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The Development of *Raspi-Met* System with Raspberry Pi3 for Meteorological Monitoring in Remote Areas

The Development of *Raspi-Met* System with Raspberry Pi3 for Meteorological Monitoring in Remote Areas

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Abstract. The development of autonomous weather station systems using Raspberry Pi3 as a new alternative, named as '*Raspi-Met*' to enhance conventional meteorological systems is reported in this paper. Today, a weather station with a compact size is required due to limited space and cost involved. Thus, this paper aims to design an application system using Raspberry Pi3 which is connected to Vaisala PTU300 sensors as Automatic Weather Station (AWS). The Python language under LINUX has been employed to design a graphical user interface (GUI) for a real-time monitoring system, acquisition process, and displaying three meteorological parameters at desired intervals. Data storage management and daily file in a text (*.txt) format have been created to archive historical data. The RTC module has also been developed and connected to Raspberry Pi3 to synchronize and maintain the time and date of the measurement system after the power is on. The system was installed at Carlini Base, Antarctica and has the ability to measure the surface pressure (*P*), temperature (*T*), and relative humidity (*H*). The results have been tested and validated that the system is capable as an AWS in the Antarctic Peninsula. The development of *Raspi-Met* system exhibits remarkable measurements of meteorological parameters for remote areas and the database organization becomes more efficient and practical.

1. Introduction

A practical and compact size of Automatic Weather Station (AWS) system is required in extreme environments to accurately measure surface meteorological parameters. The system should capable of operating for 24 hours and manage a database. Presently, conventional weather stations installed in fields require more space due to the larger size of the system and the functions are not necessarily optimal. In Antarctica, for example, the weather station must be designed with a compact size but with a higher capability to measure meteorological parameters as required. Nowadays compact AWSs consist of a processing unit (CPU, volatile memory and non-volatile memory) to be connected to a number of meteorological sensors [1]. In addition, wireless communication systems have been installed in devices with GMS, radio bridges, or satellite links [2]. AWS was also been deployed with difficult, expensive, and sometimes impractical installations [3].

For these reasons, the development and a simple installation with a low-cost of AWS system have been proposed for Carlini Base, Antarctica to measure meteorological parameters in any condition. A low-cost design of AWS system is a challenging task. However, it was successfully developed using .NET framework and the program was written in C# language [4]. This application selected ATMEL family AVR (ATmega16) as a control element of a weather station to get the meteorological data such as temperature, wind speed, and intensity of light. During the collection of meteorological data, ATmega16 has limited of internal memory to save the data. Deshmukh and Shinde [5] had proposed Raspberry Pi device as a control element to improve the capacity of ATmega16. The advantages of Raspberry Pi device such as to have a larger internal memory (depend on the memory card capacity), digital I/O port which more than three, and easy installation (small size). Lopez-Ruiz et al. [6] has also been used a compact low-cost of Raspberry Pi for a portable multispectral imaging system for general purposes. However, the device has limitation over the port communication which does not provide wireless and Bluetooth [7]. In this work, Raspberry Pi version 3 (Pi3) and open source software based on the Linux platform is employed. The Vaisala PTU300 sensors that were selected have the capability to communicate with Raspberry Pi3 by using a USB-RJ45 port. Shang et al. [8] uses Vaisala PTU300 sensors for altitude correction and control of the tropical high humidity condition. The programming language of Raspberry Pi3 for the acquisition and communications is Python. The measurement data were collected and stored into a Micro SD memory card with a specified time interval.

Based on the capability of PTU300 sensors and Raspberry Pi3, this paper presents the development of a low-cost of AWS system so-called *Raspi-Met* for monitoring the surface meteorological measurements (pressure, temperature, and relative humidity) over the Carlini Base, Antarctica. A *Raspi-Met* is an application system for meteorological monitoring and a database management which optimally integrate the Raspberry Pi3 and PUT300 sensors. The *Raspi-Met* system was installed during the 2016/2017 summer campaign. To highlight the development of AWS system using Raspberry Pi3, this paper will be organized in six sections as follows. Section 2 provides the location of study at Carlini Base, Antarctic Peninsula; Section 3 describes the design concept of the system and the development of the *Raspi-Met*; Section 4 to 5 show the overall implementation of *Raspi-Met* design, measurement results, analysis, and discussion on how to develop a real-time measurement system and storing the data into an internal memory and validation of measurements; Section 6 concludes the work**.**

