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Full Length Research Paper

Development and calibration of a self-recording cup anemometer for wind speed measurement

Fasinmirin J. T.[1,3]*, Oguntunde P. G.[1], Ladipo K. O.[2] and Dalbianco L.[3]

[1]Department of Agricultural Engineering, Federal University of Technology, Akure, Nigeria.
[2]Department of Meteorology, Federal University of Technology, Akure, Nigeria.
[3]Centro de Ciência Rurais, Universidade Federal de Santa Maria, Brazil.

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The design, development and calibration of a digital wind speed measuring device (cup anemometer) has been carried out. The instrument design consists of six electronics block stages: Power stage which supplies power through either a direct current (DC) or an alternating current (AC), input (sensor) stage which senses the number of revolutions per minute (rpm), the clock/triggering stage which was designed to monitor the time interval between the break and makeup of the pulses, and the output stage which comprises the counting stage, decoders/memory stage and lastly the seven segment display. Each block was designed in stages, simulated and constructed to give the required output, utilizing various low-power integrated circuits (ICs). The output results were then interfaced to give the final desired result. The mechanical aspect of the device was composed of a casing and three conical shape cups which was made from acrylics materials, aluminium spindle with bearings. The device after development was calibrated against the standard (Delta-T) anemometer, type ANI for accuracy and performance evaluation. The calibration statistics showed a high correlation coefficient r = 0.93 at P ≤ 0.05 between the standard and the developed anemometer. Also, sensitivity analysis of the developed anemometer gave 1.2 rpm/ms^{-1}. The developed instrument is useful in climatic studies especially in areas of irrigation agriculture, aviations, pollution control and radioactive development.

Key words: Wind speed, cup anemometer, sensor, decoder, spindle.

INTRODUCTION

Wind speed is a quantity that involves both magnitude and direction. The wind direction is that from which it blows relative to the true north, while its magnitude is a function of the speed in knots, kilometres per hour or metres per second (Ayoade, 1980). Eight prevailing winds are common in Akure but the dominant ones are Southerly, Southwesterly, Westerly and Northwesterly winds. The winds are more fairly distributed in all directions, but southwesterly and westerly winds predominate in the region in January, with a frequency of about 20% (NDES, 1997; Ojo, 1977; Utang, 2010). The direct effect of wind near the surface of the earth cannot be over-emphasized, as it manifested through soil erosion, the character of vegetation, damage of structures, and the production of waves on water surfaces (Landsea and Gray, 1992; Emmanuel, 2000).

Therefore, its practical applications in the design of structures, shelterbelts, airports and runways, control of air pollution and pests is very essential (Ayoade, 1980). At higher levels, wind directly affects aircrafts, missile and rocket operations, dispersion of industrial pollutants, radioactive products of nuclear explosions, dust, volcanic debris, and other materials (Gray, 1988). Directly or indirectly, wind is responsible for the production and transport of clouds and precipitation and for the transport of cold and warm air masses from one region to another (Dines, 2000; Bosart and Bartto, 1991; Khain and Ginis, 1991). Wind reduces any sprinkler effectiveness, because it increases evaporation and affects the watering pattern. The interaction of wind velocity, temperature and relative humidity constantly causes some losses in a high-pressure irrigation system (Bouder, 1998; Pitcher and Calder, 2000). Prediction of the wind speed in the built environment is difficult. One of the reasons is

*Corresponding author. E-mail:fasinmirin_johnson@yahoo.com.

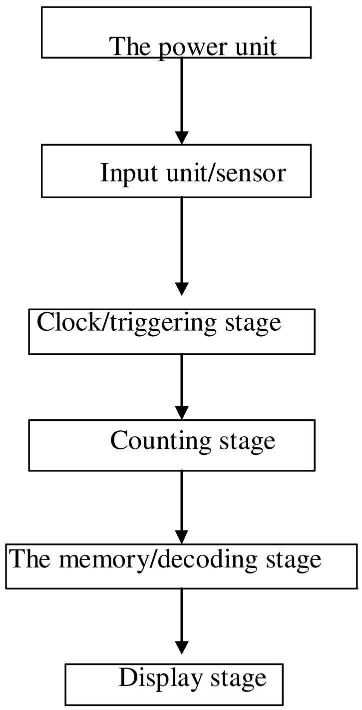

Figure 1. Design flowchart of the digital electronic system.

