

Research on Air density Measurement for measuring weights

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Abstract: According to the CIPM-2007 equation, an equipment of air density measurement that for high accuracy measurement of measuring weights is developed. Measurement of temperature, humidity, pressure and CO₂ are integrated on it to measure air density automatically. The experimental results prove that additional measurement of CO₂ can improve accuracy of air density measurement.

Key words: Air density; Weight; Air buoyancy correction; CIPM-2007 equation

1. Introduction

Measurement of measuring weights will be influenced by air buoyancy when measuring in air. This kind of influence is very important for high accuracy measurement of measuring weights and air buoyancy correction need be processed to reduce it. The major component of air buoyancy correction is the determination of the density of moist air. The air density is commonly determined from the recommended equation of state. CIPM-2007 equation is the newest equation that was endorsed by the International Committee for Weights and Measures (CIPM).

The method that most of measurement inspection institutions and laboratories used is base on approximation formula for air density presented in [1-2]. In this method, both measurements of temperature, relative humidity, pressure and calculation of air density are manual, thus measurement work is complex and deviation of measurement data may be high. Further more, approximation formula for air density can't meet the need of high accuracy measurement of measuring weights because of its low precision. To change this situation, we develop equipment that integrated measurement of temperature, humidity, pressure and CO₂ to determine air density auto automatically according CIPM-2007 equation. In this paper, the designing of equipment and support software is introduced.

2. Air density measurement principle

According CIPM-2007 equation, the density of moist air is evaluated using an equation of state

$$\rho_a = \frac{P \times M_a}{ZRT} \left[1 - x_v \left(1 - \frac{M_v}{M_a} \right) \right] \quad (1)$$

where the quantities and units are P /Pa: pressure, t /°C: air temperature, T /K:

thermodynamic temperature = 273.15 + t /°C, x_v : mole fraction of water vapour, M_a /(g mol⁻¹):

molar mass of dry air, M_v /(g mol⁻¹): molar mass of water, Z : compressibility factor, R /(J mol

$^{-1} \text{K}^{-1}$): molar gas constant.

If a measurement of CO_2 is available, then (2) should be used to improve the estimate of the molar mass of dry air[3]:

$$M_a = [28.96546 + 12.011 \cdot (x_{\text{CO}_2} - 0.0004)] \cdot 10^{-3} \text{kg mol}^{-1} \quad (2)$$

where x_{CO_2} is mole fraction of carbon dioxide.

x_v is evaluated using (3):

$$x_v = hf(p, t) \cdot \frac{p_{sv}(t)}{p} \quad (3)$$

where h is the relative humidity and has the following range: $0 \leq h \leq 1$. For example, an

instrumental relative humidity reading of '53%' is expressed as $h = 0.53$. And f is enhance

factor, p_{sv} is vapour pressure at saturation. (4) and (5) can be used to evaluate f and p_{sv} :

$$p_{sv} = \exp(AT^2 + BT + C + D/T) \quad (4)$$

$$f = \alpha + \beta p + \gamma t^2 \quad (5)$$

where $A, B, C, D, \alpha, \beta, \gamma$ are constant, t is air temperature, T is thermodynamic temperature.

The equation for Z is (6):

$$Z = 1 - \frac{P}{T} \cdot [a_0 + a_1 t + a_2 t^2 + (b_0 + b_1 t)x_v + (c_0 + c_1 t)x_v^2] + \frac{P^2}{T^2} \cdot (d + ex_v^2) \quad (6)$$

where $a_0, a_1, a_2, b_0, b_1, c_0, c_1, d, e$ are constant.

Through equations listed above, we can know that to improve the determination of the air density, four environment parameters, temperature, humidity, pressure and CO_2 , need be measured. Thus we design equipment of air density base on measurement of these four environment parameters.

3. Designing of air density measurement equipment

3.1 Design Structure

Figure 1 shows the design structure of the air density measurement equipment. Measurement of temperature, humidity, pressure and CO_2 are assembled in equipment, all measurement data is sent to module of data processing, and then air density is calculated with these data according to CIPM-2007 equation.

