Journal of ICT in Education (JICTIE)
ISSN 2289-7844 / Vol. 2 / 2015 / 26 – 39

The Development and Evaluation of an Automated System in Detecting Environmental Data for Monitoring Forest Activity

Shahrizuan Shafiril[1], Amri Yusoff[2], Che Zalina Zulkifli[2], Ashardi Abas[2] & Norma Che Yusoff[3]
[1]Faculty of Art, Computing & Creative Industry, Universiti Pendidikan Sultan Idris
[2]Computing Department, Faculty of Art, Computing & Creative Industry, Universiti Pendidikan Sultan Idris
[3]Institute of Biological Sciences, Faculty of Science, University of Malaya
cloudywolfshah86@yahoo.com[1], {amri, chezalina, ashardi}@fskik.upsi.edu.my[2], ynorma@um.edu.my[3]

Abstract

Forest ecosystems have always received worldwide attention due to their biological diversity and these forests are vital for human existence since their area is decreasing due to human negligence and over-exploitation by the human population. Recent reports showed the evidence of illegal logging and harvesting activities, detected late, thus coming up with serious consequences. Therefore, an early detection system must be developed to monitor these illegal activities by collecting the environmental data. This research characterized the dynamics, cycle of temperature, humidity, and phase particle based on the conceptual framework that has been developed. The ADDIE model was selected as the proper model to be implemented in developing the prototype. The sensing data has been identified as a salient data for preserving the forest ecosystem that must be protected as part of the population well-being and prolong heritage. The hardware components for designing this prototype consisted of temperature and humidity sensor, Solar LiPo Rider for self-powering device, and phase particle sensor. This prototype also allows for writing and simple erasing the main programming through USB port when connected to a computer. The data can also be collected via UART and can be displayed on the monitor for further analysis and monitoring the ecosystem. Therefore, the development of this automated object-based change detection system will be useful and beneficial in assisting regulatory bodies, researchers, and ecologist for identifying the changes within the ecosystems. Finally, the data gathered will be evaluated using a GraphPad Prism 6 software to compare the result of the data gained from both the Meteorological Weather

Measurement Devices and the automated system for detecting environmental data (ASDE) to see whether the data collected by the prototype are precise and accurate.

Keywords Forest monitoring, environmental remote monitoring, Arduino

---

INTRODUCTION

Our world is facing global fast deteriorating and irreversible ecosystems either deliberately done or caused by human negligence. This will result in the emergence of unhealthy phenomenon such as smog, global warming or flash floods (Brunekreef, 2010; Anderson, Thundiyil & Stolbach, 2012). When weather conditions prevent the smoke and other pollutants from clearing, it thickens and forms a veil that usually lingers in the air which will affect our vision or causes respiratory health threats. Other major contributors that causes thick haze may come from the gaseous released from industries. Air pollution index (API) is one way to determine the level of severity of the haze. It involves the measurement of the quantity of hazardous fine particles such as carbon monoxide, sulfur dioxide, nitrogen dioxide, and ozone. A distinctive and separate device is required to measure each purpose such as digital thermometer for reading the temperature, particle counter for counting the number of particles in the air, and gaseous detector to identify poisonous gases. Currently, the environmental device used for gathering meteorological data at Meteorological Department does not combine all of the weather equipment into a single device. Thus, it is difficult to capture all data and perform real-time analysis in order to see the relationship between harmful particle, gaseous, temperature, and humidity. Therefore, it is useful to develop one single handy device that is fully automated and can easily capture all these data measurements and transmit all the data in real time for correct analysis. Ideally, it would be significant if this single device is equipped with self-generating power that can be used in the remote area such as in the forest for remote data logging. This newly developed prototype will be an automated system in detecting environmental data (ASDE). The main features of this system include:

- Upgrading the existing meteorological instruments.
- Develop meteorological device that can be functional for mobile and automatic.
- To reduce the problems faced by researchers to obtain data.

