

Wireless Embedded Air Multi-Parameter Measuring System

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Abstract- The article presents an embedded solution for the measurement of air parameters such as flow direction, flow velocity, temperature and relative humidity. The air flow velocity and direction measurement is based on a solid state sensor expressed by a set of ultrasound transmitters-receivers disposed according to the main cardinal points. 40kHz ultrasound burst signals are emitted from one cardinal point transmitter and received from the opposite cardinal point receiver whose conditioning circuit delivers a TTL pulse. The widths of the pulses obtained by the receivers are used not only to calculate air flow velocity and direction but also the temperature. Signal multiplexing, the trigger pulse generation, pulse width measurement and data acquisition associated with an additional relative humidity sensing channel are performed by a microcontroller (PIC18F452). The digital values associated with the measuring channels are transmitted using an ER400TRS RF wireless module that permits a point to point connection between the RS232 ports of the microcontroller and a host PC where the advanced processing and data publishing is carried out.

I. Introduction

Nowadays, solid state sensing solutions extend to the area of weather monitoring especially in wind velocity and wind direction measurement. No moving parts imply higher reliability and lower calibration costs. Different solutions of solid state wind sensors are reported in the literature and are mainly based on ultrasound propagation time [1][2] or on differential temperature measurement using thermopile integrated sensors [3]. For data communication, commercial solutions use wire communication protocols such as RS232, for point to point communication, or network protocols such as RS-422, RS485, or SDI-12. These solutions assure the integration of the wind measurement transducer as part of a weather station. Referring to the temperature and humidity sensors, the current solutions for the weather stations are based on solid state sensors and appropriate conditioning circuits connected by wires to the local processors.

In the present work, a low cost and fully solid state sensing solution for air multi-parameter measurement is presented. A set of ultrasonic 40 kHz transmitters-receivers and a capacitive sensor are used to obtain the air velocity, 2D air flow direction, temperature and relative humidity of the air. The control, data acquisition, primary data processing and data communication is performed by a microcontroller included in the system. Using the data received from the field microcontroller through a wireless communication, a host PC calculates the air parameter values based on analytical models previously designed and implemented. Elements of air parameters statistics and data publishing using dynamic web pages are also discussed.

II. System Description

As mentioned before, the designed and implemented distributed measuring system is based on solid state sensors for air flow velocity, 2D air flow direction (wind direction), relative humidity and temperature measurement. In order to measure the air flow velocity, 2D air flow direction and air temperature a set of ultrasonic devices with a particular geometrical distribution are used. The control of the ultrasonic devices and the primary data processing of the ultrasonic receivers acquired signals are performed by a microcontroller. An additional multiplexing/demultiplexing scheme is used to distribute the control signal and to obtain the ultrasonic devices responses.

Air temperature, an important air parameter, is measured through the implementation of a virtual measuring channel that mainly uses the information of the pulse width of the ultrasonic devices response and the relation between the sound velocity in air and temperature. Additional information about air relative humidity is provided by a capacitive sensor as part of a relative humidity transducer whose output voltage is acquired using one of the analogue input channels of the microcontroller.

For data communication between the field devices and the host computer, several wireless solutions were studied, a set of RS232-wireless bridges being used in the present application.

In what concerns the software, the objective was to develop a flexible and reliable software component for the microcontroller and, at the same time, an advanced software component associated with the host PC that performs data communication, accurate calculation of air parameters using different models for the measuring channels (real and virtual), data statistics and forecasting, data logging and data publishing using dynamic pages.

A. Hardware

The wireless embedded air multi-parameter distributed measuring system includes several nodes, each node being expressed by the block diagram of Figure 1. Each node includes a set of sensing devices associated with air flow characteristics measurement and a PIC18F452 microcontroller that controls and acquires signals from the node sensing elements. Thus, it controls the conditioning circuit modules associated with ultrasonic transmitter-receiver devices and measures the pulse width from the ultrasonic modules and the voltage delivered by the relative humidity transducer.

The used conditioning scheme (USTR-CC) includes four transmitter channels and four receiver channels that implement the conditioning circuit based on the modified SRF04 ultrasonic ranger. To extract the air velocity, air direction and additionally the air temperature, four pairs of ultrasonic transmitter-receiver ($UT_j, UR_j, j=1..4$) are distributed on the N-S and E-W directions (Figure 1).

