Low Cost Module for Measurements of Wind Speed and Direction

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Abstract— **The low cost data acquisition module has been developed to allow solar collectors and wind power studies with the goal of improvement their performance. Although systems exist for this purpose, the main idea is to allow the development of new ones, using open and low cost platforms. According with this proposal, this new module will be develop for capturing data for wind speed and direction. The module sends this information to the user by the computer screen and record it in an SD card (Solid State Card) for later use. The equipment proposed can be used standalone in external environment, using a 9V battery, and register the information along a specified time period. The proposed code was designe for storage data in a plain text comma-separated (CSV). In the future, this system will receive improvements to register other relevant infomations, like temperatures, fluid flow and other reference parameters. Some tests for wind speed and direction were performed on diferent conditions for testing the apparatus and the code.**

Keywords— Anemometer, Arduino, Low Cost, Wind Direction Sensor.

1. INTRODUCTION

Wind is always present and bring benefits and harms for everyday life. On solar collectors, winds usually increases the heat loss and reduces the thermal performance of heaters. By other way, wind power is a renewable and clean energy that is available in all locations to moving aero generators that are, usually, grouped in wind farms with the purpose of reducing the costs from power generation. For wind energy be consider viable, its energy density must be greater than 500 W/m², at a height of 50 m, which requires a minimum wind speed of 7 to 8 m/s [1]. Another option of using wind power is in small wind systems known as micro wind generators, with a power of 100 kW to 1 MW, which can be connected to the electric grid. For the small-scale energy generation is necessary a minimum wind speed of 2.5 m/s. For evaluation of wind potential in a region, it is necessary a precise anemometer and quality of data collection equipment. High costs justifies its acquisition only for research projects with high costs involved and initial evaluation of small equipment for residential usually needs low cost of installation and maintenance to be viable for its implementation

Several works for developing new methodology and geometry for anemometers and wind direction sensors can be found in the references. Evaluating the anemometer design, Sanz-Andréset et al. [2] performed a mathematical analysis of the effect of rotor geometry on cup anemometer response, defining the relation of cup anemometer geometry with its behavior. On other hand, considering the device building, Fasinmirin et al [3] successfully developed and analyzed a cup anemometer coupled to a LCD display for direct use in tropical regions.

The operating conditions also needs to be evaluated. Regarding to this aspect and considering the installation on meteorological towers, Orlando at al. [4] investigated the effects of ‘‘shadowing’’ on cup anemometer wind speed data. In some conditions, reduction the wind speed up to 35% was observed. On other study, Farrugia and Sant [5] evaluated the influence on cup anemometers data for mounting them on opposite sides of meteorological tower. It was used the Levenberg–Marquardt (LM) algorithm to build a relationship between wind speed records for different concurrent anemometer. For low temperature environment, freezing can be verified on the operation. Bégin-Drolet et al. [6], developed a prototype of an ice-free anemometer, which can be integrated with icing detection algorithm. In this case, a sensor will be responsible for triggering the heating of the anemometer cups when necessary. With this control algorithm, the energy consumption was reduced by about 90% when freezing conditions are not verified.

Another important aspect is the behavior of cup anemometer along the time, Baseer et al [7] evaluated the data for some cup anemometers in a 55 months period and showed that the performance of sensors were not significantly affected along the time.

Considering the relevance of the device in several studies and the integration on a generic control system, the main goal of this work is develop a low cost cup anemometer on an open platform. In these devices, wind data acquisition can be integrated to other sensors, like wind direction sensor, environment temperature sensor and other ones with its data record in a SD card.

2. METHODOLOGY AND MATERIALS

Some devices were developed and directly used in this research. These technologies could be used also on productive sector at industries, but some of the devices could require add-ons. Most common of these ones are operational amplifiers and analogical to digital converters that will be integrated into the Arduino board. Communication, data manipulation and data reading are directly related to the code elaborated for each kind of sensor. Conflict or interference between sensors in the same module need to be avoided.

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2.1. Anemometer

A three cups anemometer was built and studied during the development of this study. This design of anemometer can be assembled with two types of sensors: Hall effect or Reed-Switch, both of them are used to count the number of turns of equipment's cups. If the sensor used in the anemometer is the Hall effect, the code to evaluates the time between two pulses can be used to calculating the wind speed.