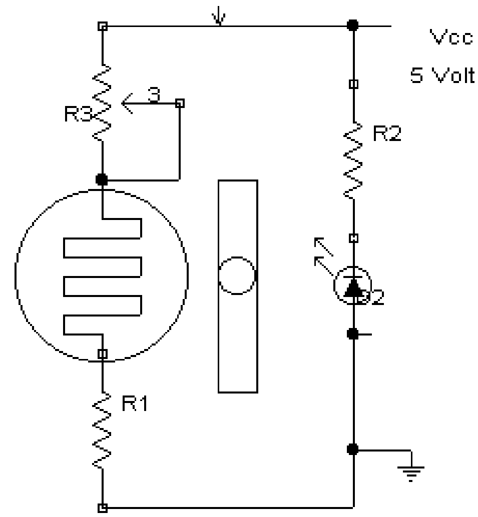

Figure 2. Schematic diagram of the input device.

"surface roughness". The many obstacles and different heights of buildings give the built environment a high roughness coefficient (WAsP, 2006), compared to open, rural locations. The roughness coefficient is generally used to extrapolate wind speed at different heights from measurement at only one or two heights and locations. A high roughness coefficient means slower acceleration of speed as height increases and therefore lower energy yields.

Several advances have been made in the development of electronic data logging equipment for wind speed measurement (Adani and Nowicki, 1990). One very good thing about cup anemometer is its simplicity but if used without electronic data logging device, several wind events may be left unrecorded. However, the cost and logistics involved in the procurement of this very sensitive device has made it difficult for research institutions, government agencies and private individuals to acquire. Therefore, the objective of the research was to design and develop a low cost digital cup anemometer, which is closely similar to the standard, using locally sourced raw materials for the monitoring of wind speed in the tropical environment.

MATERIALS AND METHODS

Design processes of the cup anemometer

The flowchart of the design of the digital electronic system for the cup anemometer is shown in Figure 1 with each block unit making up the entire design circuit. Each unit was designed to give a specific output.

Power supply unit

The power supply circuit was designed to provide low voltage of 5 and 9 volts for the system. Due to high sensitivity of digital devices to voltage, an internal DC power supply was used. The first element in the unit is transformer, which steps down input voltage of around 220 to 240 volts to 12 volts. The transformer was followed by a bridge rectifier, implemented as a network of 5341 junction diodes. Fluctuations and ripples superimposed on the rectifier DC voltage are filtered out by a 470 µF, 25 V and 102 µF capacitors. The transistor and zener diode (5.2 volts) was used to boost and regulate the output DC voltage. The zener diode acts as voltage regulator to control the DC supply, which makes the internal voltage independent of fluctuations that may occur at the main outlets in the course of using the digital access monitor.

Input unit/sensor

The input circuit comprises of phototransistor and a light emitting diode (LED) was connected in series with a 500 kΩ variable resistor to the power supply (Vcc) and 100 kΩ fixed to the GND voltage while the photocell was connected to both Vcc and GND. Also, a 10 kΩ resistor was connected in series to the Vcc (+ve) voltage and in-between the LED as shown in Figure 2.

Clock/triggering stage

The triggering sub-circuit provides momentary pulse for the counters; another 555 timer was utilized in this respect. The 555 is an integrated circuit implementing a variety of timer and multivibrator applications. It contains twenty-three transistors, two diodes and sixteen resistors on a silicon chip, controlled in an eight pin mini dual-in-package. It has three generating states: astable, monostable and bi-stable states. As an astable multivibrator, the free running frequency and the duty cycle are both accurately