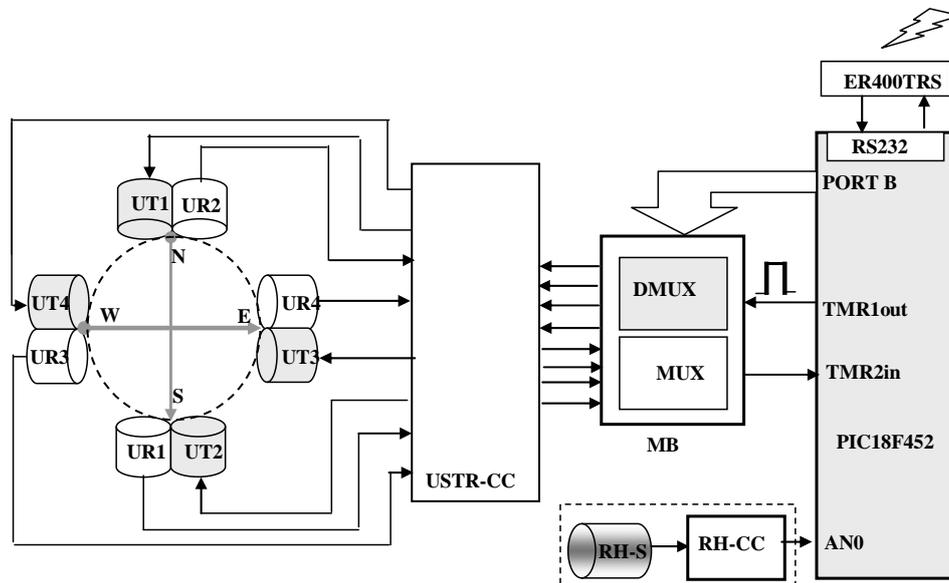


Figure 1. The block diagram of the wireless embedded air multiparameter measuring system node (USTR- ultrasonic transmitter receiver conditioning circuit, RH-S- RH sensor, RH-CC – relative humidity conditioning circuit, TMR1out – timer 1 output, TMR2in – timer 2 input, RH-S – relative humidity capacitive sensor, ER400TRS – radio transceiver, MB –multiplexer block)

Referring to the air flow velocity and air flow direction measurement based on ultrasonic devices, the ultrasonic transmitter (Murata 400ST) burst generation is controlled using trigger pulses ($10\mu\text{s}$ pulse width) obtained at the TMR1out of the microcontroller. The selection of the ultrasonic transmitter channel is made using a demultiplexer scheme based on a dual 4 channel analogue multiplexer (MM74HC4052). The ultrasonic burst pulse is detected by the ultrasonic receiver (Murata 400SR) that is mounted on a circular structure characterized by a diameter $L=25\text{ cm}$. The transmitter and receiver voltage signals ($V_{\text{tan}}, V_{\text{rec}}$) associated with the emitter-receiver S-N, N-S ultrasonic pair are presented in Figure 2. Thus, one can observe that for the particular case of L and for a trigger pulse of $10\mu\text{s}$ (generated by the TMR1out), the echo pulse variation can be obtained and measured by the microcontroller using the TMR2in. For different air flow velocity and direction, the variations of ultrasonic sound propagation are measured by the receiver detected pulse variations. Thus, measuring the receiver pulse width during the air flow velocity measurement procedure the air flow velocity for one direction is obtained. The multiplexing and de-multiplexing scheme is used to obtain the pulse width information from all the ultrasonic transmitter-receiver measuring channels. The

accuracy of the pulse width measurement conditions the accuracy of air flow velocity, air flow direction and air temperature measured values.

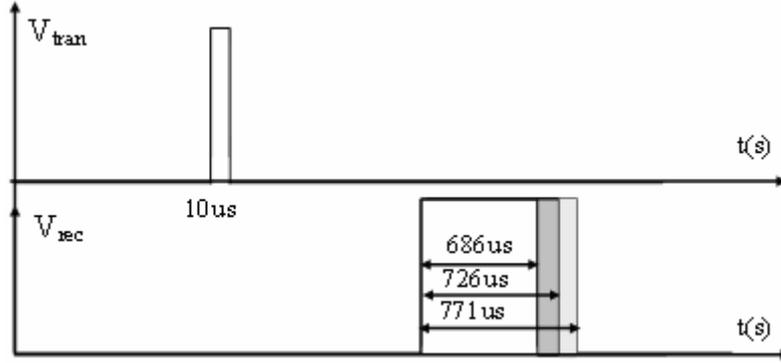


Figure 2. The transmitter pulse (V_{tran}) and receiver response (V_{rec}) for different values of air flow velocity V_{air} (-20 m/s, 0, 20m/s) and for $L=25$ cm. 726 us corresponds to 0 m/s air velocity and to 344 m/s sound velocity at 21°C

For temperature measurement, a virtual measuring channel based on ultrasonic sound velocity measurement is implemented. Comparative estimation of the temperature measurement accuracy based on the implemented technique is performed by adding a temperature sensor to the system. The acquisition of the voltage associated to this temperature sensor is performed by the PIC18F452 AN1 analogue input.

