ABSTRACT

In this paper, ASTER images are processed from two aspects: the thermal infrared data are used to estimate land surface temperature (LST), and the multi-spectral data are used for gaining land cover information. The relationship between LST and corresponding land cover is obtained. GIS is also used to simulate the evolution of thermal environment and predict its trends under the specific land cover scenarios. The results demonstrate that the simulation result is credible and it is helpful to analyze land use planning schemes from specific aspects or urban thermal environment view, so land use planning could be improved by optimizing thermal environment and avoiding the negative impacts resulted from urban heat island.

Index Terms—urban thermal environment, remote sensing, geographical information system, land surface temperature (LST)

1. INTRODUCTION

With the change of land cover over urban areas, urban heat island (UHI) has become one of the most serious environmental problems in cities. Urban thermal environment is dramatically changed as a result of urban heat island, which further results in obvious temperature difference between urban and suburban areas, and leads to pollutant concentration in urban areas and degradation of human settlement. In order to monitor the pattern, distribution and trend of urban thermal environment and predict its influences to ecological environment and human settlement, it is necessary to adopt thermal remote sensing data and geographical information system (GIS) to visualize, analyze, simulate and predict the spatial pattern and evolution trend of urban thermal environment. The integration of remote sensing and geographic information systems for urban land use has been widely applied and recognized as a powerful and effective tool. Relationship between urban air pollution patterns, land use and thermal landscape has been researched through linkage using GIS [1]. Urban growth was detected and its impacts on land surface temperature were assessed by RS and GIS method[2]. However, few studies focused on urban thermal environment simulation and prediction based on the integration of remote sensing and GIS were conducted in the past, so it is selected as the topic of this paper.

2. THE STUDY AREA AND DATA

The study area is Xuzhou City, located in the northwestern of Jiangsu Province, the middle east of China, as shown in Fig. 1. It covers 11257 km² and has a population of more than 9.1685 million in 1994 [3]. The mean annual temperature is about 14°C [4]. The highest average monthly temperature occurs in July and August, while the lowest temperature occurs in December and January.

Fig. 1 The false color composite images of study area Xuzhou (ASTER image: band 1(R), 3N(G),2(B))

The thermal infrared data of ASTER (02:59:29, November 24, 2005; 02:59:33, October 26, 2006) and MODIS L1B data (acquired on November 24, 2005,) are used to estimate land surface temperature (LST) through Split-Window Algorithm (SWA), and the multi-spectral data of ASTER are used to obtain land cover classification.
through three classifiers: Maximum Likelihood Classifier (MLC), Back Propagation Neural Network (BPNN) and Support Vector Machine (SVM). GIS is used to simulate the evolution of thermal environment and predict its trends under the specific land cover scenarios.

3. LAND COVER CLASSIFICATION

Three popular classifiers, including MLC, BPNN and SVM are applied to ASTER multi-spectral data in order to find a suitable method to derive reliable regional land use/land cover (LULC) map. Land cover is categorized into seven types: water, built-up land, bare area, woodland, public area, grassland and cropland. Figure 2 shows the results of different classifiers.

![Fig.2 classification results in 2005](image)

<table>
<thead>
<tr>
<th></th>
<th>Accuracy</th>
<th>Kappa</th>
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<tbody>
<tr>
<td>MLC</td>
<td>73.1532%</td>
<td>0.6529</td>
</tr>
<tr>
<td>BPNN</td>
<td>77.9121%</td>
<td>0.7258</td>
</tr>
<tr>
<td>SVM</td>
<td>89.0823%</td>
<td>0.8446</td>
</tr>
</tbody>
</table>

According to Table I, SVM classifier has the highest overall accuracy and kappa coefficient, so it is selected to produce land cover classification map owing to its superiority to other classifiers in terms of efficiency, accuracy and generalization ability.

4. LAND SURFACE TEMPERATURE RETRIEVE

Based on a comparison to some LST inversion methods from ASTER thermal infrared data, split-window algorithm is used to estimate LST. and the split-window algorithm can be depicted as equations (1)[5].

\[
0.14523 \varepsilon_{13} \tau_{13} T_s = 0.14523 T_0 + 33.685 \varepsilon_{13} \tau_{13} - (1 - \tau_{13})[1 + (1 - \varepsilon_{13}) \tau_{13}](0.14523 T_0 - 33.685) - 33.685 \tag{1a}
\]

\[
0.13226 \varepsilon_{14} \tau_{14} T_s = 0.13226 T_0 + 30.273 \varepsilon_{14} \tau_{14} - (1 - \tau_{14})[1 + (1 - \varepsilon_{14}) \tau_{14}](0.13226 T_0 - 30.273) - 30.273 \tag{1b}
\]

