Retrieving Land surface Component Temperature Using Multi-Angle Thermal Infrared Data

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Abstract: As non-isothermal mixed pixel is widely existed, the pixel-mean temperature cannot adequately represent the actual thermal state of land surface. The row crop was chosen as target to discuss the problem of component temperature retrieval. At first, the matrix model was found to express the thermal radiant directionality of the target. Then correlation of multi-angle infrared radiance was analyzed. In order to increase the retrieving accuracy, we chose the retrievable parameters and established the iterative method combining with inverse matrix to retrieve component temperature. It was proved by field experiment that the method could improve the retrieving accuracy and stability remarkably.

Keywords: Components temperature, Multi-angle, Retrieving

1. Introduction

Land surface temperature (LST) is an important parameter in the study of energy balance or exchange over land surface. But natural land surface is usually heterogeneous and non-isothermal mixed pixel; the pix-mean temperature cannot adequately represent the actual thermal state of the land surface. If component temperature is input, many applications can get better result than before. If the emissivity or temperature of components is obviously different, the component temperature can be retrieved by the multi-angle radiance data. In this paper we choose the row crop as the example to discuss the problem of component retrieval in detail.

We find a matrix formula $\overline{\mathbf{L}}_{\lambda}(\theta_{\mathbf{k}}) = (\mathbf{w}_{\mathbf{k},\mathbf{j}})\overline{\mathbf{L}}_{\mathbf{b}\lambda}(\mathbf{T}_{\mathbf{j}})$ [1], which can completely express the thermal radiant directionality and structural characteristics of the inhomogeneous non-isothermal target with complicated inner geometric structure. Here $\overline{\mathbf{L}}_{\lambda}(\theta_{\mathbf{k}})$ means the measured radiance of view angle of θ_k, $\overline{\mathbf{L}}_{\mathbf{b}\lambda}(\mathbf{T}_{\mathbf{j}})$ means the radiance of black body of component's temperature T_j, $(\mathbf{w}_{\mathbf{k},\mathbf{j}})$ is a matrix with K x J dimensions which is a function of emissivity and area ratio of components within field of view of sensor. So the component temperature can be retrieved by inverse matrix $(\mathbf{w}_{\mathbf{k},\mathbf{j}})^{-1}$, but influenced by many factors, the retrieving result was unsteady.

2. The Correlation of the $(\mathbf{w}_{\mathbf{k},\mathbf{j}})$

We choose the row crop as target to discuss the correlation of matrix $(\mathbf{w}_{\mathbf{k},\mathbf{j}})$ in detail. Fig.1 shows the sectional drawing of row winter wheat. Here the swath W=40cm,t he distance between swath D=40cm, and the height of crop H=60cm. The matrix model of row crop has five independent components. They are three vegetative canopy temperatures from button to the top

(Tv1, Tv2 and Tv3), the lighted soil surface temperature (Tsl) and the shadowed soil surface temperature (Tss). Let the leave angle distribution (LAD) is spherical, the zenith of the sun $\theta_i = 30°$, the emissivity of soil surface $\varepsilon_s = 0.95$, the emissivity of canopy surface $\varepsilon_v = 0.98$, the zenith of the view angle (θ) varied from 0° to 90°, the bi-directional gap probability of the row winter wheat and $(\mathbf{w}_{\mathbf{k},\mathbf{j}})$ is calculated by Monte-Carlo simulation.

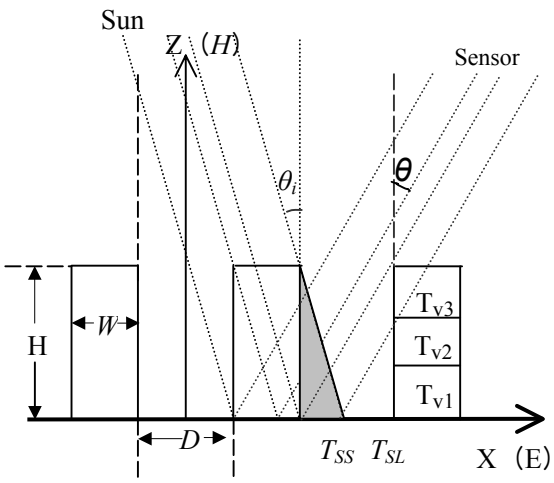

Fig. 1. The sectional drawing of winter wheat field.

We calculated the correlation coefficient between the vectors of $(\mathbf{w}_{\mathbf{k},\mathbf{j}})$ of different angles. When LAI=3.0, the view azimuth angle $\varphi = 90^\circ$, the correlation coefficient among angles is the least one(0.4529~1), when LAI =6.0, $\varphi = 90^\circ$, the correlation coefficient among angles is 0.5975~1. When LAI=3.0, the view azimuth angle $\varphi = 0^\circ$, the correlation coefficient is 0.8623~1. It shows that the correlation of multi-angle infrared radiance was obvious; it was decided by the physical and structural parameters of objects[2]. The correlation among the vectors of $(\mathbf{w}_{\mathbf{k},\mathbf{j}})$ is the key that affects the retrieving accuracy.

3. The Determination of Retrievable Parameters

When the physics and structural parameters were fixed, the structural pattern of row crop also affected the weight of different components significantly, the retrievable parameters changed correspondingly. So the appropriate structural pattern should be chosen according to the retrieving parameters and components of object.