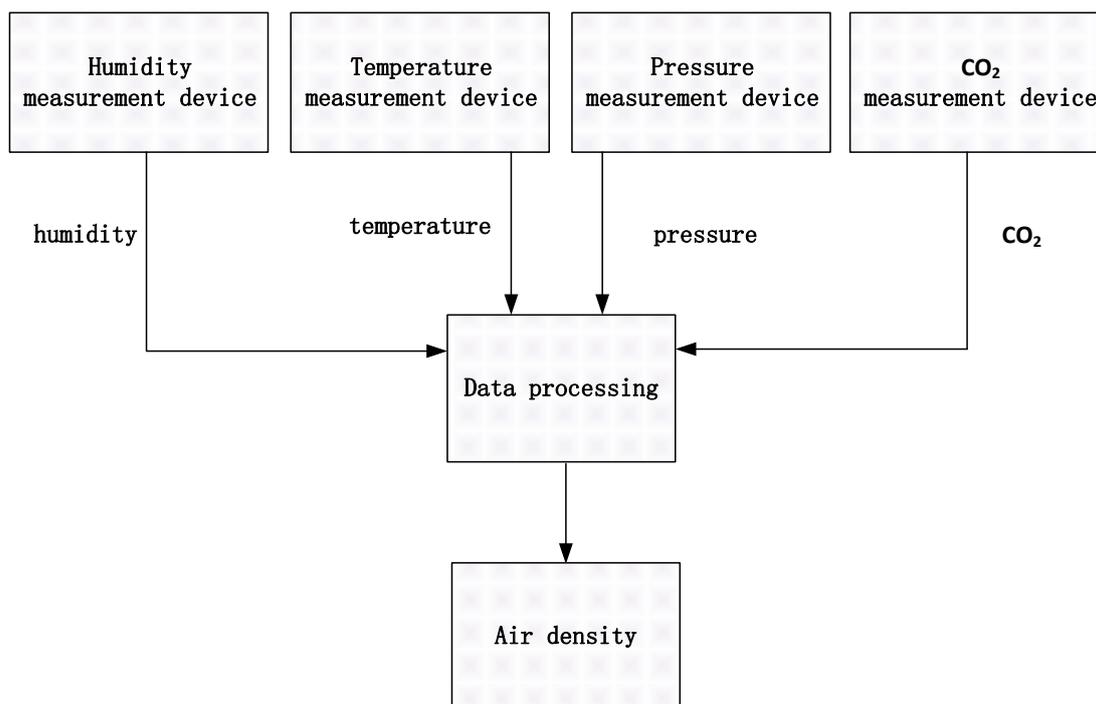


Figure 1. Design structure of equipment

3.2 Hardware and Software designing

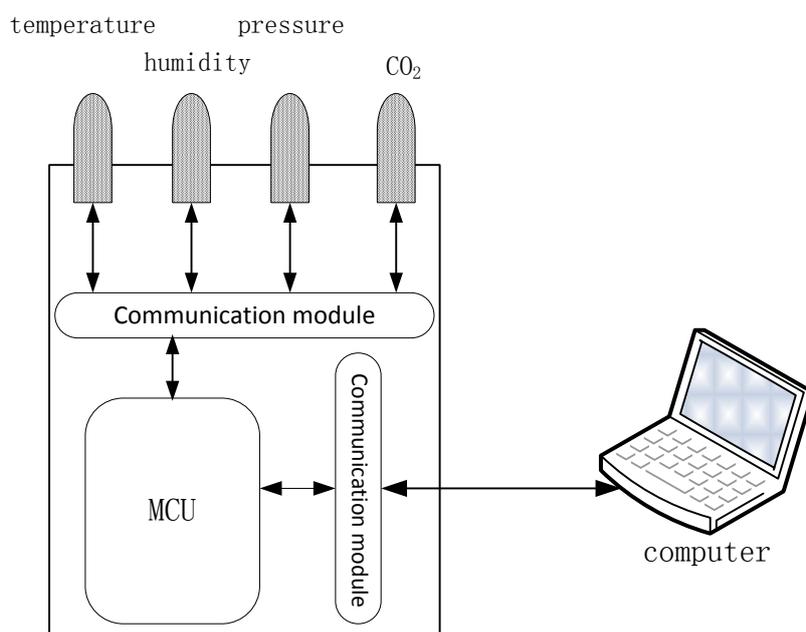


Figure 2. Equipment module structure

Figure 2 shows the structure of the equipment hardware module. Four corresponding sensors take on measurement of environment parameters (temperature, humidity, pressure and CO₂). Communication module is used to control communication between sensors and MCU or MCU and computer. MCU handles collection of measurement signals and calculation of air density. All of these devices are installed in a box which has small size for carrying and using conveniently. More functions can be used through connect with computer.

Software designing includes two parts: software in MCU and application software installed in

computer. Figure 3 shows the MCU program flow chart. Software codes design and optimize base on this flow chart. To make up for lack of SCM functionality, application software installed in computer is developed.