Pindado et al. [8], present the fundamentals of design and evaluation of a cup anemometer and how to improve its performance. The anemometer can be evaluate the wind speed by a function like:

$$V = A.f + B \quad (1)$$

where V is the wind speed, f is the output frequency of rotation, A and B are the calibration coefficients. In order to adapt the expression to the acquired data, the above equation (1) can be rewritten as a function of the pulse frequency, f_r. and the number of pulses per rotation of anemometer, N_p.. Thus, the new expression obtained is:

$$V = A.N_p.f_r + B \quad (2)$$

In anemometer which have only one sensor, independent of the model used, one pulse will occur every turn of anemometer, so the measured time between two pulses is the rotation time or period. The inverse of the period is the frequency of the device (f_r). In this case, only one sensor by turn is used (N_p=1). If the calibration data is known, the wind speed can be calculated by the equation 2.

If the anemometer has more than one sensor to define the rotation or the frequency of the equipment, the N_p variable on equation 2 needs to be correctly adjusted.

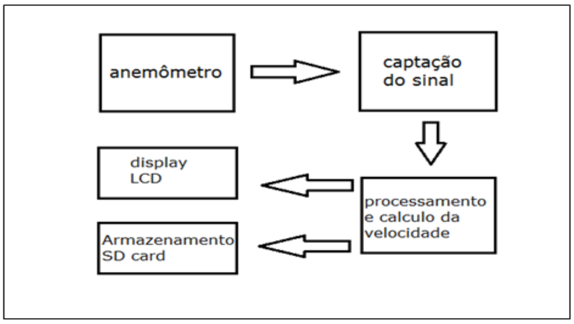
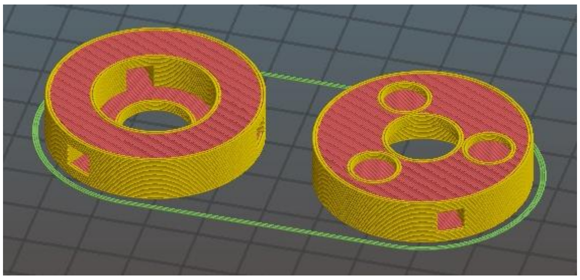


Fig. 1. Flowchart of the signal generated in the anemometer.

One device was build in this work for some tests. It is constructed with plastic PLA (polylactic acid), providing lightness, mechanical and climatic resistances. Bearing was used for reducing the friction forces on the revolution movement.

The equipment is composed by 3 cups with inner diameter of 45 mm and 85 mm turning radius, as shown in Fig. 03. The mapping of rotation is done using one Hall effect sensor. The sensor is activated by 3 circular session magnets of neodymium with 8mm diameter equally spaced along the circumference as shown on Figure 02 and 04.



design phase.

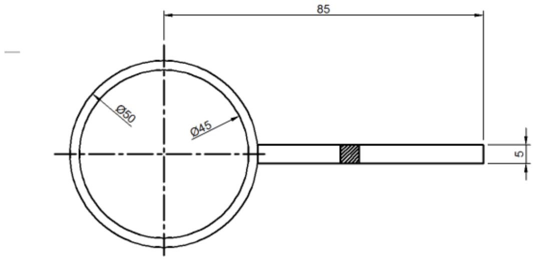


Fig. 3. Dimensions of the mugs of the anemometer.

Fig. 4. Accommodation of the magnets, bearing and shaft of the mugs.

2.1.1. Anemometer code

Using the fundamentals presented on Equation (2), a linear approximation is used for the anemometer calibration. This linear approximation was included on a specific library "Anemometro.h". For using this library function it is needed to know:

- the logical port where the device is plugged;
- the calibration constants A and B,
- the number of pulses per spin (N_p);
- define a limit for time step between two pulse.

This last information is used only for avoid some errors that could stop all acquisition data. If this time is too large, the function was interrupted but the codes remains running with no measurements at this time.

On figure 5 it is shown the Arduino code for using the anemometer. The inclusion of the library prepared to the anemometer, *Anemometro.h* is the first procedure. Right after, should inform the installation and operation data from device. On the "loop" step, the interruption of port must be evaluated by the *attachInterrupt* function. Evaluation of wind speed is done with the command *anemometro.calcvelocidade( )*. Printing this value on the computer serial uses the command *Serial.print(anemometro.velocidade).*

```
#include <Anemometro.h>
 //anemometer's information ***************
Anemometro anemometro(0.5675,-.5966,3,10000,3);
         //anemometer(calibration a, calibration b,
 // number of pulse per spin, limit time(ms)to catch
   //pulse and pin number that anemometer is connect
  int porta;//anemometer port, useful when is using
                            //two or more equipment
 void setup()
{  Serial.begin(9600); }  // start communication
void loop()
{       porta=3;
        attachInterrupt(digitalPinToInterrupt(anemo
        metro.porta),contapulso, RISING);
        anemometro.calcvelocidade();
        Serial.print (F("Wind speed average: "));
        Serial.println (anemometro.velocidade);
        Serial.println ("m/s");
        delay (60000);  }
void contapulso ()//routine that compute the pulses
 {    //using two sensor, anemometer and flow
sensor
  if (porta ==2) {vazao.contador++;}
  if (porta ==3) {anemometro.contador++;}
 }
```

