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DESIGN, CONSTRUCTION AND EVALUATION OF A METEOROLOGICAL MOBILE MAST

Kayode D. Adedayo[1†] and Kehinde Ladipo[2]

[1]Department of Physics, The Federal University of Technology, P.M.B. 704 Akure.
[2]Department of Meteorology, The Federal University of Technology, P.M.B. 704 Akure.
[†]Corresponding Author's Email: kbadedayo@yahoo.com

Abstract: A 30 metre meteorological mobile mast has been designed and constructed for upper air profile measurements. The parameters to be measured are wind speed, wind direction, temperature and relative humidity. The sensors for each parameter to be measured are constructed with locally available materials. The mechanical mast is designed in such a way that it can be collapsed like the electronic - controlled car radio antenna. It is made up of steel pipes of different diameters driven manually or by an electric motor via a pulley system. The sensors were calibrated with standard instruments and attached to different height of the mast for sample data acquisition. Data obtained from the sensors are stored in a data logger at the base of the mast. The data obtained were analyzed and there are appreciable correlations between the standard and the constructed instruments.

Keywords: Instrumented, Meteorological, Mast, Profile, Measurement.

1. INTRODUCTION

Weather is the state of the atmosphere at any given time and place with respect to variables such as temperature, moisture, cloudiness, rainfall and other meteorological conditions [1]. Weather variations affect a variety of industries: agriculture, airline, shipping, tourism and energy. With effective weather monitoring and environmental studies, organizations and industries can reduce costs and the forecast of occurrence of some events is made possible.

Weather and climatic conditions are studied through observation and analytical scientific methods [2]. Studying the atmosphere alone is not sufficient, but measuring the parameters and storing the observations for future references help in understanding how these atmospheric parameters vary with time and place.

Profile measuring masts are very useful equipments in the measurement and evaluation of atmospheric parameters which vary in time, places and height (altitude). The need to use equipment for the in situ measurement of atmospheric parameters in different places brought about the construction of this mobile mast.

Generally, profile measuring devices are used to measure different weather parameters such as humidity, temperature, wind speed, wind direction, intensity of radiation, barometric pressure and rainfall which helps in weather prediction and detection of changes in climatic conditions.

Ballooning was one of the first methods used in gathering meteorological information through the use of radiosondes [3]. Earlier measurements of wind and air pressure were done by launching balloons which climb through the denser air close to the earth to the thinner air in the upper atmosphere and the instruments carried collect data about wind in the different layers of the atmosphere as they travel. For continuous measurement and observations, meteorological instruments such as barometers, thermometers, anemometers and psychrometers could be interfaced with a data logger for data acquisition and analysis.

The following sections were involved in this research work:

Construction of the mechanical section using pulleys, electric motor for the extension and collapse of the pipes as a result of the movement of the attached shaft.

Design and construction of sensors with locally available electronic materials.

Construction of a data logger with appropriate circuitry embedded to display and to store the data retrieved from the sensors.

2. DESIGN AND CONSTRUCTION OF MECHANICAL MAST

This mast is designed to attain a height of 30 meters using steel pipes of different diameter. The pipes were selected in such a way that the smaller one can be enclosed in the bigger similar to how an electronic controlled car radio antenna operates.

The mast is incorporated with a flat belt pulley system connected to an electric motor and a winder. The shaft of the pulley is connected to a flat iron bar in a circular casing.