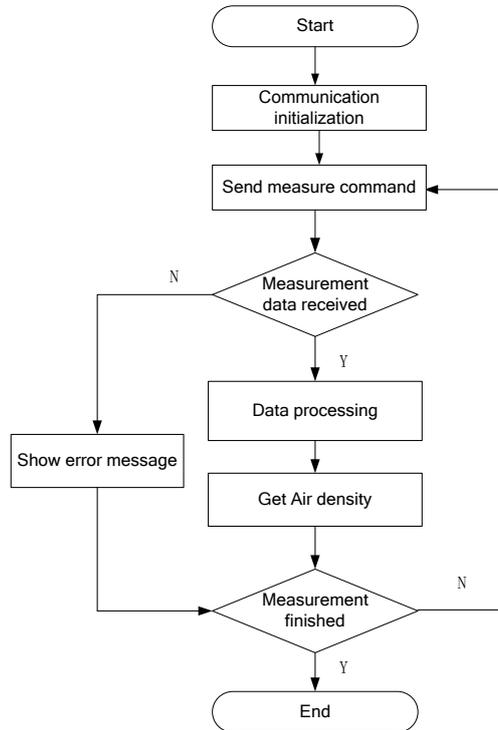


Figure 3. MCU program flow chart

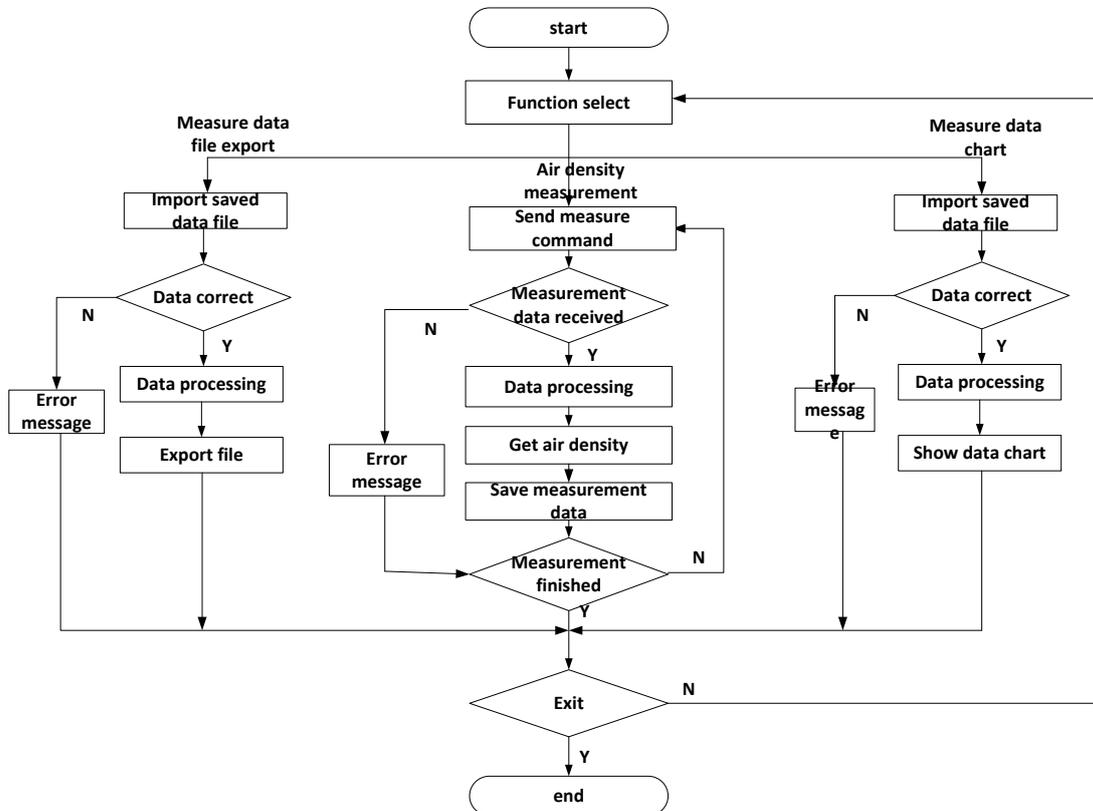


Figure 4. Application software program flow chart

Application software extends the capabilities of equipment. It provides higher accuracy of floating-point calculation and measurement data storage service in long time. User can export data stored to XLS format for using easily. Data stored also