Method for changing brightness temperature into true temperature based on twice recognition method

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The channel output of a multi-wavelength pyrometer is the brightness temperature rather than the true temperature. Twice recognition method is put forward to change the brightness temperatures of a multi-wavelength pyrometer into the true temperatures of targets. Using the data offered by Dr. F. Righini, the experimental results show that the difference between the calculated true temperature based on twice recognition method and the real true temperature is within ±20 K. The method presented in this paper is feasible and effective for the true temperature measurement of targets.

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The multi-spectral thermometry for the measurement of the true temperature of high- and ultrahigh-temperature targets and the dynamic measurement of thermalphysical properties has been researched by European and North American countries since 1980s[1,2]. European Commission developed a 6-wavelength pyrometer with the optic fiber for the beam splitting. National Institute of Standard and Technology of America (NIST) developed a 6-wavelength pyrometer with the interference filter for the wavelength restricting[3,4]. Harbin Institute of Technology developed a 35-wavelength pyrometer with the aberration compensation and focal plane in 1990s[5]. The 35-wavelength pyrometer overcomes the defect that the wavelength is restricted by the interference filter in many multi-wavelength pyrometers, which is a great progress in the research of multi-wavelength pyrometer.

How to change the brightness temperature into the true temperature with the multi-wavelength pyrometer is still a problem in the field of radiation thermometry[6,7]. We propose a method based on neural network twice recognition. The experimental results illustrate that the method is feasible and the true temperature of targets can be obtained accurately with the method.

If a multi-wavelength pyrometer has n channels, according to the Wien approximation, the relationship between the brightness temperature T_i at the ith channel and the true temperature T can be expressed as

$$\frac{1}{T} - \frac{1}{T_i} = \frac{\lambda_i}{c_2} \ln \varepsilon(\lambda_i, T), \quad (1)$$

where λ_i is the effective wavelength of the ith channel, $\varepsilon(\lambda_i, T)$ is the spectral emissivity[8], C_2 is the second Plank constant (14387.9 μm·K).

Equation (1) shows the true temperature as a function of T_i and $\varepsilon(\lambda_i, T)$, and there is a nonlinear mapping relation between T_i and T. The neural network can approximate any continuous nonlinear function to an arbitrary accuracy. So the back propagation (BP) neural network is applied to solve the problem of nonlinear mapping between T_i and T. The process of the BP network presently used is as follows.

When an m-layer network is provided, the ith node of the kth layer is designated as U_i^k, the input of U_i^k as I_i^k, and the output as O_i^k. The function between input and output is f, that is, $O_i^k = f(I_i^k)$. The weight from U_i^k to U_j^{k+1} is $W_{i,j}^{k,k+1}$. According to the input model P, if the jth node's true output of the output layer M is O_j^M, but the expected output is Y_j, the square error function can be defined as[9,10]

$$E_{\mathrm{p}} = \frac{1}{2} \sum_j (Y_j - O_j^M)^2. \quad (2)$$

Introducing the gradient drop method to reduce the error E_{p}, the correction $\Delta W_{i,j}^{k-1,k}$ of $W_{i,j}^{k-1,k}$ is[11]

$$\Delta W_{i,j}^{k-1,k} = -\varepsilon \frac{\partial E_{\mathrm{p}}}{\partial W_{i,j}^{k-1,k}}, \quad (3)$$

where ε is the correcting coefficient, $\varepsilon > 0$.

After rearranging, $\Delta W_{i,j}^{k-1,k}$ is rewritten as

$$\Delta W_{i,j}^{k-1,k} = -\varepsilon d_j^k O_i^{k-1}, \quad (4)$$

where

$$d_j^k = \begin{cases} (O_j^m - Y_j) \cdot f'(I_j^m), & k = m; \\ f'(I_j^k) \cdot \sum_l W_{j,l}^{k,k+1} \cdot d_l^{k+1}, & k \neq m, \end{cases} \quad (k = m-1, \cdots, 2).$$

The diagram of twice recognition method is shown in Fig. 1. We assume five forms of emissivity behaviors as shown in Fig. 2. The radicle network is trained by all forms of emissivity samples, and the sub-network is

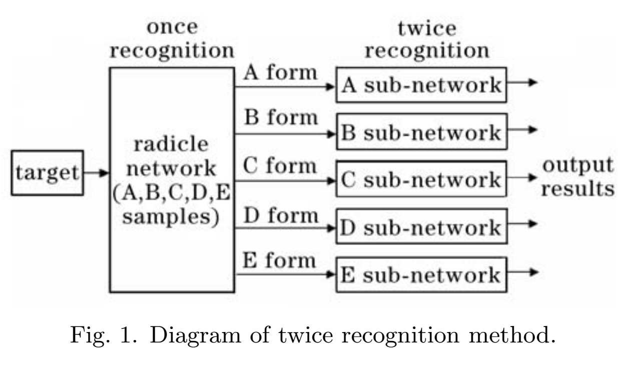

Fig. 1. Diagram of twice recognition method.

