been upgraded into a portable and low cost system where the Raspberry Pi has been used to replace the computer as a main processor for this SID system. This new system consists of loop antenna, pre-amplifier, an analogue-to-digital converter with Raspberry Pi. The acquisition software in Raspberry Pi is compiled using Python and run on a Linux environment (Deveza et al. 2018).

TABLE 2. Development of SID system (2015-2019)

Researcher	Sound card	Processor	Display	Automation
(Le Minh Tan 2015)	Sound Blaster's Audigy SE (Sampling rate: 96 ks/s)	Desktop Window OS	Computer screen	None
(Soon et al. 2015)	Sound Blaster X-Fi Go Pro! (Sampling rate: 44.1 kHz)	Raspberry Pi Model B (Raspbian Wheezy)	LCD Monitor	None
(Zakaria et al. 2018)	Sound Blaster X-Fi Go Pro! (Sampling rate: 44.1 kHz)	Data Logger	Computer screen	Semi-automated system
(Deveza et al. 2018)	ADC USB sound card (Sampling rate: 96 kHz)	Raspberry Pi 3B	LCD Monitor	Semi-automated system

Up to the author knowledge, there is still no researcher who has managed to produce a fully-automated system and fits the mobile concept. The observed data from the SID system still needs to be transferred to another computer to enable students or teachers to perform data analysis.

Based on the feedback from the program that was organized by UKM in 2020, it was found that school students and teachers experienced constraints in the process of analyzing data due to the limited or absence of computer in schools (Abdullah et al. 2016). Therefore, an interactive system needs to be implemented in UKM-SID™ to facilitate users in gaining experience directly towards SuperSID system which also helps to improve their knowledge in space science learning (Abdullah et al. 2018).

This paper describes the development of an interactive software that has been implemented in the Raspberry Pi, which is part of the UKM-SID™ system. This software was then validated in detecting the sunrise and sunset patterns of the signals observed, solar flares as well as comparison with the data from Geostationary Operational Environmental Satellites (GOES). Additionally, a new algorithm has been developed in transferring the observed data onto the server near real time.

METHODOLOGY

The development of this graphical interface software can be divided into four parts where the first part is focusing on the operating system of UKM-SID™. This is followed by the SuperSID software, the development of Graphic User Interface (GUI) and algorithm for the observed data to be uploaded in near real time onto the server.

UKM-SID™ OPERATING SYSTEM

The VLF monitoring system consists of a loop antenna, preamplifier, Analogue-to-Digital Converter (ADC) and Raspberry Pi as shown in Figure 1. The operating system of UKM-SID™ starts from a distant VLF signal received by the loop antenna. Next, the low induced output voltage is then amplified by the preamplifier. The conversion of ADC signal is performed by a sound card that picks up the amplified analogue signal at a rate of 96 kHz. Preamplifier and Raspberry Pi require 9V and 12V DC power supply to operate respectively.

UKM-SID™ system can detect signals with a maximum frequency of up to 48 KHz which is half of the sampling rate. When the SuperSID software is activated, the VLF spectrum of frequency against the power spectrum density (dB/Hz) is displayed on the screen. The received VLF signal is sampled at five-second intervals and the raw data is stored in comma-separated values (.CSV) format.

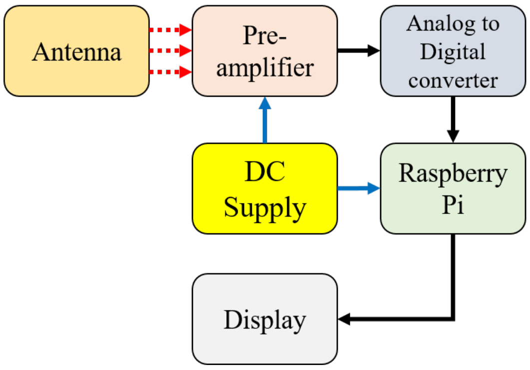


FIGURE 1. Block diagram of VLF monitoring system

SUPERSID SOFTWARE

SuperSID software used in UKM-SID™ is an open source and downloadable from the GitHub website (Gibert 2015). However, add-on modules such as *Matplotlib*, wxPython, *Numpy* and *alsaaudio* need to be installed on the Raspberry Pi. SuperSID software is a combination of four programs which are configuration, SidTimer, sampler and logger.