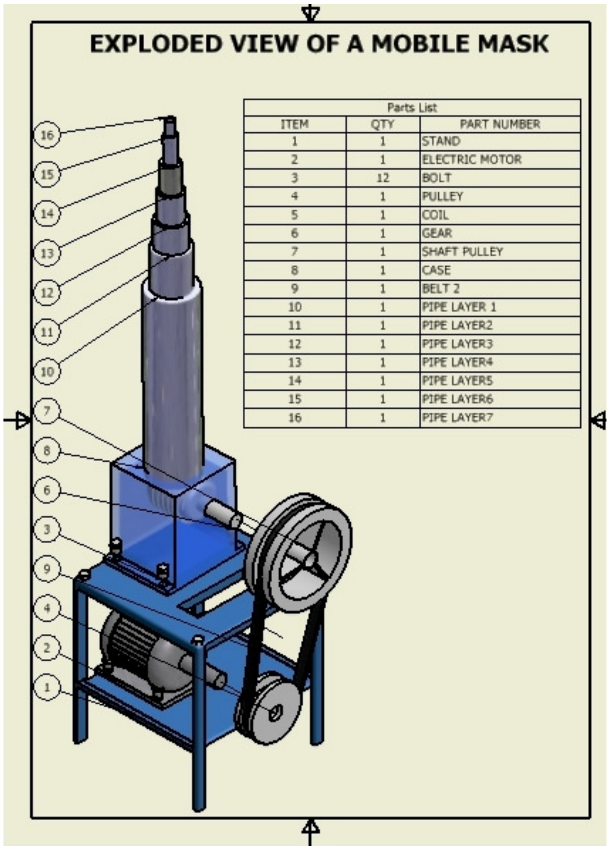

Fig. 1: Diagram of the mechanical mast showing its different parts.

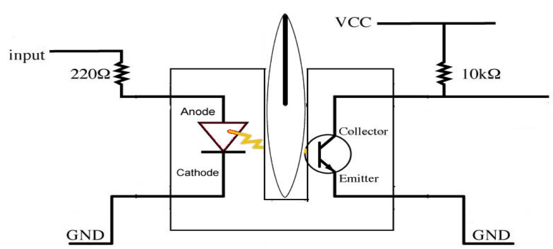

Fig. 2: Diagram of opto-coupler showing circuit connections, light passage or obstruction by disc.

In selecting the electric motor, it is expedient to determine the power required to drive the load, the working torque and speed characteristics. The motor must have enough starting torque to overcome static friction and accelerate the load up to full working speed that can handle the maximum overload [4].

The motor must satisfy the mechanical requirement represented by equation (1)

Power required $P = 2N\pi T$ (1)

where T = torque Nm (T = Force x Radius)

N = angular speed or velocity (rpm)

Fig. 3: Pictorial view of the constructed cup anemometer.

The mast works in such a way that when the electric motor or the winder is driven in the clockwise direction, the pulley rotates and releases the flat iron bar within the casing thereby pushing the pipes upwards with the smallest diameter pipe coming up until it completely stretched out to its maximum height. Stoppers are placed in each pipe to prevent the moving pipes from coming out completely and from falling back in.

The reverse is the case whenever the electric motor or the winder is driven in the anti-clockwise direction. When the flat bar is wound completely into the casing, the pipes collapse in to each other to form a shorter, compact structure. To ease the release of the flat bar from its circular casing, bearings are placed around the casing. The bearings also prevent back-tension and winding of the bar into wrong spaces within the casing. The diagram of the mechanical mast is shown in Fig.1 and the pictorial view in Fig.7.

DESIGN AND CONSTRUCTION OF CUP ANEMOMETER

The construction of the cup anemometer which is used to measure the wind speed involves the following materials: Perplex plastic, brass rods, nuts, opto-coupler, and PVC pipes.

The cup anemometer consists of three cups mounted at equal angles to each other on a vertical post. The air flowing past the cups in any horizontal direction turns the cup in a manner proportional to the wind speed. These cups were constructed by heating perplex cut into circular shape and then bent to form a cone-shaped cup. The cups were mounted on the vertical post by cutting a perplex with circular centre and three arms at 120 degrees from each other to which the cups were affixed. A brass rod which acts as a spindle rotating with ease through a bearing is attached to the centre where the three cups joined to the base of a circular casing.

An opto coupler powered by a 5 volts source is attached to the inside wall of the circular casing. This opto-coupler is connected with a NAND gate at its output (Fig.2) and it generates a digital output of 1 (5V) when it transmits through the transparent portion of the disc [5].

As the cup rotates the disc also rotates and at some point, the output of the gate becomes zero (0V). Hence, the opto-coupler generates a digital (one-zero) pulse which can be sent to a counter and be used to calculate the speed of rotation of the cups or its frequency of rotation. The pictorial view of the constructed cup anemometer is shown in Fig. 3.

DESIGN AND CONSTRUCTION OF PSYCHROMETER

A psychrometer is an instrument used in measuring humidity. Its construction involves the use of the following materials: fuel filter plastic, LM35 sensor, straw, wick, water bottle, plastic container, and perplex. A psychrometer consists of two thermometers, the bulb of one is kept wet and the other is kept dry. In this study, temperature sensors (LM35) are used in place of the thermometers.