can be loaded to create analysis chart to support user's study. Figure 5 shows the main interface of application software, every function can be found on here. Interface of data analysis chart is shown in Figure 6, analysis chart can be

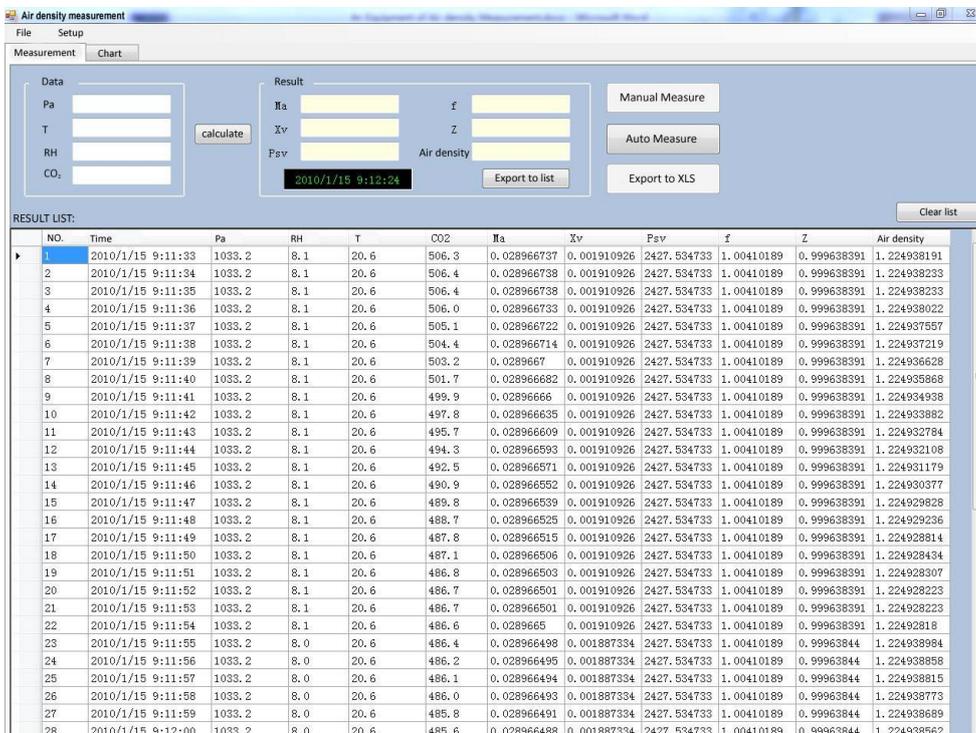


Figure 5. Application software main interface



Figure 6. Application software program flow chart

exported to JPEG format for printing.