This study focuses on gathering a unified data for temperature, humidity, and air pollution such as haze that often occurs when dust and smoke particles accumulate in a relatively dry air. Hopefully, this design will be an indicator test bed study for further improvement in a more comprehensive device that can be used by researchers for monitoring data in the field.

THE EXISTING METHOD OF DATA COLLECTIONS

Often we hear people mention about forecast weather conditions. Weather is the condition of the atmosphere at a particular time and location. The atmospheric conditions normally include temperature, humidity, pressure, wind speed, and direction. But the ongoing model prototype that has been developed will include only three measurements for temperature, humidity and air pollution index. Further improvement on the device in the future will include all major measurement above for atmospheric conditions. Also the climates in Malaysia are uniform temperature, high humidity, and abundant rainfall. Winds are generally light. Malaysia is located in the equatorial doldrums that is very rare to have a clear sky even during the periods of severe drought. Malaysia also seldom have a few days with no sunshine except during the Northeast monsoon (Malaysian Meteorological Department, 2013). Although the wind in Malaysia is generally light and variable, there are changes in the wind patterns. Malaysia experiences four seasons of changes; the southwest monsoon, northeast monsoon, and two shorter periods between the monsoons (Malaysian Meteorological Department, 2013). These are the tools that are commonly used at the Metrological Department for measuring the weather data placed at observation station.

Automated Weather Systems (AWS)

In line with the recent technology, the observation equipment has become fully automated (Zachariassen, 2003). The automated weather observation system consists of the following components:

- A set of meteorological sensors placed in protective equipment and are connected to the processing unit (data-logger) with independent wrapped cable.
- A processor unit (data logger) was used for data acquisition, processing, storage, and transmission.
- The accessories equipment such as stabilizer power source, modem, built-in diagnostics, and a local terminal are for manual data entry, editing, and viewing data.

The AWS measures the amount of rainfall, air pressure, temperature, humidity, wind speed, and direction as well as global radiation, which is also updated every minute, 24 hours a day without human assistance (Kuśmierek-Tomaszewska, Żarski, & Dudek, 2012). Automatic weather system (AWS) acts as a facility that automatically transmits or records observations obtained from the measuring instruments while automatic weather observations refers to the activities involved in converting the measurements of meteorological elements into electric signals through sensors, processing and transforming these signals into meteorological data, thus transmitting the resulting information by wire or radio or automatically storing it in a recording medium. AWS's can be divided into real-time stations, which automatically transmit the observed data at fixed times; and off-line stations, which record data on storage devices.

Real-time AWS

A station that outputs observations on a real-time basis, either regularly or upon request by the user. This type of station is used for ordinary synoptic meteorological analysis and for monitoring critical warning states such as storms and river or tide levels. It must be able to transmit observations to a network.

Off-line AWS

A station that records observations on storage devices. This type of station is used for climatological analysis or as an auxiliary facility for manual observations. The data obtained and stored by an off-line AWS need to be transmitted to the user at regular intervals.

The following advantages can be expected when automatic observation is adopted. Continuous observation is possible, and observational data at manned stations can be obtained even when no staff is present. Fully automated systems can also be installed at inaccessible sites. In addition, it is possible to reduce observer numbers and operating costs since meteorological data are taken as electrical signals, observer errors in reading are eliminated. Standardized observation techniques enable the homogenization of observed data in regions where automatic weather observation is adopted. In addition, new observation elements can be added relatively easily by installing new instruments/optimal measuring instruments with the appropriate level of measurement accuracy so the required observation can be chosen, and the need for observer training is eliminated.

Wind Direction and Speed Indicator

Wind direction is determined by the direction of the wind blowing. It is displayed in degrees and measured clockwise from the north. The wind vane is used to indicate or to record surface wind direction. Wind speed is measured in meters per second or knots. If the wind speed is less than one meter per second or two knots, wind indicators will only give readings as calm. A calm condition usually can be indicated if the wind speed is less than 0.5 meters per second, or less than one knot (Eastwood et. al., 2012). The equipment used to measure wind speed is called anemometers. The most common tool used is cup anemometer. It is formed by three cups in hemispheric. The differences of wind pressure between the cups will cause the cup to rotate (Gallego et. al., 2011) and the wind rate is calculated based on the rotation speed of the wind per time.