Configuration is an important setting and needs to be implemented to change SID parameter. Figure 2 is an example of a predefined configuration file for the data observation process. The current latitude and longitude setting needs to be updated based on the location of the UKM-SID™. In this study, the system is located at Universiti Kebangsaan Malaysia, Bangi, Selangor with geographical coordinate of 2.93°N, 101.7°S.

The audio sampling rate should be included according to the specifications of the sound card. The UKM-SID™ system uses a sound card with a sampling rate of 96 kHz. Next, the selected VLF transmitter station along with its rated frequency needs to be updated after verifying the strongest and stable frequency signal received by the loop antenna. Finally, the sound card named “audioinjectorpi” can be found on the Raspberry Pi system using [cat/proc/asound/cards] command in the LXTerminal.

SidTimer is equipped with auto-correction timer to ensure that data acquisition is done on the interval and as accurately as possible. The auto-correction compensates for the micro-seconds lost from one tick to the next. Sampler handles audio data capture, calculating Power Spectrum Density (PSD) and extracting signals at the monitored frequencies. The displayed VLF spectrum in power versus frequency graph is controlled by configuration, SidTimer and sampler programs as shown in Figure 3.

```
[PARAMETERS]
viewer = tk
site_name = UKM-SID
monitor_id = SAMPLE1
contact=ericgibert@yahoo.fr

longitude = 101.7
latitude = 2.93
utc_offset = +08:00
time_zone = MYT

audio_sampling_rate = 96000

log_interval = 5
log_format=sid_format
log_type = filtered
scaling_factor = 1.0
hourly_save = NO
data_path = /home/pi/supersid/Data
number_of_stations = 1

[STATION_1]
call_sign = NWC
color = g
frequency = 19800
[Capture]
Audio=alsaaudio
#Card=ICH7
Card=audioinjectorpi
PeriodSize = 128

[FTP]
automatic_upload = no
ftp_server = sid-ftp.stanford.edu
ftp_directory = /incoming/SuperSID/NEW/
local_tmp = /tmp
call_signs = NWC
```

FIGURE 2. Configuration file

The method used to select the VLF transmitter station is by monitoring the strongest and most stable signal peak received through the VLF spectrum on the UKM-SID™ system. Figure 3 is an example of a received signal from transmitters such as NWC (Australia), NPM (USA), JJI (Japan), NAA (USA), NLK (USA), NML (USA), and NAU (USA). The signal strength of a radio station appears as a vertical surge that stands on the noise floor. Although the noise floor rises and falls at all times, this surge remains steady at the rated frequency (Koh et al. 2018).

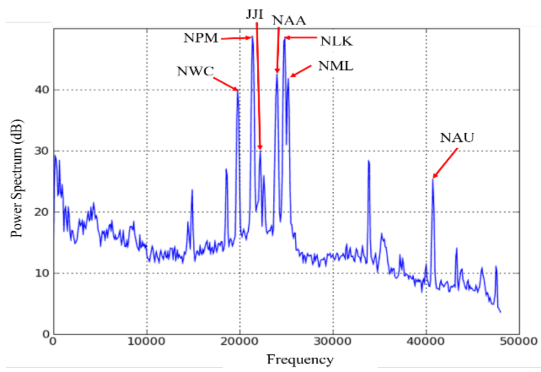
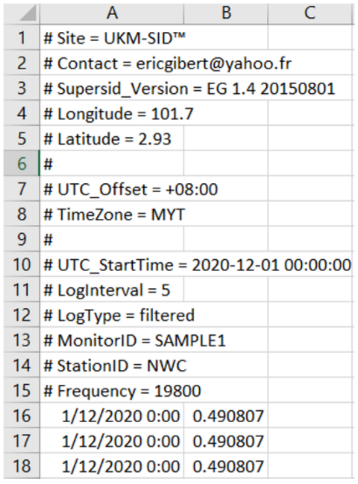


FIGURE 3. An example of VLF spectrum power versus frequency (Scherrer et al. 2010)

Based on the previous study by Wong and Mohd (Wong et al. 2012, Mohd et al. 2019), the UKM-SID™ system received the strongest, clear peak and most stable signal from NWC transmitter station in Australia. Therefore, only NWC VLF transmitter station is used in this study as shown in Figure 2. It is important to note that not all radio station frequencies will appear on the VLF spectrum; it depends on the user's current observation location.

Lastly, logger consists of a sound card and configuration software. It is assigned to record and save the data for every five-second interval into a file with comma-separated value (.csv) format automatically. Figure 4 shows the parameters that can be found in the csv file. The observed data is in Universal Time (UT), where 1 UT is equal to 0800 Local Time (LT). This data is then used to plot the SuperSID graph.