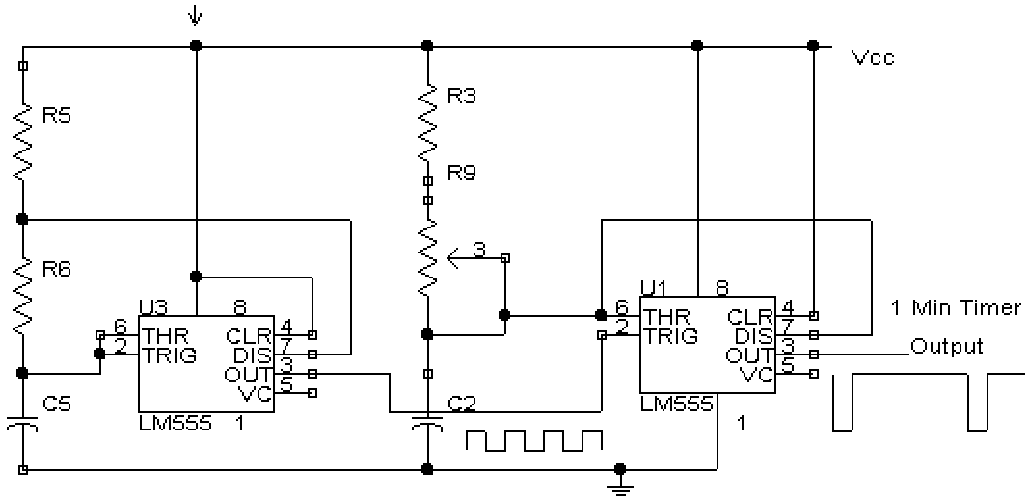

Figure 3. Pin connection of a stable clock and monostable 555 timer. When configured in a monostable mode, the 555 timer is so designed that, a pulse at the trigger input turns the timer on for a predetermined length of time.

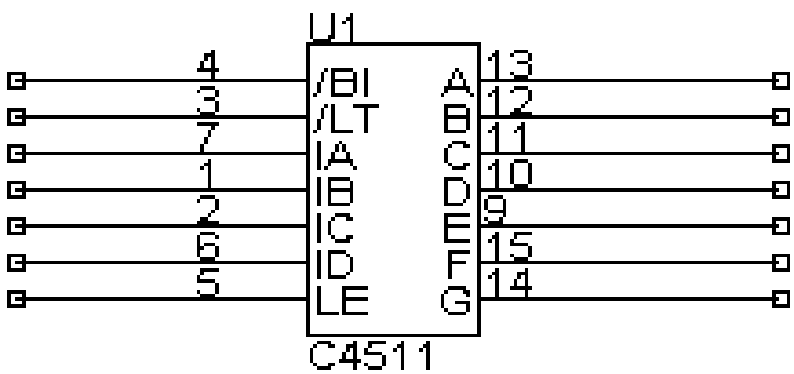

Figure 4. Pin configuration of 4511B latch/decoder.

controlled with two external resistors and one capacitor to make a TTL-compatible pulse generator, that can serve as a clock for timing purpose in digital system (Jones, 1989). Figure 3 shows the astable and monostable circuit, that was adopted to synchronize the entire system operations.

Counting stage

The 7490 integrated circuit (IC) decade counters cascade in threes at the entry and exit circuits. Figure 5 shows the pin configuration for the 7490 – decade counter. Inputs are pins 14(A) and 1(B) and the output pins were denoted by 8(Q_C), 9(Q_B), 11(Q_D), and 12(Q_A). These pins produce binary code level with Q_A serve as the LSB. Pin 12 is the output of the two-count sections. By connecting the two-count output (Q_A) to the five- count Input (B), the decade (2 x 5) counting ability was obtained. Outputs Q_B, Q_C and Q_D are the five count outputs with Q_D as the MSB. Additional inputs labelled R_D (1), R_O (2), R_D (1) and R_D (2) are the reset input. It is required that the counting operation of each counter begins at the zero state. However, because of flip-flops that have memory, each counter appeared to have a default count state, other than zero, when power is supplied to it.

The memory and decoding unit

The most popular CMOS IC for driving seven segment LED display is the 4511B BCD (Figure 4). This IC is ideally suited to driving common cathode display, since its output can each source up to 25 mA. The 4511B IC was therefore used for the developed cup anemometer. It has four BCD input terminals, seven segment driving output terminals and only three input control terminals.

The display stage

The display unit is incorporated / inbuilt in memory unit of the 4511B IC. This uses the seven-segment display (cathode display) but common anode was used. For it to perform well and inverted, the 4069 IC was used to decode it back to common-cathode.

Mechanical design of the anemometer

The cup anemometer was constructed with the aid of cup wheel made of plastic (acrylic) material mounted symmetrically about a vertical axis at the end of the arms protruding from the wheel

Figure 5. Pictorial view of the developed cup anemometer.

Table 1. Specifications of anemometers.

Delta-T anemometer	Constructed anemometer
Shaft length, 20 cm	Shaft length 20, cm
Casing diameter, 55 mm	Casing diameter, 65 mm
Attached screen table, 3m	
Rotor cup diameter, 135 mm (3-cups)	Rotor cup diameter, 75 mm (3-cups)
Total weight (350 g) including standard cable	Weight of casing with spindle, 166 g Weight of three cups, 35 g

(Figure 5). The force of the wind is higher on the concave side of the cup comparatively with the convex side and hence, the cup will rotate in the air stream. For the cup anemometer, there is a minimum wind speed which will set the cup in motion depending on the friction in the bearings of the wheel and the design parameters of the instrument.