2. Methods

2.1 The Study Area

Presently, the issue of global climate change is one the biggest threats the world. Based on that situation, researchers have studied the pattern of surface meteorological data such as pressure, temperature, relative humidity, precipitation, wind circulation, solar activity and so on [9]. With a similar purpose, the variation of surface meteorological parameters (Pressure - P, Temperature - T, and relative humidity - H) is monitored in Antarctica by installing the meteorological sensor at the Carlini Base of Antarctica (CARL: 62°14'15.24"S, 58°39'46.54"W). Carlini Base is an Argentine permanent Antarctic scientific research located in *Potter Cove*, King George Island, in the South Shetland of Antarctic Peninsula (see Fig.1).

In general, the weather condition over the Carlini Base is extreme cold with dry humidity. During the winter season, the surface temperature ranges from 10°C to -30°C. However, in the summer season, the surface temperature reaches 9°C with strong winds [10]. In addition, the effects of low surface temperatures and strong wind speeds will affect atmospheric conditions by forming an anomalous season called polar vortex [11]. A polar vortex is a large area of low-pressure in the upper level and contains cold air surrounding the poles. It will develop even stronger in winter and spreads out between the Earth's poles, and it can also cause surges in parts of Europe and Asia. Thus, part of this study will assess the possibility of polar vortex associated with climate change.

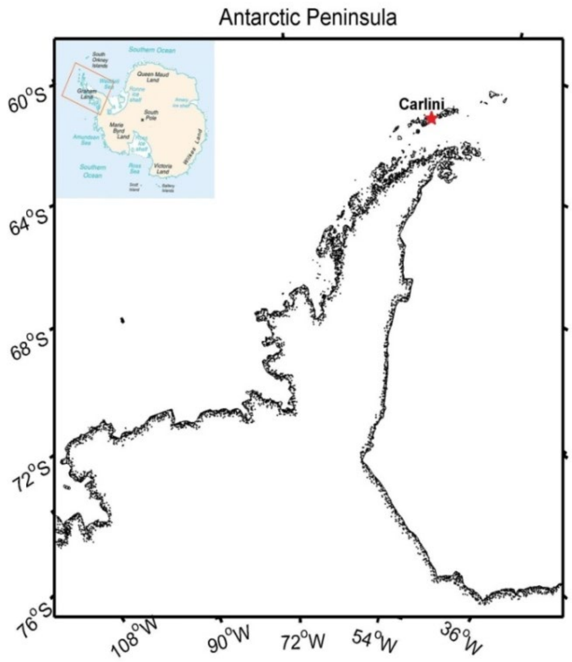

Figure 1. Location of Carlini Base in the Antarctic Peninsula.

To achieve this goal, monitoring and characterization of surface meteorological data over Antarctica are very important. The first plan is to install a low-cost AWS. The system has been developed and installed on the roof of Calbido Laboratory Building at Carlini Base and operated 24 hours throughout the season (see Figure 2). However, this paper only discusses the development of a low-cost monitoring system as shown in Figure 2(d).

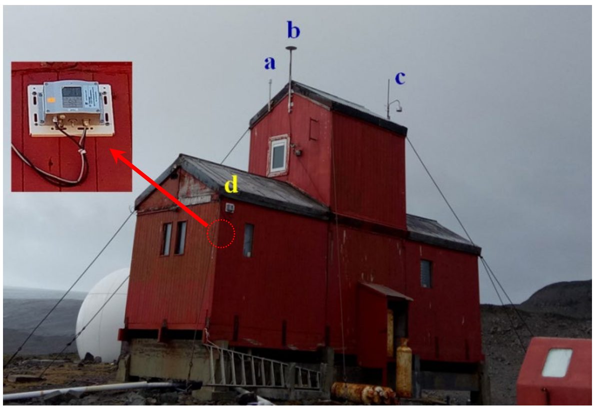

Figure 2. Meteorological station at Carlini Base, Antarctica for (a) LD-350 lightning Sensor, GPS antenna, (c) Electric Field Mill (EFM-100) antenna, and (d) Vaisala PTU300 sensors.