Fig. 5: anemometer programming

2.1.2. Calibration of cup anemometer

This prototype of anemometer was construct with PLA plastic and composed by the Hall effect sensor, generating 3 pulses per revolution. The calibration was done by a ventilation system with speed control by a 600W Dimmer. A compact turbine type anemometer with a range of 0 to 30 m/s was used to obtain the wind speed for reference. Figure 6 presents the data for cup and turbine anemometers and the calibration function.

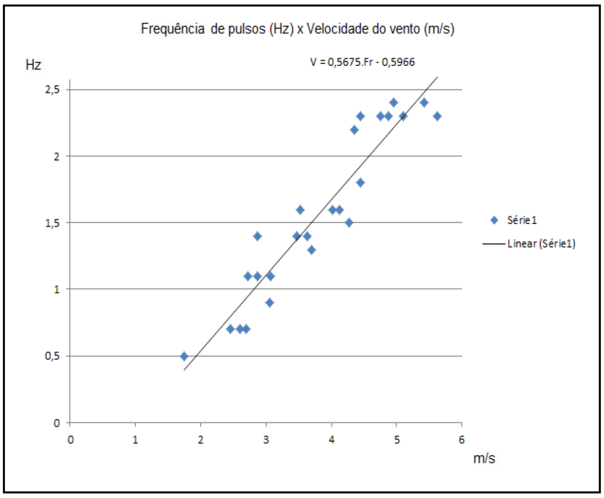


Fig. 6. Mug anemometer calibration curve, with Np = 3

2.2. Wind direction

As well as determining the wind speed, the wind direction is also an important parameter in assessing environmental conditions. Thus, it was also assembled a device capable for measuring the wind direction. This device is based on inclusion of a rudder that follows the direction of the wind. A rotation sensor need to be used for indicating its position.

The structure of device was designed and construct of PLA (polylactic acid) plastic. This material was chosen because has low specific weight and the possibility of building the prototype by a 3D printer. A scheme of the rudder was shown in figure 7. In order to reduce the mass and the inertia to displacement, the pieces was printed using a honeycomb geometry with 25% fill.

The sensor used to monitor the movement of the rudder was an encoder with 25 pulses per revolution and 360° rotation angle. The encoder yet presents 2 pulse outputs when angle pass through outdated in 90°, allowing the reading of the rotating direction. (Gray Code).

The installation scheme of the encoder could be seen in Figure 8.

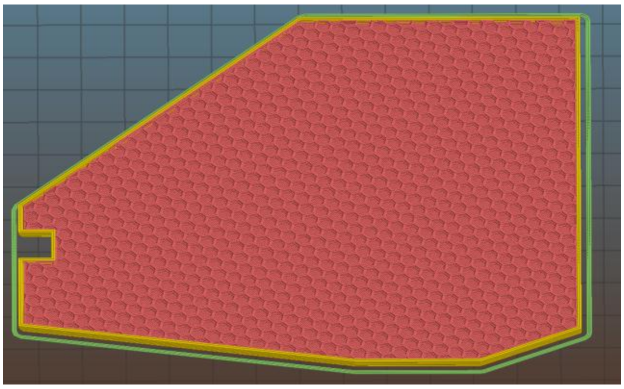


Fig. 7. Rudder design with highlight their internal honeycomb structure.

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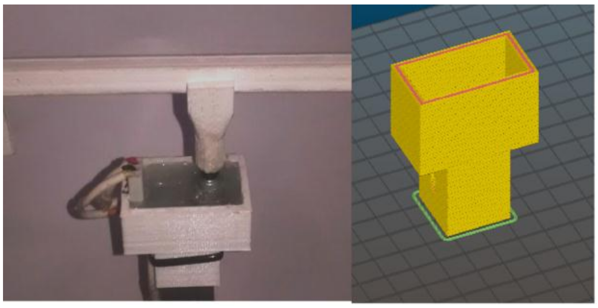

Fig. 8. Accommodation the encoder, situated at the base of the equipment.

