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Research Article

A Method to Measure Humidity Based on Dry-Bulb and Wet-Bulb Temperatures

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Abstract: This study tries to analyze the theory of measuring humidity based on dry-bulb and wet-bulb temperatures. And a theoretical formula is deduced for the calculation of relative humidity from dry-bulb and wet-bulb temperatures. Through analysis of the theoretical formula, a two-dimensional conversion table is produced to transform dry-bulb and wet-bulb temperatures into relative humidity. A method is proposed to obtain humidity by combining searching table and linear smoothing algorithm, which is suitable for rapid control. Error analysis and experimental data indicate that the relative error is less than 4%. The proposed method has certain value for humidity control in industrial control process.

Keywords: Dry-and-wet bulb equation, dry-bulb and wet-bulb temperatures, linear smoothing, relative humidity

INTRODUCTION

The air Relative Humidity (Hr) is an important control parameter in the wood drying process. There are several different methods to measure the relative humidity, such as electronic humidity sensor hygrometry, paper hygrometry and psychrometric hygrometry. The maintenance of psychrometric hygrometry is simple. In practical use, we just periodically add water to wet bulb and replace the gauze of wet bulb. Compared with electronic humidity sensor hygrometry and paper hygrometry, psychrometric hygrometry will not produce the problems of aging and decline in accuracy. Therefore, psychrometric hygrometry is more suitable for measuring humidity in the harsh environment (Zelin *et al*., 2010).

Traditional psychrometric hygrometry requires searching the saturation vapor pressure table. There are hundreds of thousands of data in the table. It is a huge workload to store the table in the microcontroller and the memory capacity is also not allowed. Therefore the table is not suitable for embedded applications (Xiaoyin and Liangen, 2003). A more efficient method of searching table and smooth transformation to calculate the air relative humidity is proposed based on the theoretical dry-and-wet bulb equation. And the proposed method is suitable for humidity control in industrial control process.

CALCULATION OF RELATIVE HUMIDITY FROM DRY-BULB AND WET-BULB TEMPERATURES

The principle of psychrometric hygrometry is that the humidity is calculated by the dry-and-wet bulb equation according to dry-bulb and wet-bulb temperatures (Zelin *et al*., 2010). The dry-and-wet bulb equation (Jun, 2008) is:

$$Hr = \frac{e_w - A * P * \Delta t}{e_d} \times 100 \quad (1)$$

where,

- Hr = The relative humidity
- e_w = The saturation vapor pressure in the wet-bulb temperature
- e_d = The saturation vapor pressure in the dry-bulb temperature
- A = The measuring humidity coefficient
- P = The mean atmospheric pressure
- Δt = The difference between the dry-bulb temperature and the wet-bulb temperature (assumed to be T_d - T_w)

According to formula (1), we can note that: The keys to getting relative humidity are e_w, e_d and A.

In this study, we use the Buck formula (Buck, 1981) to calculate e_w and e_d. Compared with the

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Table 1: Conversion table of dry-bulb and wet-bulb temperatures to relative humidity

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
20	91	82	74	66	58	51	44	37	30	24	17	11	5	0	0	0	0	0	0	0
25	92	84	77	70	63	56	50	44	38	32	27	22	16	11	7	2	0	0	0	0
30	93	86	79	73	67	61	55	49	44	39	34	29	25	20	16	12	8	4	1	0
35	93	87	81	75	69	64	59	54	49	44	40	35	31	27	23	20	16	13	9	6
40	94	88	82	77	71	66	62	57	52	48	44	40	36	32	29	26	22	19	16	13
45	94	89	83	78	73	69	64	60	55	51	47	44	40	37	33	30	27	24	21	19
50	95	89	84	79	75	70	66	62	58	54	50	47	43	40	37	34	31	28	26	23
55	95	90	85	80	76	72	68	64	60	56	53	49	46	43	40	37	34	32	29	27
60	95	90	86	81	77	73	69	65	62	58	55	52	49	46	43	40	37	35	32	30
65	95	91	86	82	78	74	70	67	63	60	57	54	51	48	45	42	40	37	35	33
70	95	91	87	83	79	75	72	68	65	61	58	55	52	50	47	44	42	39	37	35
75	96	91	87	84	80	76	73	69	66	63	60	57	54	51	49	46	44	41	39	37
80	96	92	88	84	80	77	74	70	67	64	61	58	55	53	50	48	45	43	41	39
85	96	92	88	85	81	78	74	71	68	65	62	60	57	54	52	49	47	45	43	40
90	96	92	89	85	82	78	75	72	69	66	63	61	58	56	53	51	48	46	44	42
95	96	93	89	86	82	79	76	73	70	67	64	62	59	57	54	52	50	48	46	43
100	96	93	89	86	83	80	77	74	71	68	65	63	60	58	56	53	51	49	47	45