In order to simplify the calculation process, the coefficient equations are described as follows:

\[
A_{13} = 0.145236 \varepsilon_{13} \tau_{13}
\]

\[
B_{13} = 0.145236 \varepsilon_{13} + 33.685 \varepsilon_{13} \tau_{13} - 33.685
\]

\[
C_{13} = (1 - \tau_{13})[1 + (1 - \varepsilon_{13}) \tau_{13}] * 0.145236
\]

\[
D_{13} = (1 - \tau_{13})[1 + (1 - \varepsilon_{13}) \tau_{13}] * 33.685
\]

\[
A_{14} = 0.13226 \varepsilon_{14} \tau_{14}
\]

\[
B_{14} = 0.13226 \varepsilon_{14} \tau_{14} + 30.273 \varepsilon_{14} \tau_{14} - 30.273
\]

\[
C_{14} = (1 - \tau_{14})[1 + (1 - \varepsilon_{14}) \tau_{14}] * 0.13226
\]

\[
D_{14} = (1 - \tau_{14})[1 + (1 - \varepsilon_{14}) \tau_{14}] * 30.273
\]

Then land surface temperature can be got through equation (3).

\[
T_s = (C_{14}(D_{13} + B_{13}) - C_{13}(D_{14} + B_{14}))/ (C_{14} A_{13} - C_{13} A_{14}) \tag{3}
\]

Where \( T_s \) is LST, \( T_i \) is the brightness temperature in band \( i \), \( \varepsilon_i \) is the ground emissivity, and \( \tau_i \) is atmospheric transmittance in band \( i \). There are only two unknown parameters \( \varepsilon_i \) and \( \tau_i \). Where \( \tau_i \) can be calculated through
MODIS atmospheric vapor content band (band2 and band19) by equations as follow [6].

\[
\begin{align*}
\rho_2 &= \text{scale}_2(\text{band}_2 - \text{offset}_2) \\
\rho_{19} &= \text{scale}_{19}(\text{band}_{19} - \text{offset}_{19}) \\
\alpha &= \frac{(\alpha - \ln(\rho_{19}/\rho_2))/\beta}{ZDUUE} \\
\tau_{13} &= 1.02 - 0.14w, R^2 = 0.985 \\
\tau_{14} &= 1.04 - 0.133w, R^2 = 0.9915 \\
\end{align*}
\]

Where scale2, offset2, scale19 and offset19 are constants which can be obtained from MODIS attribute data, \( \omega \) is atmosphere vapor contain, \( \alpha = 0.02 \) and \( \beta = 0.651 \).

Fig. 3 Land surface temperature retrieval result

5. RELATING LST WITH LAND COVER

Using the Zonal Statistics command of ArcGIS Spatial analyst, the maximum, minimum and mean land surface temperature of different kinds of land use types in the study area were calculated. The statistical results are shown in Fig.4.

(a) The relationship between LST and the land use type in 2005
(b) The relationship between LST and the land use type in 2006

Fig. 4 The relationship between LST and the land use type

The statistics and the figures showed that the temperature gap between water and impervious surface, like built-up and bare area, was relatively larger than the other types. The differences in green spaces, such as woodland, grassland, cropland and public area land was relatively small.

6. LAND SURFACE TEMPERATURE SIMULATION

With the knowledge of the relationship between land use types and their temperature, the LST simulation results can be calculated with the support of Arc Toolbox in ArcGIS. The LST simulation result under a specific land cover scenario is shown in Fig.5.

In order to verify the correctness and accuracy of the LST simulation result, the Raster Calculator command in ArcGIS Spatial Analyst is used to calculate the differences between the retrieved and simulated LST results. The error is shown in Fig.6, which indicated the spatial distribution of different temperature gap. The statistical result of error grid counts at different temperature gap was shown in Fig.7. It can be seen that most of the gap is between minus 2°C and 2°C, which is up to 88.32% in 2005 and 82.37% in 2006. So it can be concluded that the LST simulation result is feasible and can be used to simulate and predict LST based on the known land use scenario.

(a) Simulated LST in 2005       (b) Simulated LST in 2006

Fig.5 The LST simulation result
7. CONCLUSION AND SUGGESTIONS

LST and land cover obtained from ASTER imagery are used for simulation and prediction of urban thermal environment in this paper. Three classifiers, including MLC, BPNN and SVM are used for obtaining land cover map. The results demonstrate that SVM classifier outperforms the other two classifiers, so it has higher accuracy in the progress of creating land cover map. Based on the derived knowledge of the relationship between LST and land cover type, the LST simulation is implemented with the support of ArcGIS. Finally the correctness and accuracy of the simulation is verified. The results demonstrate that LST retrieval from ASTER thermal image by SWA and land cover obtained from ASTER multi-spectral data are suitable for simulation and prediction of the urban thermal environment.

However, there are still several main problems that need to be solved in the future. As a key parameter in urban thermal environment simulation and prediction, LST retrieved by split-window algorithm is limited to certain required conditions, so it is important to verify the algorithm to different research fields. Although LST simulation based on the statistical knowledge between LST and land cover is feasible, its accuracy and reliability still need to be improved.

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