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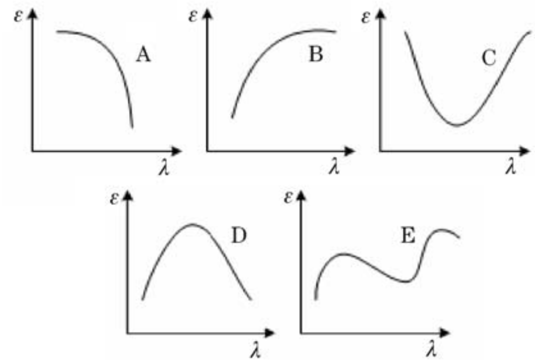

Fig. 2. Five emissivity samples.

trained by each form of emissivity samples respectively. After once recognition, the function relation between the spectral emissivity and wavelength is obtained. Then the true temperature is obtained by the corresponding sub-network after twice recognition, which can improve the recognition precision of true temperature.

We used the experimental data offered by Dr. F. Righini (NR Istituto di Metrologia "G Colonnetti" (IMGC)), as listed in Table 1. The experimental data 1 was used as an example to introduce how to calculate the true temperature by twice recognition method. The calculation process of experimental data 2, 3, and 4 was the same as that of the experimental data 1, but the wavelength used was different.

For the radicle network, the trained temperature is in the range of 1200 – 3200 K, and the temperature interval is 25 K. At each temperature, the five forms

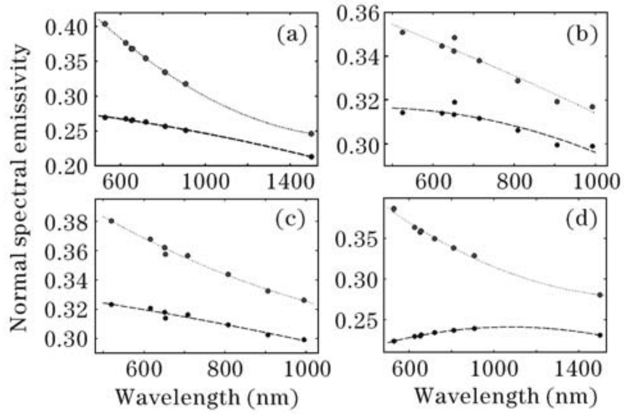

Fig. 3. Comparison between once recognition results (dashed lines) and true spectral emissivities offered by Dr. Righini (dotted lines). (a)—(d) are for the experimental data 1 – 4, respectively.

of emissivity samples are used, and each form includes 25 emissivity sets of values to train the radicle network, so the total number of emissivity samples in the radicle network is 125. The topological structure is 8-4-4-1. After 15000 repetitions, the once recognition results of true temperature are obtained, as shown in Table 2, and the once recognition results of spectral emissivity are shown in Fig. 3. From Fig. 3, the relation between the spectral emissivity and wavelength in all the four sets of experimental data belongs to A form in Fig. 2 entirely, so all the four sets of experimental data are trained by the A sub-network again. For the A sub-network, the number of emissivity samples is 125 at each temperature point, and the topological structure is 8-4-4-1. The other sub-

Table 1. Experimental Data

Data 1		Data 2		Data 3		Data 4	
Wavelength (nm)	Brightness Temperature (K)	Wavelength (nm)	Brightness Temperature (K)	Wavelength (nm)	Brightness Temperature (K)	Wavelength (nm)	Brightness Temperature (K)
529	1722.9	525	2030.2	520	2942.8	529	1703.0
626	1696.1	622	1998.4	616	2876.3	627	1677.1
653	1687.9	652	1988.4	651	2850.6	653	1669.9
657	1687.2	653	1991.3	653	2844.7	657	1669.6
720	1669.4	714	1967.8	708	2812.4	721	1653.3
811	1642.5	809	1934.7	808	2742.1	811	1630.5
908	1614.4	906	1900.4	906	2674.5	908	1606.7
1500	1443.5	993	1874.1	996	2619.2	1500	1461.1

Table 2. Calculated Results and the True Temperatures

	Data 1	Data 2	Data 3	Data 4
True Temperature (K)	1828.0	2201.0	3280.0	1811.0
Once Recognition Results (K)	1879.0	2220.6	3344.6	1879.3
Once Recognition Absolute Error (K)	51.0	19.6	64.6	68.3
Once Recognition Relative Error	2.80%	0.90%	2.00%	3.80%
Twice Recognition Results (K)	1814.6	2218.5	3292.6	1806.8
Twice Recognition Absolute Error (K)	−13.4	17.5	12.6	−4.2
Twice Recognition Relative Error	−0.73%	0.80%	0.38%	−0.23%

network is trained by the samples correspondingly with the same method. After 15000 repetitions, the twice recognition results of true temperature are obtained, as also shown in Table 2.

We can draw the following conclusions from Table 2. 1) According to the once recognition results, the radicle network recognizes the function relation between the spectral emissivity and wavelength automatically. 2) According to the twice recognition results, recognition precision of true temperature is improved, and the difference between the calculated true temperature based on twice recognition method and the real true temperature is within ±20 K.

The experimental results will not be changed obviously with different net topological structure. Decreasing the training temperature range and interval, the precision will be increased, but the lowest resolution interval is difficult within 3 K for the present net structure. The neural network is a new method able to give the true temperature and spectral emissivity without any assumption of relationship between emissivity and wavelength. The method based on twice recognition can improve the measurement precision of true temperature, and has the advantages of simplicity and practicality.

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