saturation vapor pressure formula which is proposed by Coff in 1965 (Xihua *et al*., 2003; Smithsonian, 1984), the Buck formula is simpler and easier. The Buck formula is as follows:

$$E = 6.112 * e^{\frac{17.502*t}{240.97+t}} \tag{2}$$

According to formula (2), we can get e_w and e_d. They are:

$$e_w = 6.112 * e^{\frac{17.502*T_w}{240.97+T_w}} \tag{3}$$

$$e_d = 6.112 * e^{\frac{17.502*T_d}{240.97+T_d}} \tag{4}$$

A is the conversion factor which can be calculated by empirical formula (Butler and García-Suárez, 2012):

$$A = 0.00066*(1+0.00115*T_w) \tag{5}$$

When P is the mean atmospheric pressure (assumed to be 1013.25024 mb), substituting formulas (3), (4) and (5) into formula (1), we have:

$$Hr = \frac{6.112*e^{\frac{17.502*T_w}{240.97+T_w}} - 0.00066*(1+0.00115*T_w)*P*(T_d\text{-}T_w)}{6.112*e^{\frac{17.502*T_d}{240.97+T_d}}}*100$$
$$= \frac{611.2*e^{\frac{17.502*T_w}{240.97+T_w}} - 66.8745*(1+0.00115*T_w)(T_d\text{-}T_w)}{6.112*e^{\frac{17.502*T_d}{240.97+T_d}}} \tag{6}$$

As shown in formula (6), we note that: the Relative Humidity (Hr) depends on both the dry-bulb and wet-bulb temperatures (T_d and T_w). However, formula (6) is so complex to calculate humidity that isn't suitable for embedded applications which are limited in resources.

According to formula (6), we get a two-dimensional table which transforms dry-bulb and wet-bulb temperatures into relative humidity while the dry-bulb temperature (T_d) is assumed to be 20, 25, 30…95, 100 and the difference between the dry-bulb temperature and wet-bulb temperature (Δt) is assumed to be 1, 2, 3 …39, 40. Parts of data are shown in Table 1 and the row of Table 1 is T_d and the column of Table 1 is Δt.

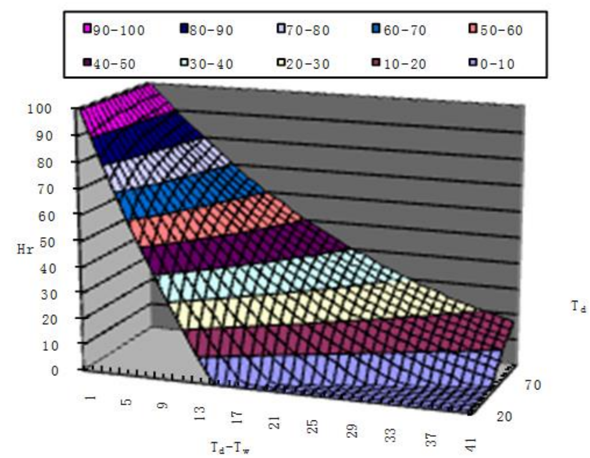

Fig. 1: Calculated data distribution diagram

Figure 1 is the surface chart generated by Table 1. As shown in Fig. 1, we note that the surface has a smooth trend.

SEARCHING TABLE AND SMOOTH TRANSFORMATION

In Table 1, for the dry-bulb temperatures (T_d) in the data table, such as 20, 25, 30 and so on, we can obtain their humidity data directly.

However, for T_d not in the data table, their humidity can be obtained by linear smoothing. The first thing is to find the upper and lower limits of the neighboring segment of T_d. Then, we look up the table to find the humidity values of the upper and lower limits. At last, we linearly smooth the two humidity values to get the humidity value of T_d.