Relative humidity measurement uses a HIH1101 capacitive sensor (about 180pF for 55% relative humidity) and the associated conditioning circuit (RH-CC). The RH-CC includes a RC-oscillator block based on a TLC555 and a frequency to voltage converter based on an AD650.

The air parameters information obtained at the microcontroller level is transmitted to the host PC through a wireless link. Thus, two RS232-wireless bridge (ER400TRS-02) [4] are used to provide point to point data wireless communication for ranges up to 250m. Other characteristics of the used bridges are: 10 user selectable frequencies between 433-434MHz, user selectable power output up to 10mW, user selectable data rate in the [4.8,76.8] kbps interval. The bridge configuration is performed using the EasyRadio configuration software. In the present case 9600 bps and the channel 1 were selected.

B. Software

The software of the wireless embedded air multi-parameter measuring system was developed using CCS C Compiler. It implements the programming of the timers associated with the transmitters, the time width measurement of the received pulses, digital control of the multiplexing device, data acquisition (AN0 and AN1) and RS232 data communication. The data received by the PC is processed using software developed in LabVIEW. The software includes the inverse model of the real and virtual measurement channels, RS232 data communication, data logging and data analysis of the air flow velocity and direction, air temperature and relative humidity.

As already mentioned, the model of air flow velocity and air flow direction is based on time width measurement of the received pulse by the ultrasonic receivers. For the particular case of the N-S ultrasonic transmitter-receiver pairs, the measured received pulse width depends on the transmitter-receiver distance (L), sound velocity and air flow velocity. The times-of-flight (t_{N-S} , t_{S-N}) for N-S direction are given by:

$$\frac{1}{t_{N-S}} = \frac{V_s + V_{airS-N}}{L}, \quad \frac{1}{t_{S-N}} = \frac{V_s - V_{airS-N}}{L} \quad (1)$$

Using the measured times the air velocity in the N-S direction is obtained:

$$V_{airN-S} = \frac{L}{2} \left(\frac{1}{t_{S-N}} - \frac{1}{t_{N-S}} \right) \quad (2)$$

where t_{S-N} and t_{N-S} represent the width of the pulse response for the L distance between the receivers and emitters.

Using the same type of procedure, the air velocity in the E-W direction, V_{airE-W} is obtained. Considering the V_{airE-W} , V_{airN-S} as components of the air velocity, the V_{air} value is calculated using the following relation:

$$V_{air} = \sqrt{V_{airN-S}^2 + V_{airE-W}^2} \quad (3)$$

The air flow direction is given by:

$$\varphi = \tan^{-1} \left(\frac{V_{airE-W}}{V_{airN-S}} \right) \quad (4)$$

Using (1) and (2) the sound velocity in air, V_s , is obtained and used to calculate the temperature based on the following relation:

$$V_s = \left| \frac{L}{2} \left(\frac{1}{t_{N-S}} + \frac{1}{t_{S-N}} \right) \right| \quad T = 1.63 \cdot (V_s - 331.45) \quad (5)$$

A temperature virtual sensing channel is implemented as part of the system software that runs on the host PC. The temperature values, obtained by virtual sensing channel described by (5), are compared in the calibration and testing phase with temperature values measured by the AD590 temperature sensor.

The calculated φ values are expressed on a wind rose implemented by the PC host LabVIEW software. The relative humidity (RH) values are obtained from Humirel HIH1101 capacitive sensor measuring channel. The voltage to RH conversion verifies the relation

$$RH = a_{RH0} + a_{RH1} V_{RH} + a_{RH2} V_{RH}^2 + a_{RH3} \cdot V_{RH}^3 \quad (6)$$

where V_{RH} is expressed in mV and RH in %, $a_{RH0} = -2.16E+01$, $a_{RH1} = 9.56E-3 \text{ V}^{-1}$, $a_{RH2} = 1.33E-05 \text{ V}^{-2}$, $a_{RH3} = -1.91E-09 \text{ V}^{-3}$.