The fuel filter plastic has a circular centre connected to two arms. The two sensors are positioned at the end of these two arms and are powered by the same 5V source generated from a voltage regulating circuit connected to a 9V battery. A wick connected to the tip of one sensor runs through a straw to a water-filled bottle attached to the circular centre of the filter, this keeps the wick wet all the time. The filter is placed in a plastic container with a cover to prevent the sensors from adverse environmental conditions. The container is punched so that the sensors can respond accurately and timely. Humidity is measured by comparing the effect of evaporative cooling of the wet sensor to the dry one. The output is obtained from pin 2 of each sensor. The relative humidity is obtained by subtracting the temperature of the wet sensor from that of the dry sensor, which gives the depression value that corresponds to a table value equal to the relative humidity. The block diagram is as shown in Fig.4.0

Relative humidity is a measure of the percentage of saturation humidity. Generally it is calculated in relation to saturated vapor density as

$$Relative\ Humidity = \frac{Actual\ Vapour\ Density}{Saturated\ Vapour\ Density} \times 100 \qquad (2)$$

The advantage of this psychrometer's design is that it can be used to measure vapor density, dew point and relative humidity. The temperature of air can be read from the output of the dry sensor.

DESIGN AND CONSTRUCTION OF WIND VANE

A wind vane is an instrument used to determine wind direction. It was constructed using the following materials: perplex plastic, brass rod, constantine wire, and conductive disc.

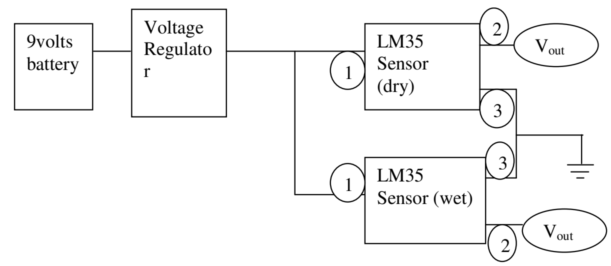

Fig. 4: Block diagram of the psychrometer circuit.

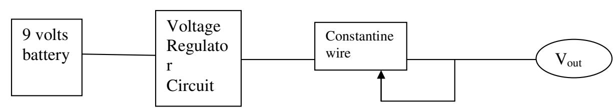

Fig.5: Block diagram of the wind vane.

Perplex was cut into shape of an arrowhead to point the direction and a triangular tail on which the wind will impinge. This tail-head structure is twisted to avoid wind blowing on any other surface except the tail. It is then balanced on a vertical post made with a hollow pipe using the principle of moments i.e. the product of the mass of the tail and its distance from the post must be equal to the product of the mass of the arrowhead and its distance from the post.

A constantine wire wound on the edges of a circular hollow plastic forms a sort of resistive sensor. A spindle (brass rod) running from the top of the post connected to the tail-head structure is also affixed to a conductive disc which is etched except for a thin line running from its centre to its circumference.

This etched disc is made to rest on the top of the circular resistive sensor. As the arrow head spins, the spindle and disc also spin and the conductive part of the disc is in contact with a line on the resistive sensor. The resistance at that point to the initial point of the constantine wire is measured and associated to the cardinal points. This type of measurement system is similar to a variable resistor. The block diagram of the assemblage is as shown in Fig.5. The total resistance of the wound constantine wire R = 30Ω and the supply voltage V is 5V, hence, the current I flowing through the circuit is 0.1667A.

DESIGN AND CONSTRUCTION OF DATA LOGGER

The construction of the data logger involves the following electronic components: multiplexers (74HC4051), shift registers (74HC164), LCD screen, memory card slot, keypad, USB port, microcontroller

(PIC18F4550). The data logger is designed to sample 30 analog inputs coming from different sensors [6].

The Microcontroller has 40 pins and 32 of these cannot be dedicated to sampling input data alone, thus the analog inputs have to be multiplexed using 4 different multiplexers of 8-input each.