	A	B	C
1	# Site = UKM-SID™		
2	# Contact = ericgibert@yahoo.fr		
3	# Supersid_Version = EG 1.4 20150801		
4	# Longitude = 101.7		
5	# Latitude = 2.93		
6	#		
7	# UTC_Offset = +08:00		
8	# TimeZone = MYT		
9	#		
10	# UTC_StartTime = 2020-12-01 00:00:00		
11	# LogInterval = 5		
12	# LogType = filtered		
13	# MonitorID = SAMPLE1		
14	# StationID = NWC		
15	# Frequency = 19800		
16	1/12/2020 0:00	0.490807	
17	1/12/2020 0:00	0.490807	
18	1/12/2020 0:00	0.490807	

FIGURE 4. Parameters in .csv file

GRAPHIC USER INTERFACE (GUI) SOFTWARE

GUI software is run on Eric Python IDE software, a complete Python editor and IDE, written in Python.

In order to use the software, add-on modules need to be installed on the Raspberry Pi. Figure 5 shows the first process in the development of GUI which is the generation of display setting. It is important to note that display setting is important for each of the block arrangement since it will be displayed on the main screen once the software is activated. The compilation of the display setting form file must be done at the end of the process.

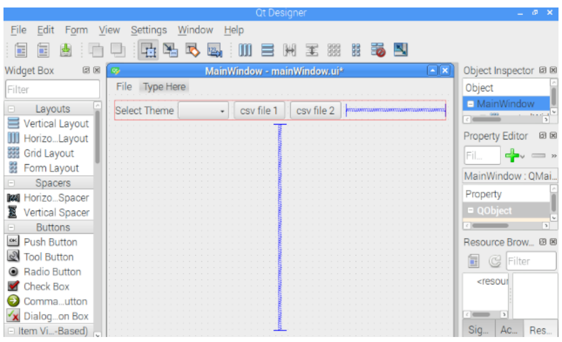


FIGURE 5. GUI display setting

GUI programming system is divided into three sections which are the display setting registration, 24-hour plot generation and 48-hour plot generation. The subroutine and function of each block used on the display setting has been properly arranged and defined as shown in Table 3. The name of subroutine used in the programming must be the same as declared in the display setting form file. This procedure is important in order to execute the command accordingly in the process of jumping or calling a function name. In UKM-SID™ GUI system, "self" is used to execute commands automatically without having to wait for an instruction by the user. The block selections on the display setting allow the user to access 24-hour or 48-hour function in the programming since the process of csv file selection is dependent on the instructions given by the user as shown in Figure 6. The second section is 24-hour plot generation. For this, the system can directly read and execute the observation data via "Self.getFile24hours" subroutine

TABLE 3. Block registration in programming

No	Block	Subroutine	Do
1.	File-24 hours	Self.getFile24hours	Read & Plot
2.	File-48 hours	Self.getFile1 Self.getFile2	Read, Saved, merge & plot
3.	File- exits	Mainwindow.close	Exit
4.	Csv file 1	Self.getFile1	Read & Saved
5.	Csv file 2	Self.getFile2	Merge & plot
6.	Theme	Theme selection	Select

The third section, which is 48-hour plot generation, the programming system requires two csv files on a different date to produce the one-day plot due to the time difference between UT and LT.

One-day plot in LT is compulsory in this analysis in order to validate and verify the observed data. The daily observation data is stored from 12:00 am to 11:59 pm UTC. In "Self.getFile1" subroutine, the program separates the last eight hours' data from the first csv file and stored in a new data set. Next, a linked data set command is done via "Self.getFile2" by concatenating (merging) the first 16 hours' data from the second csv file with the data stored in the new data set to generate a complete one-day plot in local time. A complete of UKM-SID™ system with GUI are shown in Figure 6.

ALGORITHM FOR DATA TRANSFER NEAR REAL TIME

An algorithm was also being developed in this paper in order to give easy access to all users at any place and time. The Firebase cloud server was chosen because it is available at no cost and meets the requirements needed by UKM-SID™. Besides, the process of registering a new user account on Firebase website was simple and orderly. The registration of each member is compulsory in order to get direct access to the Firebase storage.

To connect the Raspberry Pi with the server, a real time database link, storage link, as well as a json file are included in the programming system. The links and file were provided by the Firebase software once the account registration has been made. The algorithm is compiled with Python and run in the Linux environment. There are new modules which have been added to the Raspberry Pi such as *get update*, *python-pip python-dev ipython*, *google cloud storage*, *firebase* and *python-firebase* to make this programming work. The data transmission process requires an internet connection on the Raspberry Pi.