2.2 Hardware Architecture

2.2.1 Meteorological Instrumentation. To characterize the surface meteorological data over the Carlini Base, a PTU300 sensor manufactured by Vaisala is employed in this study. This instrument has the capability to measure *P*, *T*, and *H* in the range of 500 - 1000 hPa, -40°C - 60°C, and 0 - 100%, respectively. In addition, the PTU300 sensors with a compact size equipped with six adjustment buttons and LCD to display the real-time measurement as well as for initially setting up the sensor is shown in Figure 3. These sensors have one probe and one barometric pressure to measure *T* and *H*, respectively as well as *P*.

Figure 3. Vaisala PTU 300 meteorology sensors with a LCD display.

For data collection, data loggers are equipped with three communication options including an RS232 serial interface that displays MODBUS communication protocols and analog outputs. In this work, the serial communication USB-RJ45 port is used to communicate between PTU300 sensors and data loggers, such as to store collected data into disk space.

2.2.2 Raspberry Pi3. A single board, lower power Raspberry Pi3 model B computer was used as the core unit of *Raspi-Met* system. The Raspberry Pi3 module is depicted in Figure 4. It has the function to handle all the processing and controlling tasks as well as to ensure all systems work properly. It collects information and stores measurement data into the desired destination such as micro SD, flash disk, and hard disk. This model comes with onboard 64-bit quad-core ARMv8 processor featuring 1.2 GHz clock speed. With this specification, it has the ability to process an application faster as compared to its predecessor [12]. Regarding its interfacing peripherals, this model was equipped with USB ports, an HDMI port, an Ethernet port, camera interface, display interface, micro SD card storage, Bluetooth 4.1 and 802.11n Wireless LAN. An external device such as a monitor, keyboard, and mouse can be connected directly to Raspberry Pi3 using HDMI and USB ports which serve as in the case of a desktop computer. This module supports multiple operating systems including Debian-based Linux operating system and other third-party operating systems which are available through the official website, i.e. Ubuntu MATE, Snappy Ubuntu Core, Windows 10 IoT Core, and RISC OS.

In order to communicate with other devices through serial communication, this module comes with four serial protocols including Serial Peripheral Interface (SPI), Inter-Integrated Circuit interface or I2C, standard Universal Asynchronous Receiver Transmitter (UART), and USB. The I2C is synchronous which able to connect multiple slaves to a single master (like SPI). The variety of serial protocols provided in this module makes it easier to interface with other instruments such as sensors.

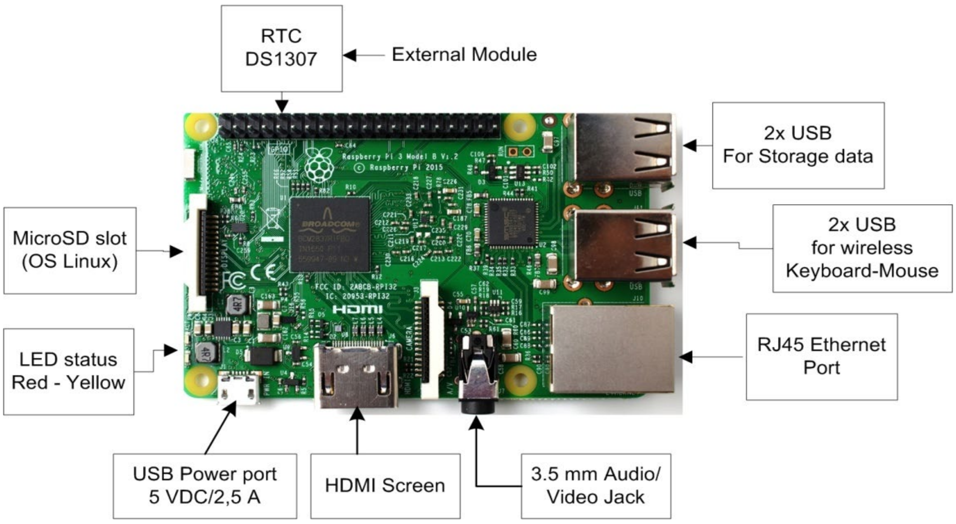

Figure 4. Interfacing between Vaisala PTU300 meteorological sensors and Raspberry Pi3 model B using USB-RJ45 port.