4. Experimental Analysis

An experiment using this equipment connected with computer has been made in an air-conditioned room at 2010/3/24 12:00 to 14:00. The results of measurement of CO₂ are shown in Figure 7. The content of CO₂ generally remained at around 400ppm from 12:00 to 12:40. From 12:40 it increased rapidly and reached its peak of 937ppm at 13:32, then began to decline slowly. The reason of CO₂ changed is that one worker went into the room at 12:40 and left at 13:32, the breath of worker increase the content of CO₂ in the room. Figure 8 shows the change of air density in same period. Two curves represent the air density which calculated by CIPM-2007 equation and approximation formula for air density. From 2 charts we can know that, the influence of CO₂ for air density is neglected by approximation formula. And 10 group measurement data and comparisons are given in Table 1. These experiment results prove that we can obtain a more accurate air density by using CIPM-2007 equation than approximation formula.

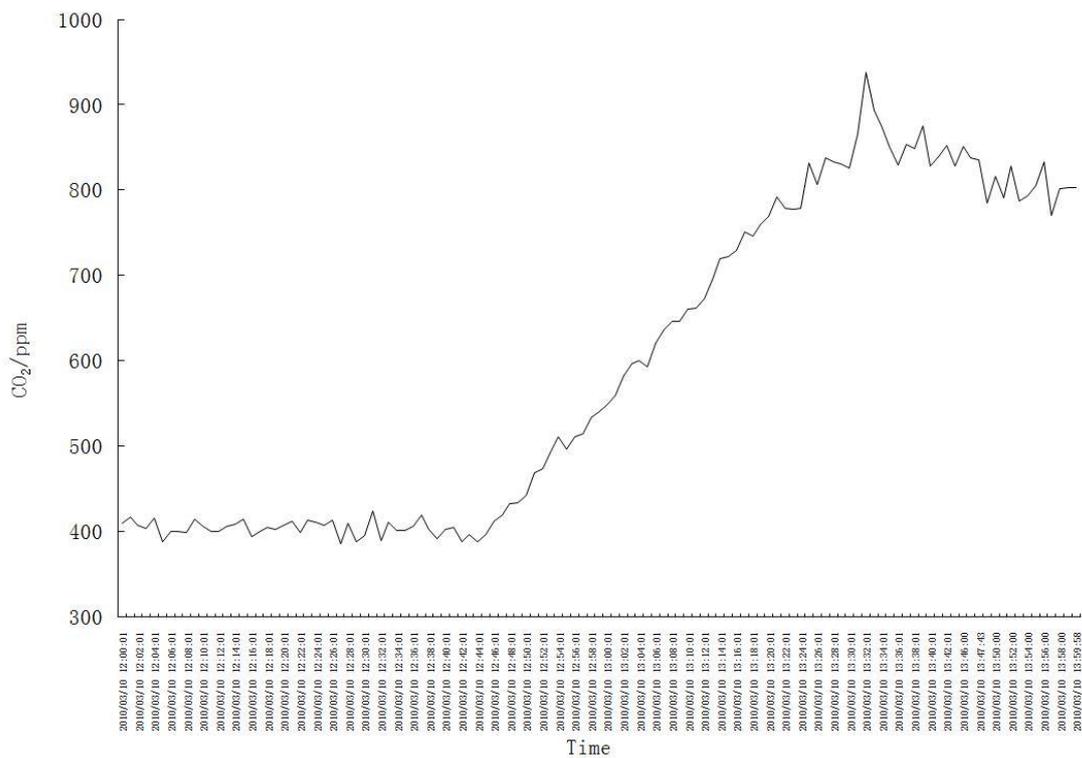


Figure 7. Measurement data of CO₂