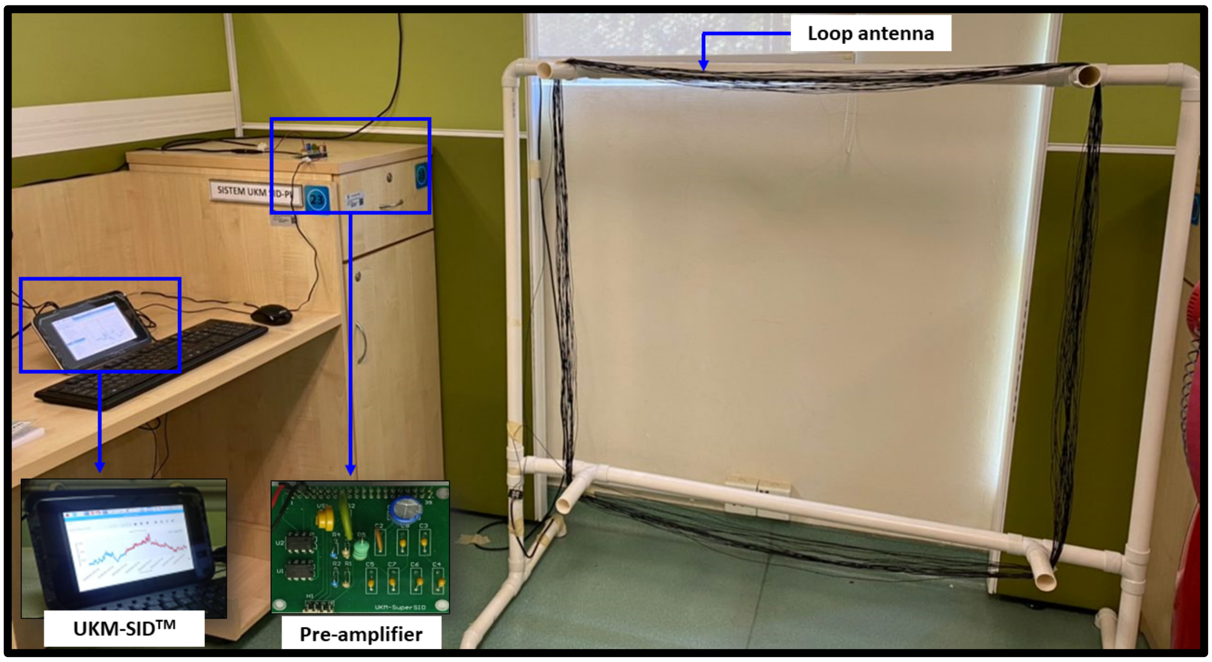


FIGURE 5. Complete UKM-SID™ with GUI

RESULT AND DISCUSSION

DAILY AUTOMATED PLOT VISUALIZATION SYSTEM

The interactive software to produce power versus time plot using GUI has been developed in UKM-SID™ system, where the user can produce power versus time plot directly on the Raspberry Pi. A user can use this software by selecting either 24-hour or 48-hour data depending on the analysis that needs to be done as shown in Figure 7. The observed data from year 2020 has been used to validate this software.

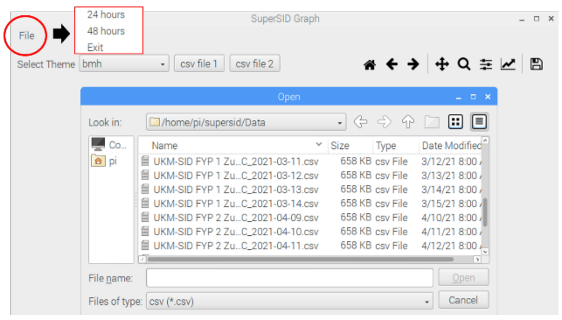


FIGURE 7. Selection of process

Data on 29 October 2020 was used and plotted as shown in Figure 8. The system was located at Universiti Kebangsaan Malaysia, Bangi, Selangor with geographical coordinate of 2.93°N, 101.7°E by using NWC transmitter. A diurnal variation of the 24-hour data was observed where the x-axis represents time in UT and y-axis is the receiving signal strength in watt. It can be clearly seen that sunset appeared at 11:06 am UT.