2.2.3 Real Time Clock (RTC). The time and date have an important role as a marker of events that occurred during the recording process. However, the Raspberry Pi3 does not include an internal clock and consequently, it does not have the capability to store time and date continuously. As an alternative, an internet connection should be required to synchronize time and date after recovery from a shutdown. In addition, internet access is also limited in Carlini Base. Thus, an RTC module has been developed and programmed to provide the time and date as required. This module consists of the DS 1307 IC (integrated circuit) from the MAXIM, crystal clock 32.768 kHz and lithium battery CR-2025 3V. In addition, this module has been equipped with an I2C which uses two wires for data transmission to other instruments. The I2C is synchronous which able to connect multiple slaves to a single master (like SPI). The RTC module is connected as in Figure 4.

2.2.4 Structure Design. The *Raspi-Met* hardware consists of several subsystems including the power supply unit, sensing unit, central unit, and storage unit. All the process in this system will be conducted by a central unit (Raspberry Pi3) to manage the data collection, processing, display and storing. The data that was collected will be stored in the storage unit. Since the capacity of Micro SD card of Raspberry Pi3 memory is limited (less than 8 GB) to store the data in long-term, an external storage memory such as a flash disk or external hard disk has been used as the storage unit to increase the capacity of Micro SD. Two kinds of power supply i.e. 12 VDC and 5 VDC have been used to supply the sensing unit and main component unit, respectively. Figure 5 summarizes the block diagram of a *Raspi-Met* monitoring system that contains the main components and functional units together with their output.

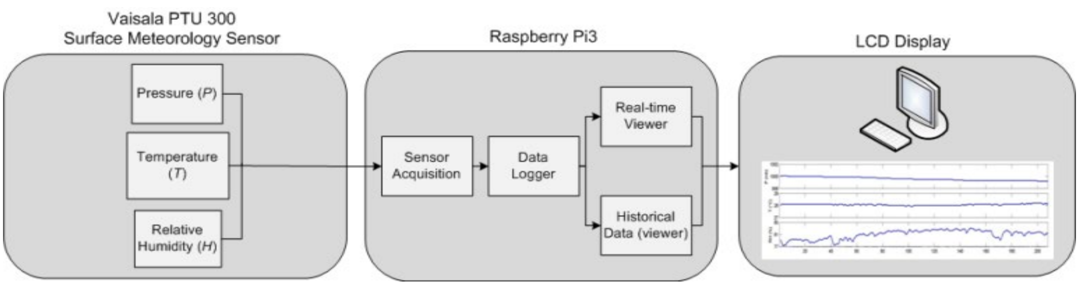

Figure 5. General scheme of *Raspi-Met* monitoring system for surface meteorology.

2.2.5. Software Architecture. Before designing a system application, the main software with their dependencies required by the system should be installed in Raspberry Pi3 including Python libraries. These dependencies add more functionality to the use of Python in Raspberry Pi3 and make the development of the application easier. A Python is easy language to program the devices like Raspberry Pi. Figure 6 presents a flow diagram of the main routines that establish the *Raspi-Met* monitoring system in the Carlini Base. The main component is represented by the main loop, where the PTU300 sensors are powered up, read the data, and store the data into the disk space.