An 8-input multiplexer has eight inputs and one output. It can select only one input at a time and forward it to the output. For 2^n inputs, the multiplexer has n control pins used to select which input line to send to the output and for an 8-input multiplexer (*n =3*), there are 3 control pins. The analogue output of each of the multiplexer is combined and sent serially to the microcontroller which consists of an analog to digital converter to transform the signal (sampling). The multiplexer also has an inhibit pin to switch on and off the multiplexer, this gives a total of four pins to control each multiplexer.

The microcontroller still cannot control 16 lines (4 from each multiplexer), hence a shift register was employed to convert the 16 parallel lines to a single serial line before it is sent to the microcontroller. Two 8-input shift-registers was used to perform the serial-parallel conversion. The two shift-registers are connected together and the serial output is sent to the data pin of the microcontroller. The shift register also has a clock and reset pin which goes to the corresponding pins on the microcontroller.

In order to control the sensor input to be read by the microcontroller, it sends a serial data along the data line to the shift-register which converts the signal to parallel and then sends it to the multiplexer that determines the inputs that come 'ON' and send its signal to the output which goes back to the microcontroller for sampling.

PIC18F4550 as a choice of microcontroller was employed in this work because it has a USB interface, five ports (A to E), thirteen ADC inputs, and it supports external interrupt on port B. The output from each sensor is stored in blocks on the memory card inserted into the memory card slot of the microcontroller. Each block on the memory card has a capacity of 512 bytes [7].

The Universal Serial Bus (USB) port of the microcontroller allows it to be interfaced with a computer to transfer data from the sensors to the computer. The LCD screen displays the particular function that the microcontroller performs at a particular time which may be: logging, USB connected, memory card inserted, logging stopped etc. The external interrupt allows the keyboard to send and select options from the logger menu. The circuit diagram of the data logger is as shown in Fig. 6.

3. RESULTS

All the constructed sensors were calibrated against standards to ascertain their precision and accuracy. This process was carried out in order to determine deviations from the accurate measurement and to compensate for errors. The graphical representations of the constructed

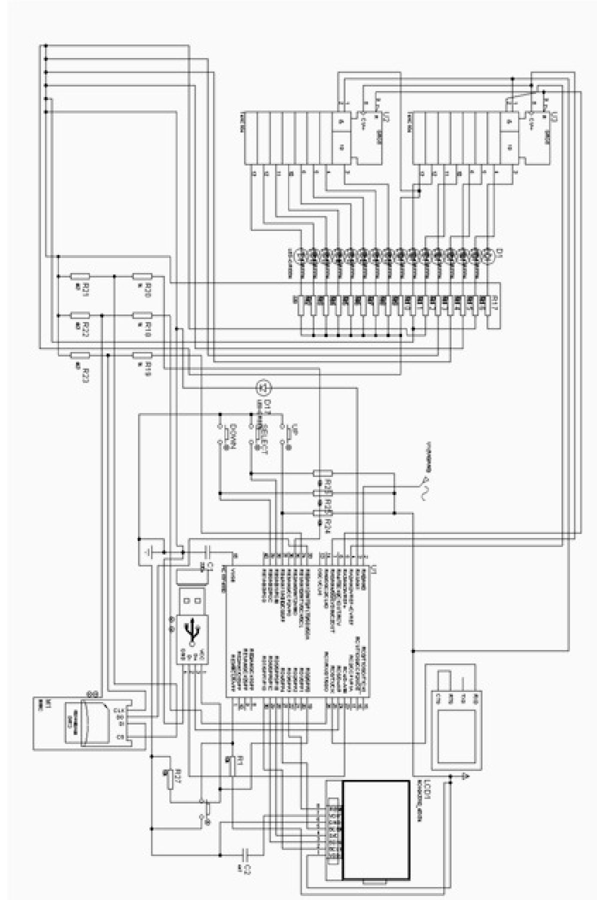

Fig.6: Simulation circuit of the data logger.

measuring instrument were plotted against standard and the calibration constants determining error compensation were obtained.

The constructed anemometer was calibrated against the Delta-T (standard) to obtain its accuracy in terms of resolution, error and sensitivity.

Sample data were collected and analyzed. The results are as shown in figure 8. The calibration constant of 1.032 ms^{-1}/Hz was obtained from the calibration equation i.e.

$$y = mx + c \qquad (3)$$

where *m* is the calibration constant and R^2 value from the graph (Fig. 8) is 0.623. This is the correlation coefficient and it indicates the correlation between the two variables (constructed and standard anemometer speed)

This correlation coefficient shows a good relationship between the constructed cup anemometer and the standard anemometer used for calibration.