Temperature Gauges

The equipment used for measuring temperature gives a fairly accurate temperature due to the usage of internal circuit technology that combines with platinum resistance thermometer elements (Cai et. al., 2012). It is filled either with a liquid such as mercury or an evaporating fluid as used in refrigerators. In both cases, the inside of the sensor head and the connecting tube are completely full. Any rise in temperature produces expansion or evaporation of the liquid so the sensor becomes pressurized. The pressure is related to the temperature and it may be indicated on a simple pressure gauge. Another well-known principle that if two metals are rigidly joined together as a two layer and heated, the difference in the expansion rate causes the strip to bend. The strip is twisted into a long thin coil inside the tube. One end is fixed at the bottom of the tube and the other turns and moves a pointer on a dial. Steveson screen is one of the equipment used to indicate temperature and humidity. The Steveson system consists of wet and dry bulb thermometers which are supported vertically inside the shelter. Thermometer bulb is wrapped with a wet muslin cloth and tied with a thread placed in a reservoir filled with distilled water. This system collects the humidity data and dew points by analyzing the moisture change inside the shelter.

Solarimeter/Pyranometer

Solarimeter is to measure the solar radiation at the Earth's surface on a regular basis. It has a thermocouple sensor element. The detector element is coated with a stable inorganic carbon which can give the absorption spectrum and stability characteristics for a long time (Sartarelli et. al., 2010). These detector elements are usually placed under a glass dome. This instrument also consists of a pyrheliometer directed towards the sun by an automatic tracking system to measure direct solar radiation. The period of direct solar radiation exceeding 120 Wm^{-2}, the value recommended by WMO as the sunshine threshold, is counted as sunshine duration. The automatic tracking system is also equipped with a pyranometer which tracks the sun directly using a sunlight sensor when there is sunshine and a built-in-arithmetic and logic unit when there is no sunshine. This system enables accurate measurement of sunshine duration throughout the year, and the amount of maintenance work required for tracking setup is reduced. As a further application, it can also measure either global solar or diffuse sky radiation in addition to direct solar radiation. Diffuse sky radiation is measured by shading only direct solar rays reaching the pyranometer using a tracking shade disk.

Air Pressure Measure

Air pressure is the amount of pressure that exerted by air upon certain area or region. Changes in air pressure are measured using an instrument called a barometer. A barometer kind of looks like an air temperature thermometer with a tube that holds a mercury substance that moves as the air pressure changes.

The normal pressure sensor is calculated based on the pressure capsule or solid state capacitive device in which the output voltage is digitally encoded prior transfer to the air pressure (Lei, 2009). The weather equipment used in Malaysia can be further improved and refined so that it gives more effective and accurate real-time data and in the future this data can be integrated with the cloud for more innovative and data collected sharing over the internet for gathering information (Caporin & Preś, 2012). The proposed systems are being developed and designed to cater this technology and it is a fully automated system for detecting environment (ASDE) data. The complete system will have a combination of all systems plus the improvement in data collection technique, portable and scale to smaller size, self-powered by solar, and it can be a direct substitution to the present equipment.