The encoder used on device is an incremental one and must be activated in a known position. After this position is defined, every movement of the rudder will be generated a high level signal which the software will interpret as the change of position. The code has been designed to provide to user the angular movement to the reference position in degrees. An overview picture of the instrument is shown in figure. 9.

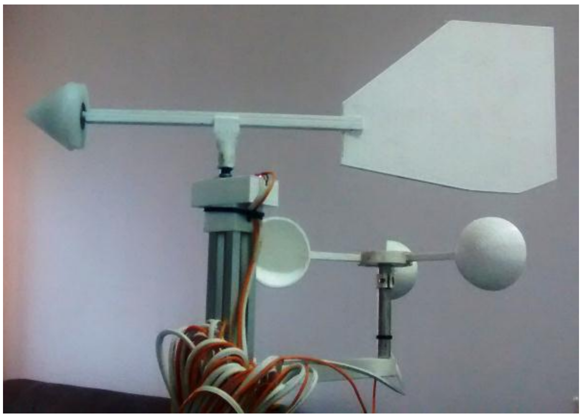

Fig. 9. Measuring system of wind speed and position.

2.2.1 *Wind direction code*

As previously discussed, the wind direction sensor uses the incremental encoder to determine its angular position. Thus, for determining this parameters it was necessary a known position. So, it must start the equipment directed to the North and the further angular positions will be determined from this one (in degrees).

For developing the code was used the library *RotaryEncoder (_, _)*, it is also necessary inform the Arduino UNO port which the encoder is connected. For example, in this work the ports A2 and A3 were used. Using this library, the rotating direction of the equipment was measured by number of pulses and each electric pulse represents a 15° displacement. The figure 10 shows the arduino code used for measurements of the wind direction sensor.

```
#include <Direcaovento.h>
/*include the encoder library that keep arduino
   pin with high signal, store the last position
                        and update the position */

        //pin where sensor is conected
Direcaovento encoder(A2, A3);
static int Pos = 0; //start position

void setup()
{
             // start communication
  Serial.begin(9600);
     /*enable change interruption in all analogic
                                   pin(PortC)*/
 PCICR |= (1 << PCIE1);
 /*enable change interruption in analogical pin
                2(01) and 3(11)*/
 PCMSK1 |= (1 << PCINT10) | (1 << PCINT11);
}
// store and check the signal in the pin A2 e A3
// if the position was changed, update it
 ISR(PCINT1_vect) {
                 encoder.tick();
                 }

 /*now start the routine that check the position
             and transmit to user*/
void loop()
{
 static int pos = 0; //start position
 int newPos = encoder.getPosition();
 //convert the position in degrees  - clockwise
 if (newPos > 0){ newPos = newPos * 15;}
/*convert    the    position    in    degrees-
anticlockwise*/
  if (newPos < 0){ newPos = (newPos * 15)+360;}

  //********Wind direction*********************
Serial.print (F("Wind direction: "));
Serial.println (newPos);
Serial.println (F("********************"));
}
```

Fig. 10: Code sketch of the wind direction sensor.

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2.3. Result and discussions

According to the previous proposal, the anemometer and the wind direction sensor were mounted on the Arduino board. Thus, when the measurement system is used for data acquisition other sensors such as thermocouples, semiconductors, thermistor and add-on components are usually required. For testing how this code works with other measurement sensors, it was assembly a device module including various applications. It was added some sensors that are common in a system of this kind:

- Thermocouple Temperature Sensor;
- Thermistor Temperature Sensor;
- Temperature Sensor DS18b20 model Dallas manufacturer;
- Flow sensors;
- Anemometer;
- Radiometers;
- Calendar and time Module;
- SD card reader/write module;

The measurements of all sensors was registered and stored on a SD card file with plain text format. These data acquisition also included date and time stamp due to the presence of clock module.

Using this procedure, the data is stored in sequence, with comma separator. The first line identifies data or the sensor that collected these data. These acquired data can be exported to spreadsheet format, using the comma separated resource.