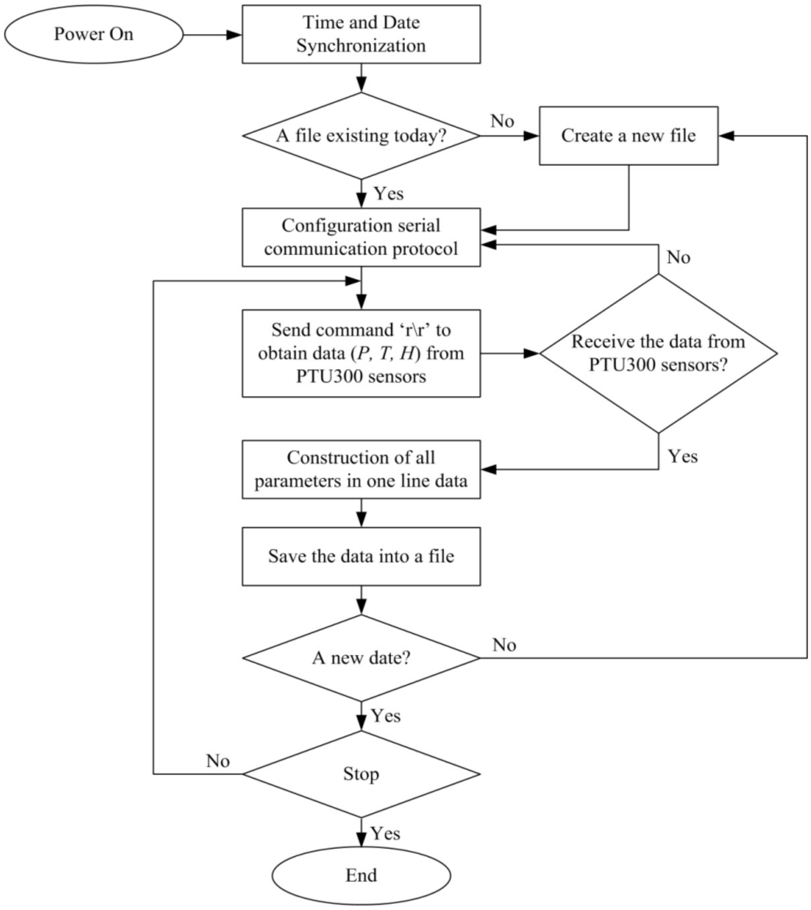

Figure 6. Flow diagram of the *Raspi-Met* application system

On power up, the Raspberry Pi3 will be synchronized with the time stamp from the RTC module to make sure it has the appropriate and accurate time signature. In the next step, the application will be checking the current today file in the directory and will be creating a new file if the "today file" is not found. The configuration of the serial communication protocol between the PTU300 sensors and Raspberry Pi3 is described in Table 1. If one of the parameters is different, the data transmission with the Raspberry Pi3 will fail.

Table 1. Configuration of serial port protocols.

Parameter	Value
Bauds	19200
Parity	None
Data bits	8
Stop bits	1
Flow control	None

In this system, the sampling time for the data collected from the PTU300 sensors was set 10 seconds. In order to measure and collect the data from the PTU300 sensors, the application that has been developed in *Raspi-Met* must send the “r\r” command in ASCII format. When the command is received by the PTU300 sensors, it will evaluates the command and sends the data with the format, for example, “P = 1021.6 hPa, T = 23.2°C, and H = 5.8%”.

After data collection was conducted, the main loop of the *Raspi-Met* system will go to the recording process. All parameters including date, time, P, T, and H are constructed in a single file per day. This strategy is created with the aim of reducing the load and simplifying file indexing. In addition, when the system recovers from a shutdown, an appended filling technique has also been incorporated in the application system to prevent overwriting the previous data or creating a new file in the same day. This technique incorporates new measurement data into “today’s files” based on the time of recorded observations. On the other hand, if a blackout case turned out, the data that was recorded will not be lost. The system works automatically without resetting and it has the capability to manage its own database. Note that the application systems that existed before the *Raspi-Met*, such as the Digiquartz®Interactive (DQI) software from Paroscientific, Inc. show that their system always creates new files when electricity is recovered from outages. This drawback has been improved by Suparta and Leng [13] by appended filling techniques as described above.