THE DESIGN MODEL OF ASDE

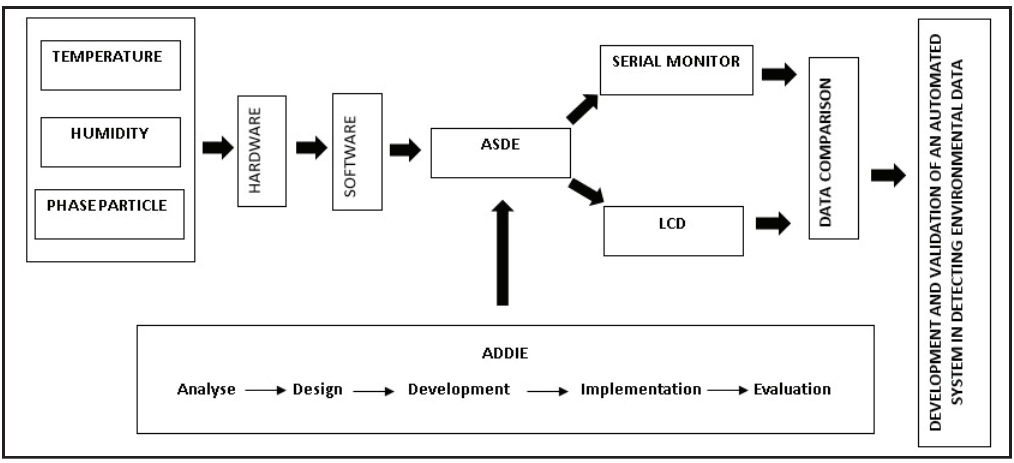

Figure 1 Conceptual Framework

Figure 1 is the proposed conceptual framework for the automated system for detecting environment (ASDE).

Figure 2 A Complete Prototype of ASDE

The complete prototype of ASDE is shown in Figure 2. The detail explanation of the conceptual framework is as follows:

Input

There are three inputs data used to collect the environmental data and to absorb solar in order to self-power the device.

Temperature and Humidity

This section is for detecting temperature and humidity. The data is measured in analog and the sensor needs to be configured internally and programmed by a controller before it can be used. The value of the temperature and humidity can be read out through a serial monitor via USB via a personal computer or can be displayed on LCD located in front of the system.

Solar

This section is the power supply module to the system. The system does not require any external power as the system is self-powered by the solar. This proves to be handy because the system does not need regular maintenance such as battery replacement by the operator or a periodic inspection on the existing device. The Solar LiPo Rider Pro will supply the power to the controller as well as charge the internal battery from the solar panel located at the top of the ASDE. This section also acts as a power switch (on/off) for the ASDE.

Phase Particle

This section is the detection system for air pollution such as haze that often occurs due to dust and smoke particles. This sensor will detect the particles using a measurement value of $\mu g/m^3$.

Microcontroller

The controller used in this device is the development board for the programmable integrated circuit. This section will handle all the necessary inputs and transfer data to the output. All the data measurements are calculated inside the controller. The algorithm program can be downloaded via USB without the need to open the casing. The transfer rate is fast and can be read and write erasable up to 2Kbytes of memory. Figure 3 is an example of the program written for the controller.

Output

There are two outputs used in this device: LCD and Serial Monitor.

LCD

LCD stands for liquid crystal display. The reading of temperature, humidity, and phase particle will be displayed in 2×16 alphanumeric characters with LED backlight. The value of readings will alternately change for about 10 seconds while displaying in the order of temperature, humidity, and phase particle.

Serial Monitor

The reading can also be displayed on a serial monitor from a PC or a laptop using a special debugging software provided by the controller.

```
#include <dht11.h>
#include "DHT11.h"
#define dht11_dpin A0 //no ; here. Set equal to channel sensor is on
#define LIGHT_SENSOR_PIN 1
// include the library code:
#include <LiquidCrystal.h>

void setup() {
  //Blink LED to detect hangs
        pinMode(13, OUTPUT);
        // set up the LCD's number of columns and rows:
        lcd.begin(16, 2);
        lcd.print("Starting...");
        //Serial.begin(9600);
        delay(300); //Let system settle
        //Serial.println("Humidity and temperature\n\n");
        delay(700); //Wait rest of 1000ms recommended delay before
        //accessing sensor
}
void loop() {
         DHT11.read(dht11_dpin);
        lcd.setCursor(0, 0);
        calcVoltage = voMeasured * (3.3 / 1024);
        dustDensity = 0.17 * calcVoltage - 0.1;

                lcd.print("Temp :   (C)");
                lcd.setCursor(7, 0);
                lcd.print( DHT11.temperature);
                lcd.setCursor(0, 1);
                //Every 7 out of 15 times we show humidity, rest temp
                if ((flip % 15) > 7 )
                {
                        lcd.print("Humidity :   (%)");
                        lcd.setCursor(12, 1);
                        lcd.print(DHT11.humidity);
                } else  {
                        lcd.print("Haze :    ( ug/m3)");
                        lcd.setCursor(8, 1);
                        lcd.print(dustDensity);
                }
```