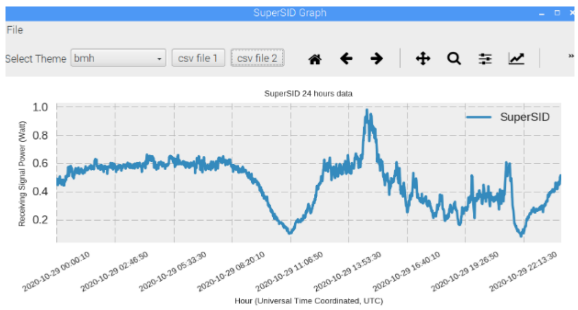


FIGURE 8. 24-hour plot (in UTC time)

ONE-DAY PLOT IN LOCAL TIME

As mentioned earlier, a one-day plot in LT is compulsory in this analysis in order to validate and verify the observed data. Data on 26-27 October 2020 was plotted and shown in Figure 9. The system was located at Universiti Kebangsaan Malaysia, Bangi, Selangor with geographical coordinate of 2.93°N, 101.7°E using NWC transmitter. The first process is to verify the sunrise and sunset patterns of the observed data. The sharp downward slope is the process of sunrise while the sharp upward slope is the process of sunset as shown by the red circles in Figure 9.

The sunrise and sunset can be seen at 06:20 am LT and 7:30 pm LT, respectively. The area of determination of the occurrence of solar flares will be referred during the day time (Zakaria et al. 2018). This result is in agreement with the previous study done by Wong et al. (2012), Abdullah et al. (2013) and Soon et al. (2015). The color differences seen in Figure 8 is used to differentiate the data on the first day (blue) and the second day (red). This shows that the developed software is able to observe the daily data at a local station.

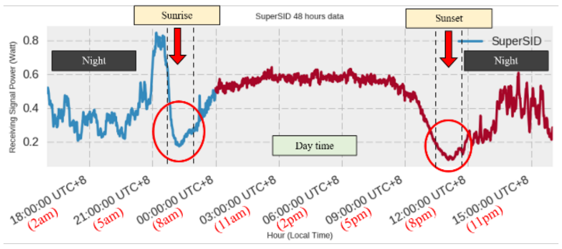


FIGURE 9. 48-hour plot (in local time)

SOLAR FLARE DETECTION

To observe solar flares using UT data (24-hour data), the selection area to detect the occurrence of flares is only during day time based on local time in Malaysia.

The process of analyzing a one-day plot (48-hour data) obtained by UKM-SID™ system needs to be done by comparing the data from GOES satellite as shown in Figure 10. 48 hour data is needed for data validation where data is recorded in UTC and 0000 UTC is equals to 0800 LT as mention earlier. This process is important to validate that the system can detect solar flares (Zakaria et al. 2018). Day time is used as flares observation area because the VLF signal can detect the sun activity perfectly as the ionosphere layer is ionized by the sunlight (Toriumi et al. 2016).

UKM-SID™ has recorded C class flare on 01 December 2020 as shown in Figure 10. Based on Figure 10, the flare started at 12:18 pm and reached its maximum peak at 12:35 pm. It then ended at 12:39 pm. By comparing UKM-SID™ with GOES data, the latter recorded the C3.86 flare at 12:08