Figure 11 shows the data stores in file in original format.

```
date,hours,wind_speed m/s,flow L/h,temp_int,temp_MAX6675, sensor A0_A1 (V),sensor A2_A3 (V),wind direction
07.01.2017,14:58:16,0.00,0.00,30.50,34.50,0.00000,0.00000,0,
07.01.2017,14:59:20,1.97,0.00,30.50,34.50,0.00000,-0.00018,270,
07.01.2017,15:00:21,0.53,0.00,30.50,34.25,0.00000,0.00000,270,
07.01.2017,15:01:23,0.83,0.00,30.50,34.50,0.00000,0.00000,255,
07.01.2017,15:02:25,1.57,0.00,30.50,34.00,0.00000,0.00000,285,
07.01.2017,15:03:27,0.00,0.00,30.50,34.50,0.00000,0.00000,225,
07.01.2017,15:04:30,0.91,0.00,30.50,34.25,0.00000,0.00000,300,
07.01.2017,15:05:32,2.26,0.00,31.00,34.75,0.00000,0.00000,285,
07.01.2017,15:06:33,2.98,0.00,31.00,34.50,-0.00018,-0.00018,225,
07.01.2017,15:07:34,0.34,0.00,31.00,34.75,0.00000,0.00000,270,
07.01.2017,15:08:37,0.46,0.00,31.00,35.00,0.00000,0.00000,195,
07.01.2017,15:09:39,0.48,0.00,31.00,35.00,0.00000,-0.00018,240,
07.01.2017,15:10:41,0.94,0.00,31.00,34.50,0.00000,0.00000,255,
07.01.2017,15:11:43,1.26,0.00,31.00,34.75,0.00000,0.00000,255,
07.01.2017,15:12:45,0.96,0.00,31.00,34.75,0.00000,0.00000,285,
07.01.2017,15:13:46,0.00,0.00,31.00,34.50,0.00000,-0.00018,270,
```

Fig. 11. Data collected and stored on the SD card, comma separator format.

This device was instaled in a simple structure of 3 meter high. It was used for acquiring the data of wind velocity, wind direction and temperature during 3 days. On this time period, normal conditions of weather, with small times of rain, occurred. The code was defined to record data every 1 minute in the file in the SD card. figure 12 shows the results and one can see that there is no perturbation on sensors data. So, the device and the code works well for the proposed goals.

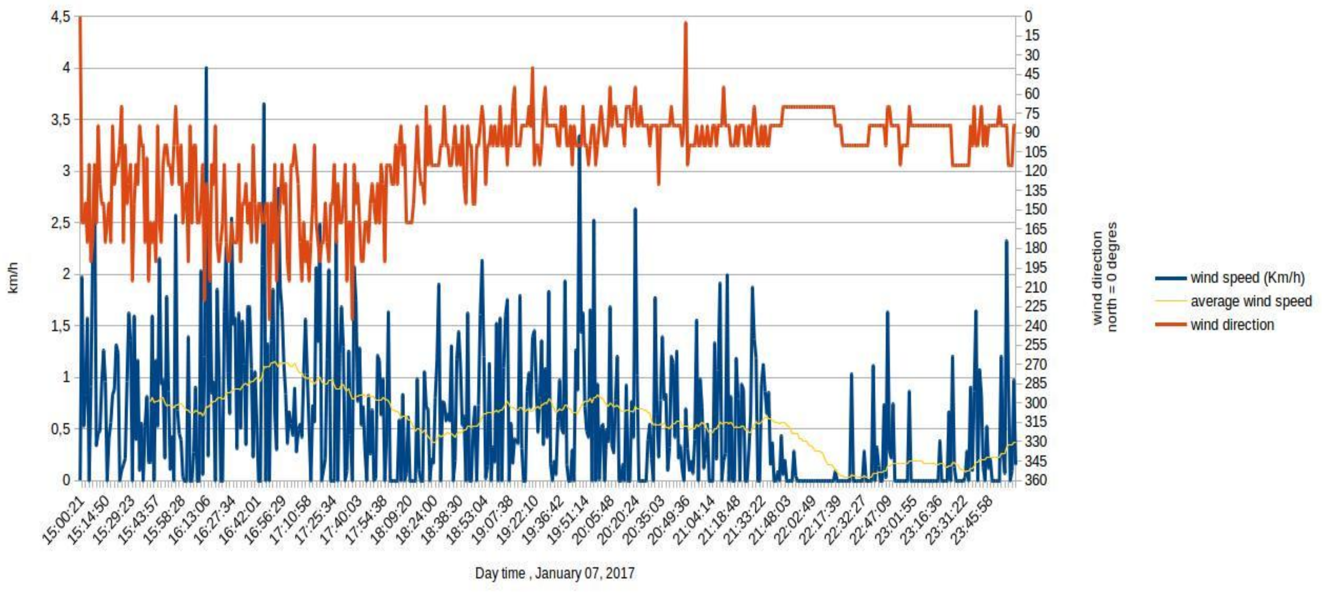

Figure 12: Data collected on January 7, 2017

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