3. Results and Discussion

The advantage of the system developed is that it can store weather information automatically in one single file per day. When the Raspberry Pi3 power is on, the script in Python should be opened and run to start the application. After the application started and the “today file” is created, it will read and automatically starting to acquire all the data from the PTU300 sensors as well as store the data into the disk space. For the system in Carlini Base, a hard disk has been used for data storage. The file created in the system is with format text: MMDDYYYY.txt, where MM, DD, and YYYY stand for Month, Date, and Year, respectively. As an example, the date of the measurement is 4 February 2017 and the created file will be named as 02042017.txt. Each file containing the date (MM DD YYYY), time (HH:MM:SS), P in mbar (hPa), T in °C, and H in percent (%), where the interval of measurement was 10 s. The file containing data can be opened directly in the Raspberry Pi3 using a text editor software as shown in Figure 7.

To calculate the accuracy of the measurement, all data measured by the PTU300 sensors is then validated with other surface meteorological data. In this validation, meteorological data from the Servicio Meteorológico Nacional (SMN) of Carlini Base are employed. The meteorological data from SMN was available in 3-hour interval, and the data from the PTU300 sensors with a 10 s sampling time is averaged in 3-hour interval. Data for the validation process uses four measurement days, starting from 4 February until 7 February 2017. Figure 8 shows a comparison of surface meteorological data such as P, T, and H which provided by the PTU300 sensors and SMN at Carlini Base. In this figure, the missing data points correspond to *Raspi-Met* maintenance time. Based on the pattern of data from both systems, they have a good correspondence to each other. It found that H trend is the opposite to that of T. On the other hand, either P from the PTU300 sensors or SMN it has a minimum value at the mid-night of 4 February 2017 and gradually increasing until the mid-day of 6 February 2017 and gradually decreasing on the 7 February 2017. These results indicate that the meteorology data from the new system is well correlated with the existing system and capable used such as for weather monitoring.

To access the accuracy of the system, the coefficient of determination (R^2), percent error (PE), and root mean square error (RMSE) are used to perform this validation. Table 2 shows the statistical comparison of surface meteorological data from both measurement systems. The results showed that the surface meteorological data from the new system (see Fig. 9) have a strong correlation with the data from SMN. It can be noticed that all data from the new system has a strong relationship, significantly at the 99% confidence level for P, T, and H, respectively. Comparing with the SMN data,

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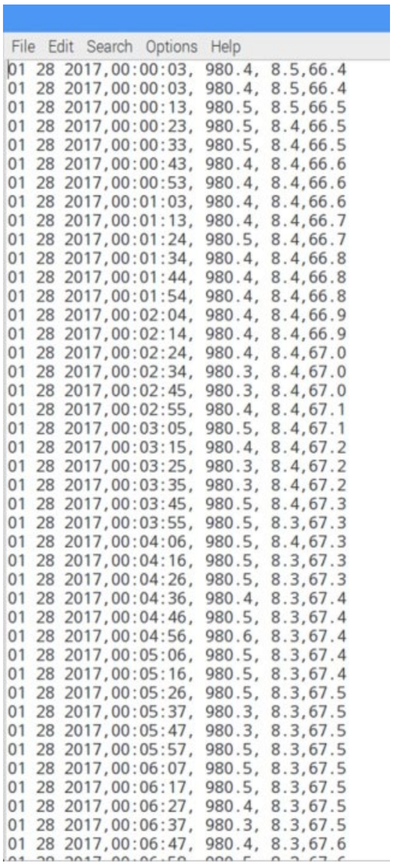
data from the new system shows RMSE below 5% with PE values for *P* and *H* is below 1%, except *T* whose sensitivity is possibly affected by distance (~300 m) and altitude locations of the two sensors.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01 28 2017,00:00:03, 980.4, 8.5,66.4
01 28 2017,00:00:03, 980.4, 8.5,66.4
01 28 2017,00:00:13, 980.5, 8.5,66.5
01 28 2017,00:00:23, 980.5, 8.4,66.5
01 28 2017,00:00:33, 980.5, 8.4,66.5
01 28 2017,00:00:43, 980.4, 8.4,66.6
01 28 2017,00:00:53, 980.4, 8.4,66.6
01 28 2017,00:01:03, 980.4, 8.4,66.6
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01 28 2017,00:06:47, 980.4, 8.3,67.6
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Figure 7. Example of the data recorded in a .txt file format.