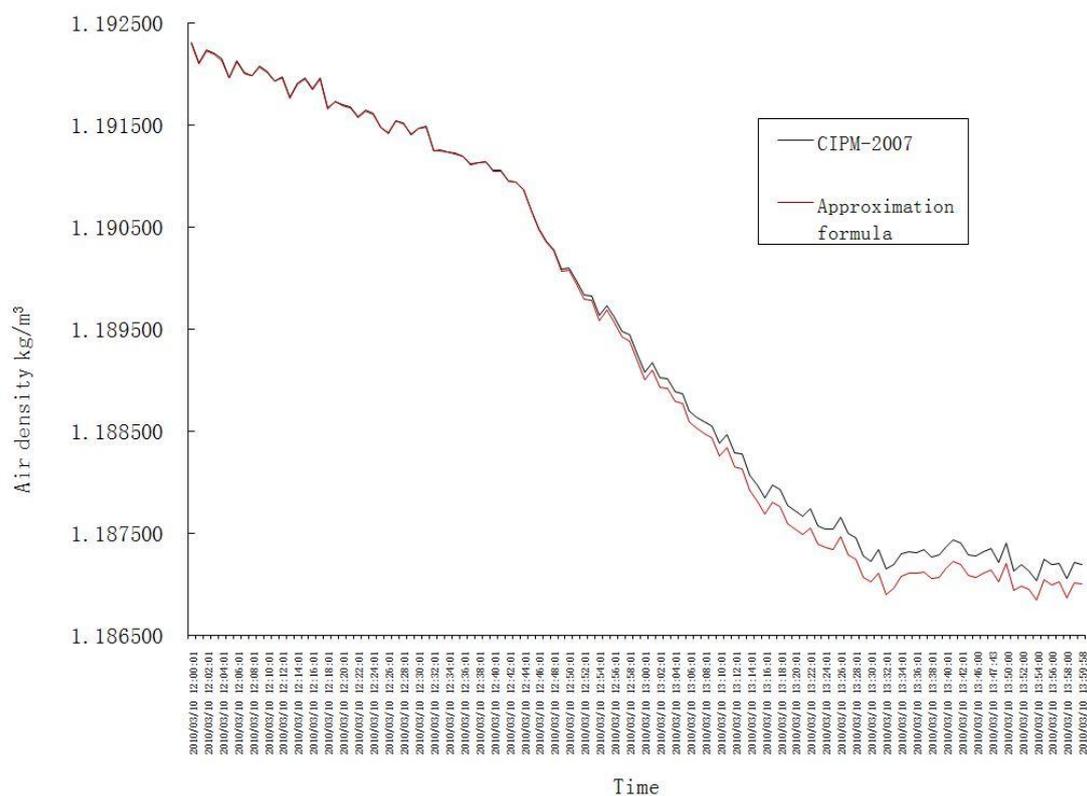


Figure 8. Measurement data of air density

Table 1. Data comparison

t (°C)	RH(%)	Pa (hPa)	CO ₂	Air density (kg/m ³)		Relative error (%)
				approximation formula	CIPM-2007 equation	
21.23	42.48	1006.800	858.5	1.187084	1.187302	0.018
21.23	42.49	1006.796	860.6	1.187078	1.187297	0.018
21.23	42.46	1006.824	865.0	1.187115	1.187336	0.019
21.25	42.43	1006.801	870.2	1.187004	1.187228	0.019
21.26	42.39	1006.801	877.9	1.186966	1.187193	0.019
21.23	42.37	1006.802	886.8	1.187099	1.187331	0.020
21.25	42.38	1006.797	893.7	1.187005	1.187240	0.020
21.25	42.38	1006.797	901.0	1.187005	1.187244	0.020
21.21	42.37	1006.794	906.8	1.187176	1.187418	0.020
21.25	42.45	1006.713	937.4	1.186897	1.187154	0.022

5. Conclusions

The equipment of air density measurement introduced in this paper has good features: small size, portable and high accuracy. Furthermore, it can support user's research work by using application software. For high accuracy measurement of measuring weights, the method that using CIPM-2007 equation to determining air density is a better choice.

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