Figure 3 The program that has been created using Arduino Software Serial

The program shown in Figure 3 above has been created to gather all information regarding the data that need to be collected such as temperature, humidity, and phase particle. The DHT11 sensor is for collecting the data of temperature and humidity. Temperature is represented by Celsius (°C) while humidity data is represented by %. DHT11 sensor can only gather data within the range of 0° Celsius - 50° Celsius. Values higher than that need to use more complicated and expensive devices while phase particle values are represented in ug/m^3, which is the value of dust. The most important thing before creating these programs is that the source code containing (.cpp and .pde) program need to be placed in the Arduino library folder to make it work, otherwise the program will get an error. The source code can be downloaded from the Arduino website. Then, it must be included in the compiler as (dht.h); this will inform the compiler to fetch the data needed from the library. Next, the part of the Arduino analog data need to be used must be defined, so this program must be written as #define dht_dpin A0. The A0 (Analog 0) is where the data will be placed within the Arduino, it is for the set equal to channel sensor is on. To display it on the serial monitor, the things that need to be done is to write Serial.begin (9600). The 9600 is a baud rate for displaying the data on the serial monitor. The baud rate can be changed depending on the data needed. The maximum baud rate that can be used is 115000. The next thing to do is delaying the data from overflowing. So in this case delay is used. From the program, 1000 millisecond (same value as 1 second) delay is used before accessing the sensor. Then the power on the LED need to be controlled by writing this program digitalWrite (ledPower,LOW). After that, to read the phase particle value, this part of program need to be written voMeasured = analogRead (measurePin). Note that a linear equation is needed to synchronize the values of both voltage and phase particle so that correct values can be obtained from it. From the equation, the value needed for phase particle is dustDensity = 0.17 * calcVoltage - 0.1. Last but not least, to display the data on a serial monitor, it is required to write Serial.println program for temperature, humidity, and phase particle. The Serial.println will display the data on the serial monitor in line so that the data will be displayed from top to bottom, while using Serial.print without (ln) will display the data horizontally from left to right. This sometimes will confuse the users because users might lose sight of the data. In addition, using Arduino has many advantages; like in this case, the data can be displayed on liquid crystal display (LCD) instead of serial monitor.

HARDWARE COMPONENTS INSIDE ASDE

Below are the lists and detail explanations of the hardware used in constructing the ASDE prototype.

Arduino

Arduino board has been selected for the controller due to its several advantages. Some of its benefits are open-source, software and hardware

are easily accessible, and flexible for customization and expansion. Arduino offers a variety of digital and analog inputs, SPI and serial interface, and digital and PWM outputs. It is easy to use, connects to the computer via USB and communicates using standard serial protocol, runs in standalone mode, and as an interface connected to computers. It is inexpensive, comes with free authoring software Arduino, and fully supported by a growing online community. It also comes with many online examples of source code and the examples can be shared and posted for others to view and help.

DHT11 Temperature and Humidity Sensor

DHT11 temperature and humidity sensor features a temperature and humidity sensor complex with a calibrated digital signal output. By using the exclusive digital-signal-acquisition technique and temperature and humidity sensing technology, it ensures high reliability and excellent long-term stability. This sensor includes a resistive-type humidity measurement component and an NTC temperature measurement component. It connects to a high-performance 8-bit microcontroller, offering excellent quality, fast response, anti-interference ability, and cost-effectiveness.