The constructed psychrometer consists of two LM35 sensors; one dry and the other wet. They were both calibrated for temperature measurement and their calibration constant was obtained. The error in LM 35 sensor was obtained using equation 4.

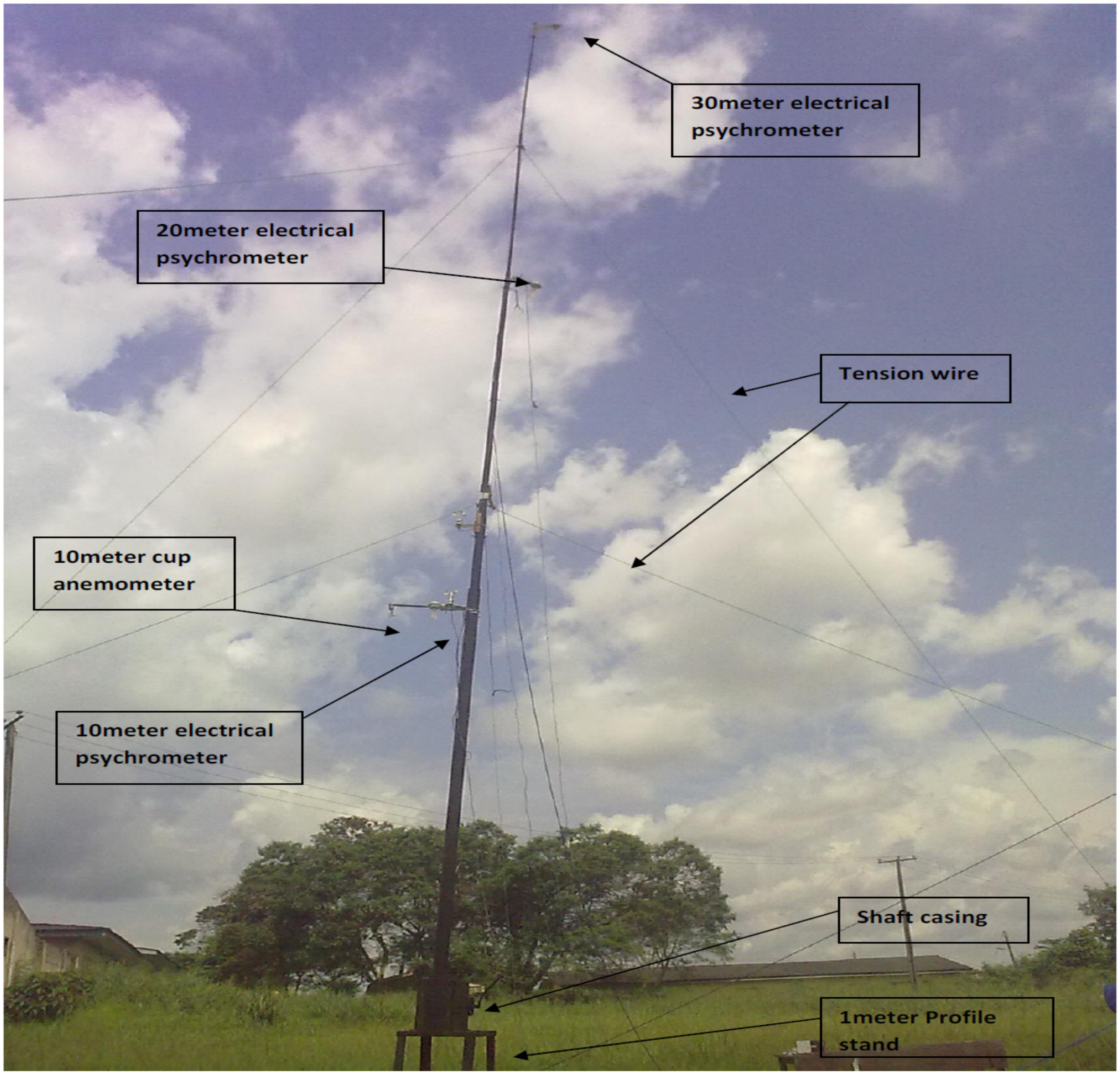

Fig.7: Pictorial diagram of the constructed 30 m profile.