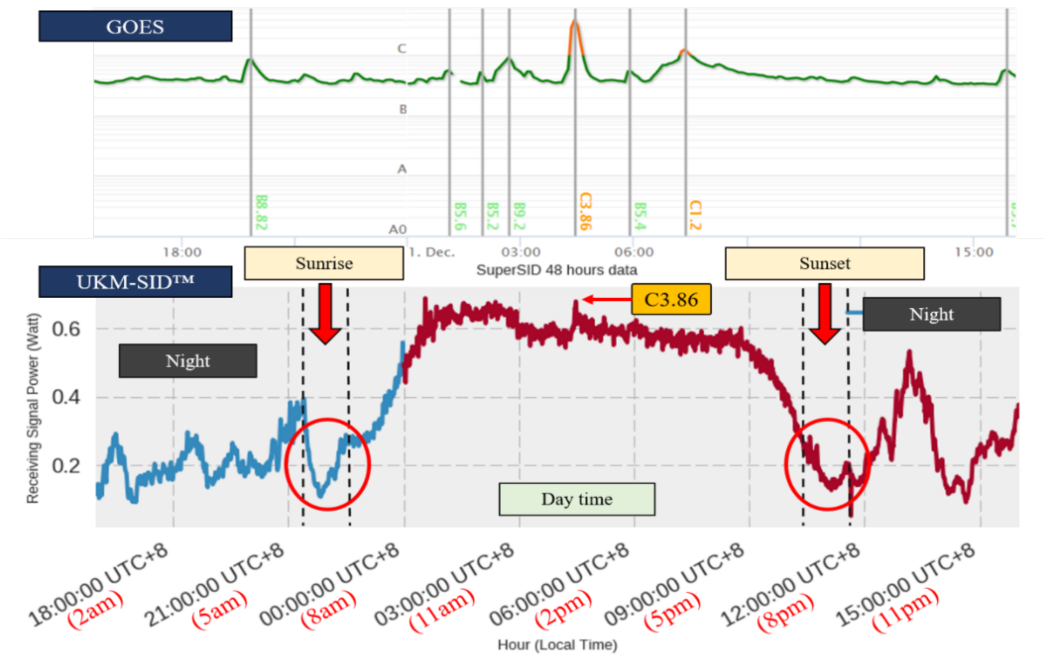


FIGURE 10. Comparing data from UKM-SID™ and GOES

pm. The maximum peak occurred at 12:27 pm and ended at 12:34 pm. The obtained result shows that there is a delay in the UKM-SID™ system in detecting the occurrence of solar flare where the peak at UKM-SID™ is at 12:35 pm while GOES is at 12:27 pm. The main reason for the delay is because the flares took approximately eight minutes to reach and affect the Earth's ionospheric layer dramatically.

The UKM-SID™ device is used on the Earth's surface while GOES data is taken directly from the satellite in space. The other reason is the delay might probably come from the noise and other types of disturbance that affected the radio communication waves between the VLF transmitter and the SID receiver (Guo et al. 2021). GOES satellite data can be obtained online through Space Weather Live website (Space Weather Live 2021). The comparison result shows that the software can be used to detect solar flare occurrences.

NEAR REAL TIME DATA TRANSFER

UKM-SID™ system has been equipped with an algorithm to transfer the observed data to the server. The advantage of this system is a user can easily conduct a group discussion over an important observation. In order to perform the data transmission, a string ("") must be added to the file path as well as the file name in the command window to allow the Python system to read. Figure 10 shows the Python shell window where the user can provide input to the file path to be transferred to the Firebase server.

The command window prints a success status when each file has been received by Firebase storage. Users can transfer files as many as needed as this program depends entirely on the user's command. Once the transferred process succeeds, users can view and download the files on Firebase storage as shown in Figure 11.

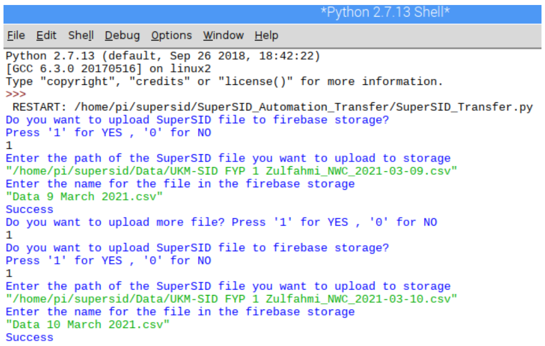


FIGURE 11. Python shell (command prompt)

Only a registered member can view the files in the Firebase storage. The red circle in Figure 12 is the file received by the Firebase system while the blue circle is the location of the file on the Firebase system. Data is saved onto the user's device automatically when the download link is clicked. This data transmission system will facilitate researchers to conduct further analysis of solar flares occurrences.

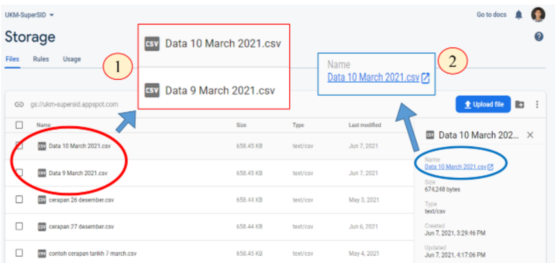


FIGURE 12. Received files from UKM-SID™ system

CONCLUSION

The development of portable solar flare observation kit or known as UKM-SID™ has developed an automation system for generation of SID power against time graph and data transmission to the server in near real time. This feature provides benefits to the users in terms of time consumption and the latest technology applications that are loaded onto UKM-SID™ portable kit. Finally, this latest version of SuperSID is a helpful teaching aid that can provide an exciting new experience for the users in STEM development and space science education.

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DECLARATION OF COMPETING INTEREST

None

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