Phase Particle Sensor (GP2Y1010AU0F)

Phase particle is a dust sensor by an optical sensing system. An infrared emitting diode (IRED) and a phototransistor are diagonally arranged in this device. It detects the reflected light of dust in air. Especially, it is effective to detect a very fine particle like the cigarette smoke. In addition, it can distinguish smoke from house dust by the pulse pattern of the output voltage.

Solar (LiPo Rider Pro)

LiPo Rider supply heavier load output (1A peak) than Lipo Rider. The LiPo Rider Pro board allows to ride the solar wave to run 5V device. The LiPo Rider Pro board is the ideal green power solution for outdoor sensor design. When LiPo Rider Pro board is attached to the sensor board, it can run on solar power forever. It can also be used to charge mobile phones. The LiPo Rider Pro is extremely affordable and easy to use. No programming is required. Plug it in and it works. The internal charger (IC) handles all the power flow between the various components. In case solar power is not sufficient, the mini USB port allows to charge the lithium battery through USB. It can also be used to program a kit without detaching the LiPo Rider Pro board. One important application of the Lipo Rider Pro board is as an affordable power supply for outdoor sensors. The outdoor sensor device will be powered by the lithium battery supplemented by the solar panel. Please note that it is not recommended to run the outdoor sensor only on solar power as this may vary during the day and may cause the sensor to reset/power down unexpectedly.

In this case, the device is running in "USB Mode". If a firmware reprogram for the outdoor sensor device is required, simply connect the mini USB port to the PC which will put the device under "Program Mode" as explained above. Larger/multiple batteries and/or solar panels can be used but only with end-user modifications.

RESULT AND DISCUSSION

The explanation of the data below consists of temperature, humidity, and phase particle. The data were gathered in November 2013 starting from 10 November until 16 November. These data were observed every day and then compared to the data gained from the Meteorological Department. GraphPad Prism 6 was used as the alternative software rather than Statistic Package for Science Social (SPSS) because of its advantages for clinical sample analysis. It is also easy and reliable as an origin to plot the data as the differences between the data can be determined accurately. This analysis determined if there are any huge significant differences between the data gathered. If the data have a huge gap, then it can be assumed that the prototype is a failure, but if the data only have slight differences, then the prototype is assumed to be working properly as the researcher want it to be.

Table 1 Data comparison between meteorological devices and ASDE

No.	Day	ASDE			Meteorological Weather Measurement Devices		
		Temp (°C)	Humidity (%)	Phase Particle (μg/m³)	Temp (°C)	Humidity (%)	Phase Particle (μg/m³)
1	Monday	26	93	24	26	92	25
2	Tuesday	25	92	24	26	93	25
3	Wednesday	25	92	24	25	92	25
4	Thursday	24	92	25	25	92	25
5	Friday	24	91	25	25	92	25
6	Saturday	25	93	25	25	93	26
7	Sunday	24	91	26	25	93	26