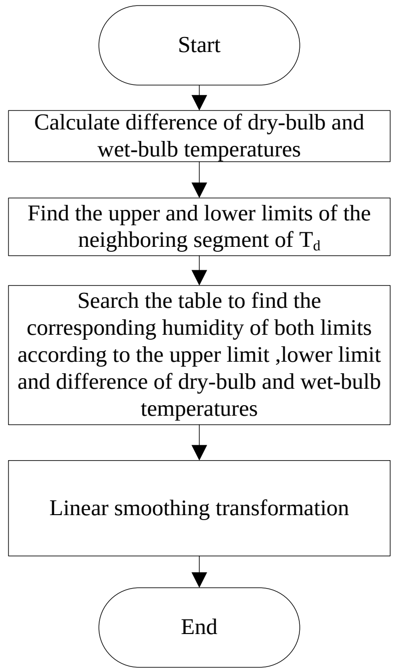

Fig. 1: Flow chart of searching table and smooth transformation

For example, when T_d is 53 and T_w is 41, we find: T_{dl} is 50 and T_{dh} is 55. Because the difference between T_d and T_w is 12, we note: Hr_l is 47, Hr_h is 49. Then we have:

$$\frac{Hr_h - Hr_l}{T_{dh} - T_{dl}} = \frac{Hr - Hr_l}{T_d - T_{dl}} \tag{7}$$

Then note that:

$$\begin{aligned} Hr &= Hr_l + \frac{Hr_h - Hr_l}{T_{dh} - T_{dl}} * (T_d - T_{dl}) \\ &= 47+(49-47)*(53-50)/(55-50) \\ &\approx 48 \end{aligned} \tag{8}$$

Based on the above ideas, the flow chart of searching table and smooth transformation is shown in Fig. 2.

COMPARISON OF THEORETICAL VALUES AND LINEAR SMOOTH VALUES

The essence of the calculation method is that, when the conversion table obtained from the theoretical formula is as reference data, we search the reference data to find two humidity values according to the dry-bulb and wet-bulb temperatures and linearly smooth the two values to obtain the humidity value of T_d. As shown in Table 2, we randomly calculate ten values of Hr and compare with theoretical values obtained from manual look-up table (Environmental Standards Committee Working Group, 1986).

Table 2: Comparison of theoretical values and linear smooth values

		Relative humidity (%)		
Dry-bulb temperature (°C)	Wet-bulb temperature (°C)	Theoretical values	Linear smooth values	Relative error (%)
20	15	58.8	58.0	1.4
36	21	25.1	24.2	3.6
45	29	30.7	30.0	2.3
58	44	45.0	44.8	0.4
60	58	90.4	90.0	0.6
72	62	62.4	61.8	0.9
85	77	71.6	71.0	0.8
91	84	75.7	75.4	0.4
98	87	65.5	64.6	1.4
100	87	60.8	60.0	1.3

According to Table 2, we note that, the maximum relative error between the linear smooth values and the theoretical values is 3.6%. For the error analysis theory, we know that, the absolute error of total synthesis function is equal to the algebraic sum of the product of the absolute error of each part and the partial derivative of each part. The absolute error of T_d and T_w is assumed to be ΔT_d and ΔT_w. The relative error of Hr is assumed to be $\Delta Hr/Hr$, so we have:

$$\frac{\Delta Hr}{Hr} = \frac{1}{Hr} * \left|\frac{\partial Hr}{\partial T_d}\right|_{T_w} * \Delta T_d + \frac{1}{Hr} * \left|\frac{\partial Hr}{\partial T_w}\right|_{T_d} * \Delta T_w \tag{9}$$

Calculated by formula (9), the relative error of Hr is less than 4%. The method is suitable for engineering calculations with high accuracy.

In point of computing speed, searching table is faster than theoretical formula. And the linear smoothing algorithm is also fast and the algorithm time complexity is only O (n). In this study, we use a combination of searching table and linear smoothing algorithms, which is very suitable for embedded applications with limited resources.

Through of analysis of error and computing speed, the proposed method has certain value for humidity control in industrial control process.

CONCLUSION

This study tries to analyze the theory of measuring humidity based on dry-bulb and wet-bulb temperatures. And a theoretical formula is deduced for the calculation of relative humidity from dry-bulb and wet-bulb temperatures on the basis of accurately determining the empirical formulas of measuring humidity coefficient and saturation vapor pressure. A conversion table is produced according to the theoretical formula. A method is proposed to obtain humidity by combining searching table and linear smoothing algorithm, which is suitable for rapid control. Experimental data shows that, compared with the traditional manual searching table, the proposed method is not only simple and fast but also has high veracity. And its relative error is less than 4%. Therefore, the proposed method has certain value for humidity control in industrial control process.

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