$$\%\,\text{Error} = \frac{\text{Average standard reading} - \text{calibration constant}}{\text{Average standard reading}} \times 100 \quad (4)$$

The sensitivity of the constructed psychrometer is the reciprocal of the calibration constant. (Equation 5)

$$\left.\begin{aligned} \text{Sensitivity} &= \frac{1}{\text{Calibration constant}} \\ &= 1/(1.032) \;=\; 0.968\, Hz/ms^{-1} \end{aligned}\right\} \quad (5)$$

The dry LM35 sensor is used for air temperature measurement. By checking the temperature variation at different heights of the mast for different time of 20 minutes interval, a time series graph was plotted as shown in Fig. 9. The same procedure was repeated to obtain the graphical representations shown in Fig. 10 to Fig. 13.

The relative humidity is gotten from the dry and wet sensors using the formulas below:

$$es = 6.11\exp\frac{(17.67 * Tdry)}{(Tdry + 243.5)} \quad (6)$$

$$ew = 6.11\exp\frac{(17.67 * Twet)}{(Twet + 243.5)} \quad (7)$$

$$\left.\begin{aligned} e &= ew - Psta \times (Tdry - Twet) \\ &\quad \times 0.00066 \times (1 + (0.0015 * Twet)) \end{aligned}\right\} \quad (8)$$

where e_s = saturated vapor pressure over air

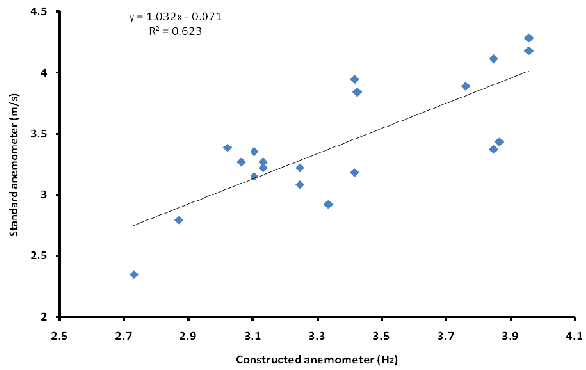

Fig. 8: The graph of the standardized anemometer (m/s) against the constructed cup anemometer (Hz).

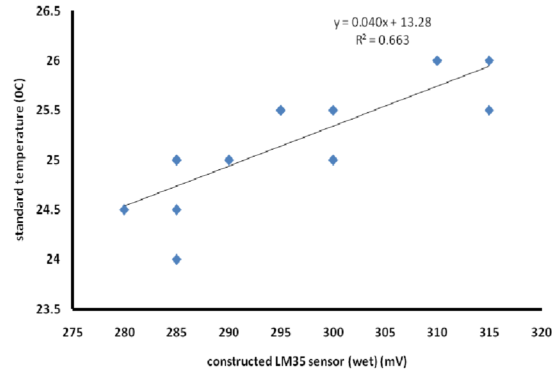

Fig.11: Calibration graph of wet LM35 sensor.

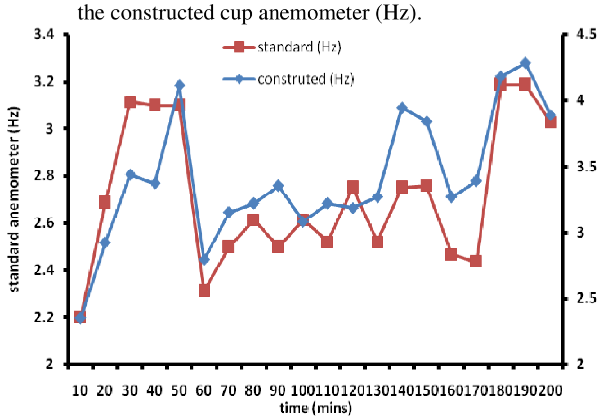

Fig. 9: Time series of the constructed anemometer (m/s) against the standardized delta anemometer.