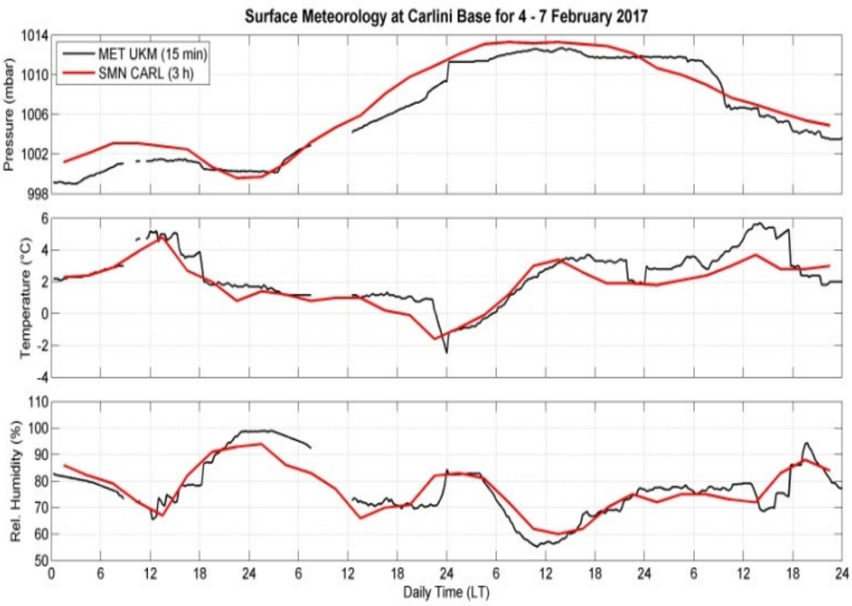
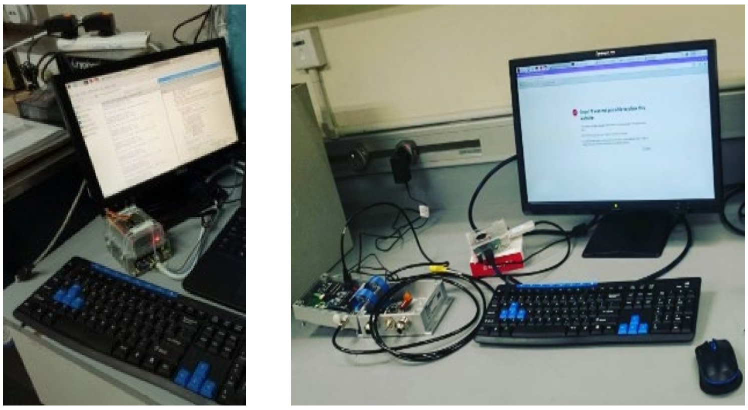


Figure 8. Comparison between surface meteorological data from the new system ('Raspi-Met') and SMC Carlini Base station during four days (4 - 7 February 2017).

Table 2. Statistical result of comparison between surface meteorological performance from the new system and SMN of Carlini Base.

Parameter	R^2	PE (%)	RMSE
P	0.944	0.090	1.417
T	0.792	7.197	4.933
H	0.760	0.272	0.842



(a) **(b)**

Figure 9. Ground-based meteorological station with Raspberry Pi3 model B implemented for (a) running at the Carlini Base, Antarctic Peninsula and (b) during calibration and testing in UKM Bangi, Malaysia.

4. Conclusion

A *Raspi-Met* system for monitoring and managing meteorological parameters in remote areas like Carlini Base of Antarctic Peninsula has been developed using the Raspberry Pi3. The application system has been built using Python software. This system embedded with a Vaisala PTU300 sensor, tested on the site, and has the capability to measure the surface meteorological data (*P*, *T*, and *H*), manipulate the information, displaying the real-time measurements, and store the data into disk space. In addition, the system is robust which capable of providing systematic error handling, solving problems in data missing due to power outages and merges them into one today file.

The accuracy of the measurement system from the new system has been validated with the surface meteorological data from SMN at Carlini Base. Both data showed a good correspondence with a strong relationship where determination coefficients are above 0.75, significantly at the 99% confidence level. Finally, data from the new system would be beneficial for applications in the field of meteorology and climatology such as to improve the accuracy of weather forecasting as well as for climate studies.

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