In a steady wind, the cup performs well from almost 0.5 ms^{-1} to 60 ms^{-1}. In gusty wind however, it tends to read a higher average wind speed than the actual one. This is because the cup wheel, having inertia, accelerates more rapidly with an increasing wind speed than it decelerates with decreasing wind speed. The mechanical specifications of the constructed and the Delta-T anemometer are shown in Table 1.

Calibration of the developed anemometer

A portable hand held cup anemometer (standard) model AM – 4220, ISO 9001 was calibrated against the constructed anemometer, to compare the efficiency of the anemometer in terms of resolution and error in the data collected. The standard instrument has a cup wheel comprising of three conical cups with bedded edges and free to rotate in a horizontal plane. The cup wheel spindle is connected by worm gearing to a revolution counter mounted inside water proof housing. The spindle is supported on two bearings, ball bearing at top and thrust bearing at bottom. The instrument is equipped with liquid crystal display (LCD) which records the minimum and maximum air velocity, a data logger and measures wind speed up to 35 ms^{-1}. The data collected was statistically analysed using Bio-Estat 5 to obtain the maximums, standard deviations, standard errors and Pearson correlation coefficients among the values obtained during calibrations.

RESULTS AND DISCUSSION

The plot showing the relationship between the wind speed values of standard anemometer and laboratory developed anemometer is presented in Figures 6 and 7. The maximum wind speed recorded during the first calibration experiment were 1.58 ms^{-1} (±0.33) and 0.98 ms^{-1} (±0.21) from the standard and developed anemometers, respectively. The standard errors (STE) among wind speed values recorded during the first and second calibrations were 0.042 and 0.027, and 0.037 and 0.026 for the standard and laboratory manufactured anemometers, respectively. The calibration constant obtained from the linear graph during the first calibration was 0.5921, with significantly high coefficient of determination R^2 = 0.833. However, a higher coefficient of determination was obtained during the second calibration exercise (R^2 = 0.9016).

Pearson correlation analysis of wind speed data from the standard and laboratory manufactured cup anemometers showed that, difference were only significant at the $P<0.0001$ as shown in Table 2. The

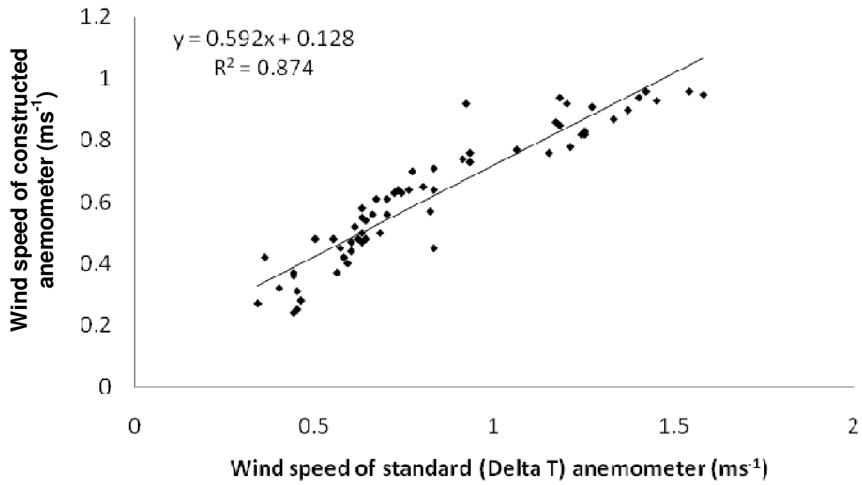

Figure 6. Calibration curve 1 showing the relationship between constructed and standard cup anemometer.

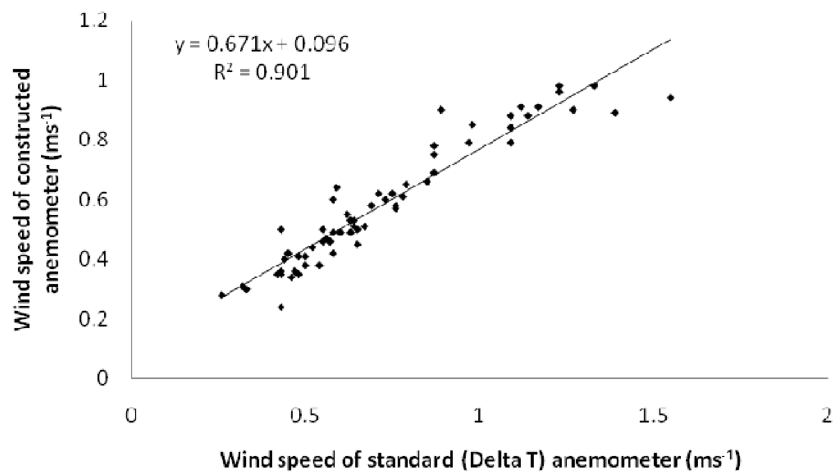

Figure 7. Calibration curve 1 showing the relationship between constructed and standard cup anemometer.