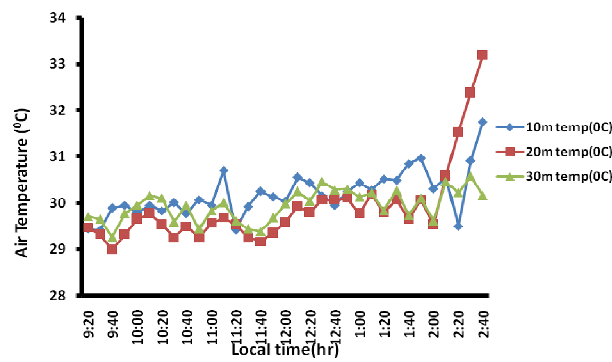

Fig.12: Graph of 30 meter temperature profile measurement.

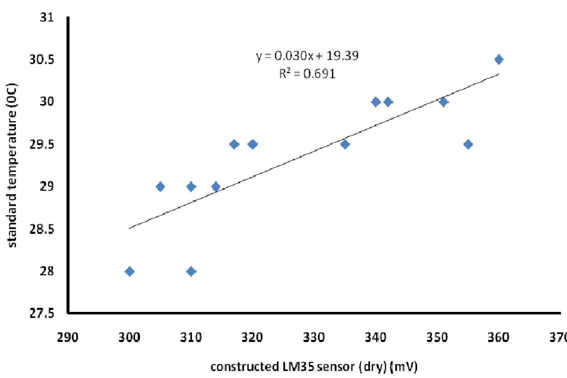

Fig. 10: Calibration graph of dry LM35 sensor.

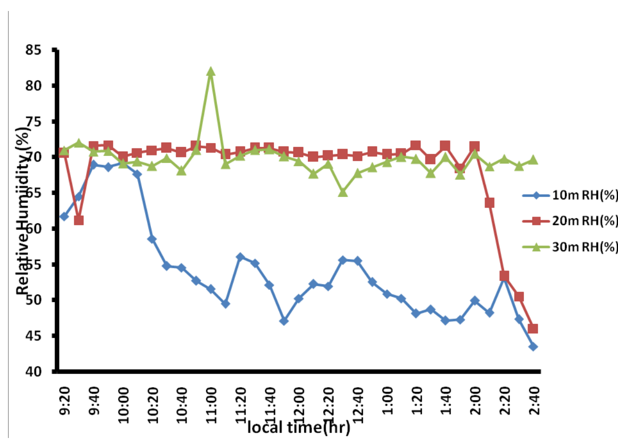

Fig. 13: Graph of 30 meter relative humidity profile measurement.

e_w = saturated vapor pressure over water
e = actual vapor pressure

The data logger was programmed to log data at a pre–determined time interval of ten minutes. The data obtained were processed and analyzed to obtain the graphical representations shown in Fig. 8 to Fig. 13.

4. DISCUSSION

The results of the calibration carried out on the developed mobile mast with various instruments mounted on it revealed a reasonable correlation between the standard and the constructed instrument. The constructed weather sensors (cup anemometer, wind vane, psychrometer) and data logger gave data that compares favourably with the standard equipment used in the calibration. The sensitivity of the constructed sensors is high when compared to the standard. The error margins were compensated for using the calibration constant and the regression coefficient R^2 as shown in Fig. 9, Fig. 10 and Fig. 11. The results obtained from temperature measurements (Fig. 12) were adequate and correct with high temperature values recorded mostly at the ten metres height profile. This observation confirms the environmental law that says "the higher you go the cooler it becomes." The relative humidity profile measurement revealed that the highest relative humidity values were recorded at the thirty metres height profile (Fig. 13).

This mast is unique in that it can be used for in situ profile measurement of weather parameters in every location of choice. It can be collapsed and transported easily. It can even be used in locations where there is no electricity supply since it can be installed with or without the electric motor. The data logger serves as a data storage tank where data can easily be downloaded at any pre - determined time. Although for real profile measurement, the mast ought to be higher than thirty metres, yet the results obtained from this work are reasonably adequate and correct. Meanwhile, effort is still on going to increase the height and as well incorporate other weather parameter sensors for effective and efficient weather profile measurements.

5. CONCLUSION

From the results obtained, constructed mobile mast of 30 meter height is suitable for upper air measurement of temperature, relative humidity and wind speed. After the calibration of the sensors, accurate results that compares favourably with standards were obtained. The mast can be used to acquire meteorological data in different locations because it is movable unlike other mast that is stationary. Research work is still on course to increase its height.

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