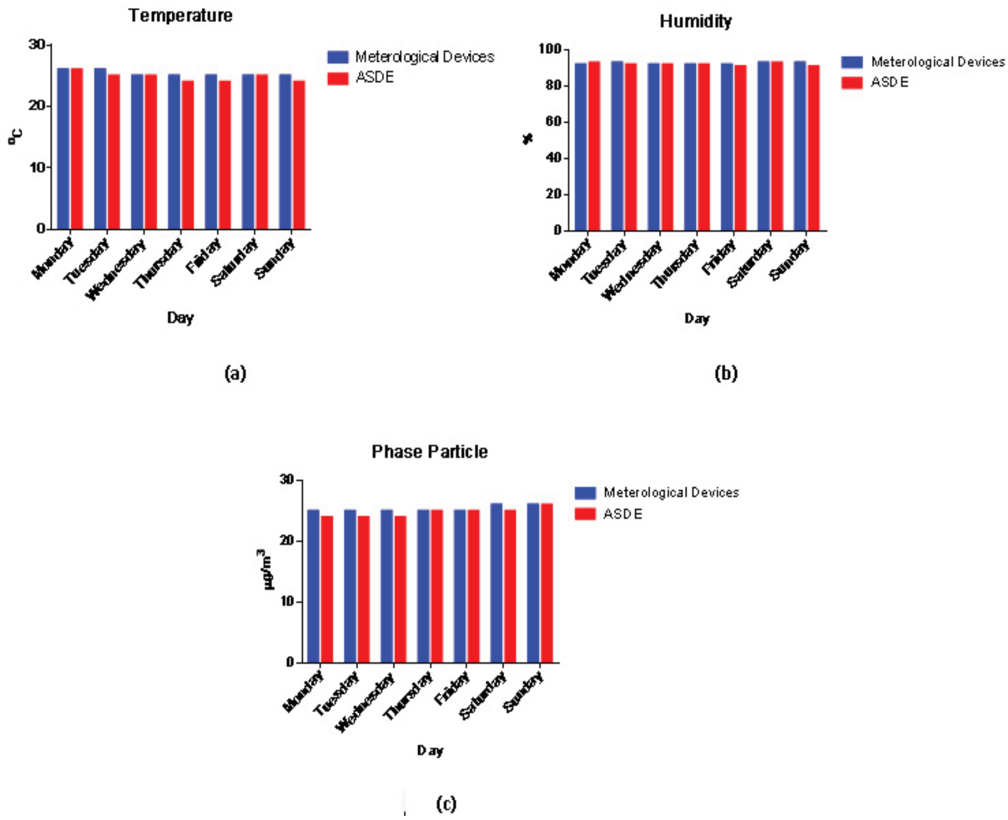

Figure 4 (a) Temperature data comparison between meteorological devices and ASDE; (b) Humidity data comparison between meteorological devices; and (c) Phase particle data comparison between meteorological devices.

This is the data gathered at the end of November 2013 when the raining season occurred, thus affecting the temperature values based on Figure 4 (a). The data had already been compared to the data from the Meteorological Department. As shown above, the data only had a slight difference of 0.1°C. This shows that the prototype did work and can be improved a bit more. From the graph above, on Sunday the data gained by the Meteorological Department was 25°C, while the data gained by ASDE was 24°C. Next, on Monday, the data gained by ASDE shared the same value as the data gained by the Meteorological Department that was 26°C. Then, on Tuesday the data gained by the Meteorological Department was 26°C while the data from ASDE was 25°C. On Wednesday, the data from both Meteorological Department and ASDE were the same (25°C). The temperatures gained on Thursday and Friday were the same in which the Meteorological Department data gained 25°C while ASDE gained 24°C. Lastly, on Saturday the data gained from the Meteorological Department and ASDE were the same, 25°C.

Figure 4 (b) shows that the data gained for humidity also have room for improvement in terms of prototype. The data were also compared to the data gained from the Meteorological Department. The graph above shows the data gained from the Meteorological Department and the prototype that has been developed, that is ASDE. On Sunday, the percentage of humidity obtained by Meteorological Department and ASDE only had 2% differences in which the data gathered by the Meteorological Department was 93% while ASDE gathered 91%. Then on Monday, the data had a difference of only 1% showing that the data gained from the Meteorological Department was 92% while ASDE gathered 93%. After that, on Tuesday, the Meteorological Department gathered 93% while ASDE gathered 92%. Next on Wednesday and Thursday, both Meteorological Department and ASDE shared the same value of data (92%). On Friday, the Meteorological Department gathered 92% while ASDE gathered 91%. Last but not least, on Saturday, they both also shared the same data (93%).