correlation coeffient (r pearson) was highest (r = 0.94) between the wind speeds of standard and constructed anemometers during the second calibration exercise. The relatively high values of r between the standard and constructed anemometers during the first and second calibrations shows that, the locally manufactured anemometer is suitable for the measurement of wind speed of the site of experiment.

Resolution

The minimum speed that will set the constructed and the Delta – T (standard) cup anemometers on rotational motion were estimated at 0.047 and 0.072 ms^{-1}, respectively. The curve showing the relationship in wind speed obtained from the standard and the developed anemometers is presented in Figure 8. The highest and lowest measured values of wind speed from the standard and constructed cup anemometers were 6.89 and 0.34, and 6.05 and 0.24 ms^{-1}, respectively. Though the values of wind speed under the constructed anemometer are lower comparatively with the values from standard anemometer, the trend of wind speed measurement were reasonable similar. The sensitivity of the constructed anemometer which was determined from the reciprocal of the calibration coefficient of correlation was estimated to be 1.06.

Conclusion

A digital cup anemometer has been designed, developed and calibrated. The relationship established between the

Table 2. Results of Pearson correlation analysis of wind speeds.

Parameters	S1 and C1	S1 and S2	S1 and C2	S2 and C1	C1 and C2	S2 and C2n
	62	62	62	62	62	62
r (Pearson)	0.93*	0.69*	0.65*	0.66*	0.66*	0.94*
R2	0.87	0.48*	0.42	0.44	0.44	0.90
t	20.48	7.45	6.54	6.84	6.84	23.44
P	<0.000	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

* Significantly different at P<0.0001 probability level. S1 – Wind speed of standard anemometer during calibration 1; S2 – Wind speed of standard anemometer during calibration 2; C1 – Wind speed of constructed anemometer during calibration 1; C2 – Wind speed of constructed anemometer during calibration 2.

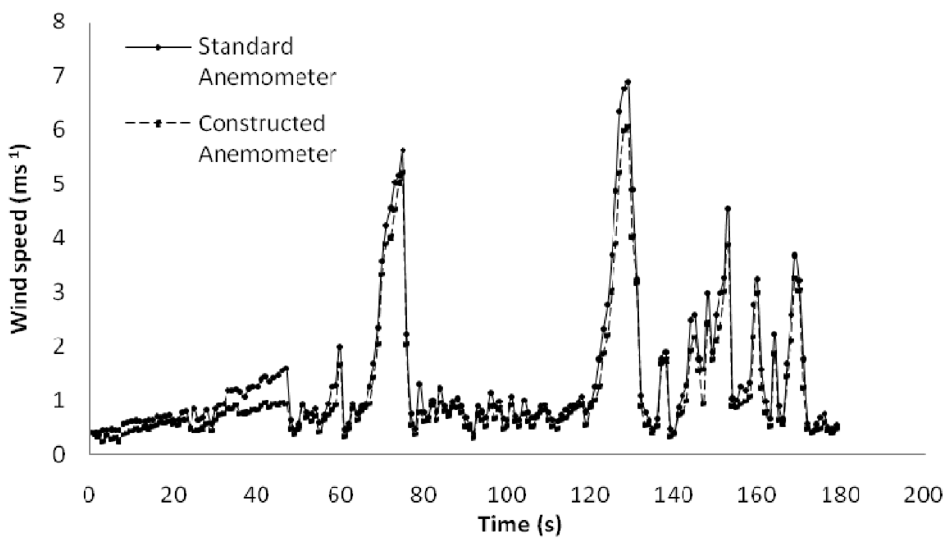

Figure 8. Wind speed measured from standard and constructed anemometer.

standard (Delta-T) and the developed anemometer gave a calibration coefficient of correlation (0.94), which at any condition could be used as a factor for conversion, to obtain values similar to the standards. Though the developed anemometer statistically correlated well with the standard, the variations in dimension must have led to the disparity in the measured wind speed during calibration. However, the developed anemometer was found to be low cost and appropriate for wind speed measurement in the tropical environment.

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