Based on the theory of relative errors propagation of matrix[3-5], we have:

$$\frac{\|\delta \mathbf{L}_{\mathbf{b}}(\mathbf{T}_{\mathbf{j}})\|}{\|\mathbf{L}_{\mathbf{b}}(\mathbf{T}_{\mathbf{j}})\|} \le \frac{\|\mathbf{w}_{\mathbf{k},\mathbf{j}}^{-1}\|\|\mathbf{w}_{\mathbf{k},\mathbf{j}}\|\left[\frac{\|\delta \mathbf{w}_{\mathbf{k},\mathbf{j}}\|}{\|\mathbf{w}_{\mathbf{k},\mathbf{j}}\|} + \frac{\|\delta \mathbf{L}(\theta_{\mathbf{k}})\|}{\|\mathbf{L}(\theta_{\mathbf{k}})\|}\right]}{1 - \|\mathbf{w}_{\mathbf{k},\mathbf{j}}^{-1}\|\|\delta \mathbf{w}_{\mathbf{k},\mathbf{j}}\|} \qquad (1)$$

Here $\frac{\|\delta \mathbf{L}_{\mathbf{b}}(\mathbf{T}_{\mathbf{j}})\|}{\|\mathbf{L}_{\mathbf{b}}(\mathbf{T}_{\mathbf{j}})\|}$ represents the relative error of retrieved values, $\frac{\|\delta \mathbf{w}_{\mathbf{k},\mathbf{j}}\|}{\|\mathbf{w}_{\mathbf{k},\mathbf{j}}\|}$ and $\frac{\|\delta L(\theta_k)\|}{\|L(\theta_k)\|}$ represent the relative errors of modeling and measurements respectively. $\|\mathbf{w}_{\mathbf{k},\mathbf{j}}^{-1}\|\|\mathbf{w}_{\mathbf{k},\mathbf{j}}\|$ is the conditional number.

Table 1. LAI=3.0, $\varphi = 90^\circ$ the eigenvalues and the conditional number of $(\mathbf{w}_{\mathbf{k},\mathbf{j}})$

	λ_1	λ_2	λ_3	λ_4	λ_5
Eigenvalues of 3	0.727	0.161	0.067		
Conditional number		2.125	3.294		
Eigenvalues of 6	1.3174	0.2310	0.1044	0.0029	0.0003
Conditional number		2.388	3.552	21.314	66.267
Eigenvalues of 9	1.96	0.33	0.14	0.01	4.33E-04
Conditional number		2.437	3.742	14.000	67.280
Eigenvalues of12	2.90	0.62	0.24	0.04	6.43E-04
Conditional number		2.163	3.476	8.515	67.157

Table 1 shows the eigenvalues λ_i and the conditional numbers as using 3, 6, 9, 12 view angles. It was proven that the number of retrievable parameters didn't increase as viewing angles increased.

If the relative errors of modeling and measurements are not larger than 0.05%, the relative accuracy of retrieved values are expected within 0.3%-0.5%, $\left(\frac{\lambda_1}{\lambda_3}\right)^{\frac{1}{2}}$ =3.29~3.74, the number of retrievable parameters is 3.

4. Integrated retrieving method and experiment Validating

Depended on the research mentioned above, the iterative method combining with inverse matrix was established to retrieve component temperature. The initial value was calculated by the inverse matrix method.

$$\mathbf{L_c}(\theta_k) = \sum_{j=1}^{N} \mathbf{W_{k,j}} \mathbf{L^{(i)}{}_b}(\mathbf{T_j}) \qquad (3)$$

$$\mathbf{L_m}(\theta_k) - \sum_{j=1}^{N} \mathbf{W_{k,j}} \mathbf{L_b^{(i-1)}}(\mathbf{T_j}) = \delta \mathbf{L_b^{(i)}}(\mathbf{T_k}) \qquad (4)$$

$$\delta \mathbf{L_b^{(i)}}(\mathbf{T_k}) + \mathbf{L_b^{(i-1)}}(\mathbf{T_k}) = \mathbf{L_b^{(i)}}(\mathbf{T_k}) \qquad (5)$$

$(\mathbf{k} = 1,2,...,\mathbf{M}, \quad \mathbf{i} = 1,2,...)$, (i) is the times of iteration.

Comparing the value of output error using formula (5) for different viewing angle group, we choose the optimal viewing angle group (O°, 40°, 75°), when W=5cm, H=13.7cm, D=15cm, LAI=3.0, Ψ=90°, ε_v =0.98, ε_s =0.96. The distance from sensor to the top of crop is 150cm. Then we retrieved the temperature of vegetation, lighted soil and shadowed soil by the multi-angle radiance value observed in field, in Shunyi County, Beijing, in April 20th, 2001. The sensor was fixed on a framework, which can automatically move, the bandwidth of sensor is 8-11um and the field of view is 15 degree. The retrieval results of soil and plant temperature shows in Table 2.

Table 2. The retrieving result

		Maximum error	Minimum error	Average error	SSE
Ts	inverse matrix	4.7429	0.3386	0.9127	2.53
	iterative retrieval	3.9413	0.1113	0.7959	2.28
Tv	inverse matrix	6.88	0.4196	2.14	3.50
	iterative retrieval	5.87	0.0352	2.7185	3.15

It was proved by the field experiment that this method can improve the retrieving accuracy and stability remarkably.

5. Conclusion

High correlation exists in the multi-angle thermal infrared radiance data. The distribution of correlation coefficient is inhomogeneous in the hemisphere; it is the major obstacle for improving the retrieved accuracy.

The iterative method combining with inverse matrix can improve the retrieving accuracy remarkably. The study results can provide a theoretical basis for multi-angle thermal infrared remote sensing and components temperature retrieval.

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