The data of the phase particle gathered through this prototype are shown in Figure 4 (c). On Sunday, the data gathered by the Meteorological Department and ASDE were both the same which was 26.6 $\mu g/m^3$. Then, on Monday, the data gathered by the Meteorological Department was 25 $\mu g/m^3$ while the data gathered by ASDE was 24 $\mu g/m^3$. The data gathered on Tuesday were also the same as the data gathered on Monday by both Meteorological Department and ASDE. The data gathered on Wednesday were also the same as on Monday and Tuesday. Next, on Thursday, the data gathered by both Meteorological Department and ASDE shared the same result which was 25 $\mu g/m^3$. The data gathered on Friday were also the same as on Thursday, while the data gathered on Saturday showed that the data gathered by the Meteorological Department was 26 $\mu g/m^3$ and the data gathered by ASDE was 25 $\mu g/m^3$.

CONCLUSION

The automated system for detecting environment (ASDE) is still in the early stage of development but performs well for transferring and logging the values from various sensor nodes. It allows relatively easy connection to nodes and communication. Further work is required with regards to battery and self-powering from solar panels or other renewable sources. The actual experiment showed that ASDE can detect temperature, humidity, and phase particle with 90-95% accuracy. Researchers who are currently involved in the study regarding the remote sensing and augmentation of forest ecosystem temperature, humidity, and phase particle may find that the data taken from the ASDE will be useful for real-time analysis for the investigation on what factors contribute to global warming due to deforestation and open burning in the suspected hot spot areas. Further investigation is planned for integrating the measurement by using GSM and GPS integrated system. There is a wish to create and have an application to perform an analysis on the data sent and received, where the calculation of the analysis should account for sensor value correction such as the system allows for relatively easy use and can be operated with standard commercial products that are widely use, thus allowing users to utilize the equipment already in use.

ACKNOWLEDGEMENTS

We would like to thank UPSI and KPT for the research grant and for giving us the opportunity to take part in respective competitions.

REFERENCES

Anderson, J. O., Thundiyil, J. G., and Stolbach, A. (2012). Clearing the air: A review of the effects of particulate matter air pollution on human health. *Journal of Medical Toxicology*. 8, pp. 166–175.

Brunekreef, B. (2010). Air pollution and human health: From local to global issues. *Procedia: Social and Behavioral Sciences.* 2, pp. 6661–6669.

Cai, S., Chen, Y-C., Tsai, C., & DeNatale, J.F. (2012). Development of a platinum resistance thermometer on the silicon substrate for phase change studies. *Journal of Micromechanics and Microengineering*. 22.

Caporin, M. & J. Preś, J. (2012). Modelling and forecasting wind speed intensity for weather risk management. *Comput. Stat. Data Analysis.* 56, pp. 3459–3476.

Eastwood, N., Kocurek, G., Mohrig, D., & Swanson, T. (2012). Methodology for reconstructing wind direction, wind speed and duration of wind events from aeolian cross-strat. *J. Geophys. Res. F Earth Surf*. 117.

Gallego, P., Madsen, H., Costa, A., & Cuerva, A. (2011). Influence of local wind speed and direction on wind power dynamics: Application to offshore very short-term forecasting. *Appl. Energy*. 88, pp. 4087–4096.

Kuśmierek-Tomaszewska, R., Żarski, J., & Dudek, S. (2012). Meteorological automated weather station data application for plant water requirements estimation. *Computers and Electronics in Agriculture*.88, pp. 44–51.

Lei, M., Shiyan, L., Chuanwen, J., Hongling, L., & Yan, Z. (2009). A review on the forecasting of wind speed and generated power. *Renewable and Sustainable Energy Reviews*. 13, pp. 915–920.

Sartarelli, A., Vera, S., Echarri, R., Cyrulies, E., & Sams, I. (2010). Heat flux solarimeter. *Solar Energy*. 84, pp. 2173–2178.

Zachariassen, J., Zeller, K., Nikolov, N., and McClelland, T. (2003). A review of the forest service remote automated weather station (RAWS) Network.