III. Results and Discussions

To evaluate the air flow velocity measurement performance of the system several laboratory tests were carried out. Trigger signals of 10 μ s were generated and the system response, for different values of L , ($L = \{0.25, 0.5, 1\}$ [m]) and different values of air flow velocities ($V_{air} = [1; 20]$ m/s) produced inside a wind tunnel, was measured. For low values of the air flow velocity, the pulse width measurement requires high resolution and accuracy since the variation of the pulse width is then very small. For the present case, considering that the pulse width obtained from the ultrasonic devices is measured using the microcontroller and that its clock only allows a $\Delta t_u = 0.8 \mu$ s time measurement resolution, only values of the air flow velocity higher than 0.3 m/s can be measured. The air flow velocity measuring error for the considered measurement channel is less than 4% for the operational range (20 m/s). Several results are presented in Fig 3.a.

The wind direction was evaluated based on the S-N and E-W wind velocity components. The measurement errors (Fig. 3 b) are smaller than 4° for the considered tests (V_{air} about 5 m/s).

In what concerns the temperature virtual sensing channel, several test were conducted for different values of air temperature inside a oven ($T_{test} = [5; 25]$ °C) for $V_{air} = 0$. A comparison between the measured temperatures using the virtual temperature measurement channel (based on sound velocity measurement) and real temperature measurement channel (based on AD590) was carried out (Figure 4).

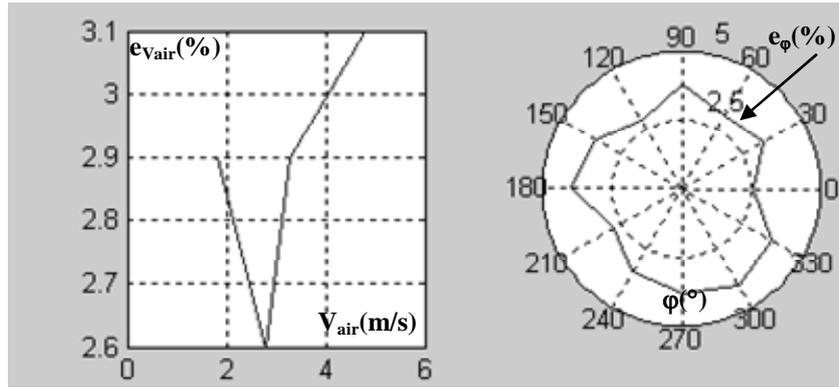


Figure 3. The air flow velocity measurement error ($e_{V_{air}}(\%)$) for $1.8m/s < V_{air} < 5m/s$ and air flow direction measurement error ($e_{\phi}(\%)$) for $V_{air}=5m/s$

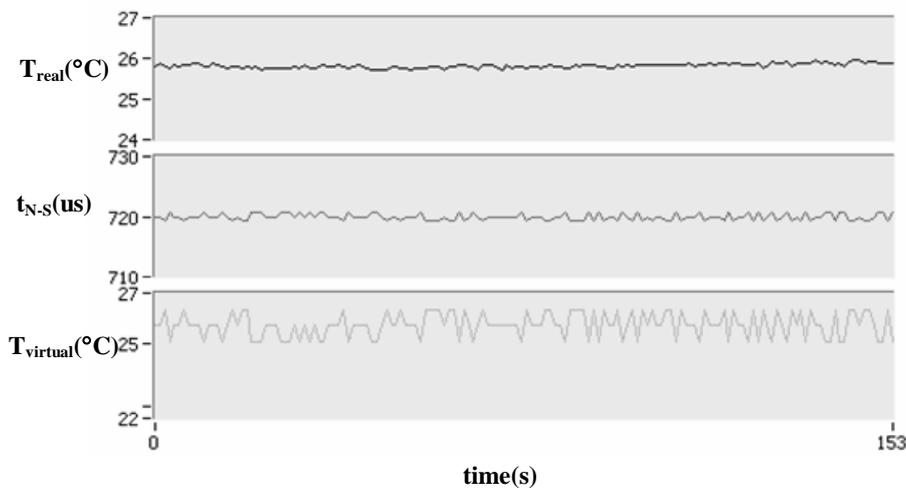


Figure 4. The evolution of real (T_{real}) and virtual ($T_{virtual}$) temperature measurement channels output and the measured time-of-flight (t_{N-s}) associated with virtual measurement channel.

As it can be observed in Figure 4, the temperature estimation error is less than $1^{\circ}C$ taking the values obtained by the real temperature channel as reference values.

The evolution of the relative humidity during the test of the temperature measurement channels is presented in figure 5. The measurement error is lower than 4% of the operational range (10% to 95% relative humidity). To increase the relative humidity measurement accuracy the compensation of temperature drift errors can be implemented using neural network inverse modelling of the relative humidity channels [5][6].

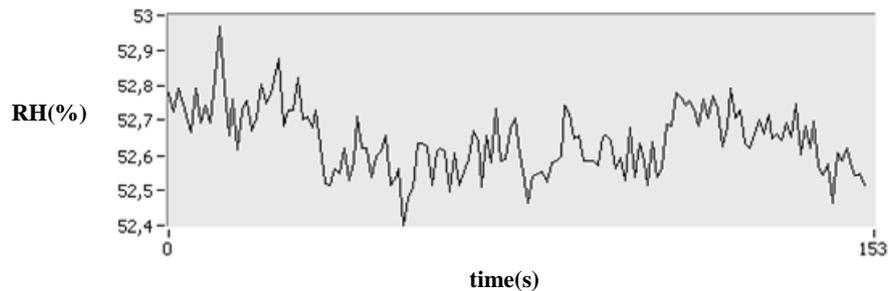


Figure 5. The evolution of relative humidity during the comparative temperature measurement tests

The control and measuring virtual interface (Figure 6) implemented in the host computer was developed in LabVIEW and is characterized by three general classes of functionalities: (a) the RF communication configuration (RS232-RF bridge configuration), (b) Measurement, which corresponds to the measured data display (air flow velocity, air flow direction, air flow temperature, air flow

relative humidity) and (c) Analyze, which includes several statistical parameters such as mean and standard deviation of the air measured parameters, the histogram of air flow direction and a table that permits the visualization of numerical values during parameters logging.

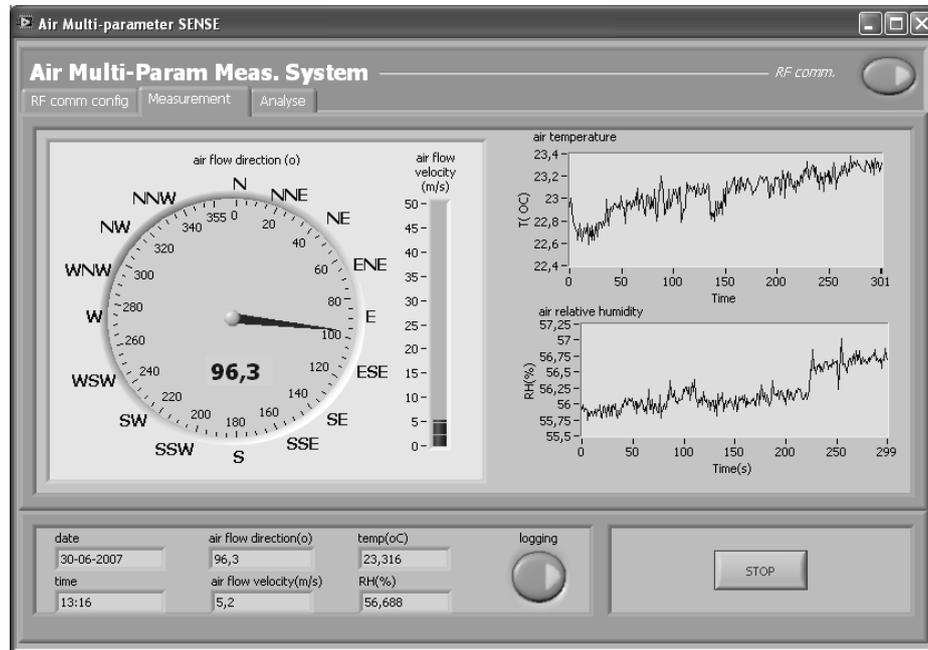


Figure 6. The air multi-parameter measuring system interface

IV. Conclusion

The developed wireless embedded multi-parameter air measuring node designed to integrate a distributed system is characterized by low cost and high reliability since measurements are based on solid state sensors expressed by multiple ultrasonic transmitter-receiver pairs. The main challenge of the work is to measure small variation of the pulse response that expresses the influence of the airflow velocity on the ultrasonic time-of-flight between transmitter and receiver. The triggering of the sonic pulse generation and the pulse width measurement is based on the utilization of two PIC18F452 timers and the ultrasonic transmitter-receiver selection is based on a multiplexer-demultiplexer architecture controlled by the microcontroller digital outputs. Data communication between the microcontroller and the host computer for advanced data processing uses a RS232-wireless bridge. Relative humidity is also measured using a capacitive sensor and a conditioning circuit whose output voltage is acquired using an analogue input of the microcontroller.

Referring to the system metrological performance, the conducted tests indicate values of airflow velocity and temperature measurement accuracy strongly dependent on time measurement but comparable to the accuracy of commercial solutions.

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