LAND SURFACE TEMPERATURE ESTIMATION FROM THERMAL BAND OF LANDSAT SENSOR, CASE STUDY: ALASHTAR CITY

T. Alipour a,*, M.R. Sarajian b, A. Esmaeily a
a Dept. of Geomatic Engineering, Kerman Graduate University of Technology, tayebalipour@gmail.com
b Dept. of Geomatic Engineering, University of Tehran, sarajian@ut.ac.ir

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ABSTRACT:
Land Surface Temperature monitoring major parameters of climate change country studies. In this paper, two methods to retrieve the land surface temperature (LST) from thermal infrared data supplied by band 6 of the Enhanced Thematic Mapper Plus (ETM+) sensor onboard the Landsat 7 satellite are compared. The two are the mono-window algorithm developed by Qin et al. [International Journal of Remote Sensing 22 (2001) 3719] and the single-channel algorithm developed by Jimenez-Munoz and Sobrino [Journal of Geophysical Research 108 (2003)]. To calculate the emissivity factor two methods were used.1) NDVI Base Method, 2) Classification. Finally, we present a comparison between the LST measured in situ (from metrological stations) and the retrieved by the algorithms over an agricultural region of Alashtar city. The result show R^2 = 0.85 for Qin algorithm and R^2 = 0.79 for Jimenez-Munoz and Sobrino algorithm.

1. INTRODUCTION

The importance of land surface temperature (LST) for environmental studies has been highlighted by several authors: Barton [1992], Lagouarde et al. [1995], Qin and Karnieli [1999], Dash et al. [2002], Schmugge et al. [2002], etc. Land surface temperature, an important indicator in the study of energy balance models on the ground and the greenhouse effect and the main parameters of surface interactions in regional and global scale. Land surface temperatures directly affect the air temperature. Various algorithms have been developed to retrieve LST from at-sensor and auxiliary data: single-channel methods, split-window technique and multi-angle methods. To apply the last two methods at least two thermal channels are required. The estimation of LST with only one thermal channel is the main advantage for single-channel methods.

The Landsat Program is the longest running enterprise for acquisition of imagery of the earth from space. The instruments on the Landsat satellites have acquired millions of images that are a unique resource for global change research and applications in agriculture, geology, forestry, regional planning, education and environment. The temporal resolution of the sensor is 16 days. On the descending (N to S) daytime portion of an orbit, the satellite crosses the equator at approximately 10:00 AM local solar time. Landsat TM/ETM+ band 6, with the spatial resolution of 120*120m for TM6 and 60*60m for ETM+6, respectively, records the surface radiance in 10.4–12.5 mm spectral range and provides information about radiant values which are determined by temperature and the emissivity of the surface. It is quite suitable to study the thermal environment, especially for an urban area. More information about Landsat program can be found on the web of http://landsat.gsfc.nasa.gov. Many studies have been finished by using thermal band of Landsat TM/ETM+ (Aniello et al., 1995; Weng, 2003; Weng et al., 2004; Kato & Yamaguchi, 2005). Additionally, Voogt and Oke (2003) gave a complete review of thermal remote sensing study on urban climates.

Land surface temperature retrieval algorithm successfully to detailed information of atmospheric effects, the exact amount being emissivity factor and quality of radiation data, including thermal infrared band spectral response function, signal to noise, power and precision of radiometric calibration separation depends.

As far as the Landsat TM and ETM+ are concerned, three different single-channel methods have been proposed to retrieve LST from their thermal bands. These three methods are: (i) the radiative transfer equation, (ii) Qin et al’s. (2001) mono-window algorithm, and (iii) Jimenez-Munoz and Sobrino’s algorithm (Sobrino et al., 2004). For the first method, it needs in situ atmospheric profile launched simultaneously with the satellite passes and it is a big constraint for using it. Usually, the second and third methods are used when the ground truth data is not available. To calculate the emissivity factor use NDVI base method and classification base method were used.

2. MATERIAL AND METHODS

2.1 Study area

Alashtar city is located in the western part of the IRAN in Lorestan province. The study area is delimited by latitudes 33°52’ 00”N and 33° 59’ 21”N and longitudes 48° 08’ 01”E and 48° 15’ 50”E, covering an area of approximately 150,290 km². In the study area Alashtar city and Good quality agricultural land surrounding the city to be seen. Average temperatures between 10 degrees below zero to 35 degrees above zero are variable (Figure 1 show the study area).

To estimate land surface temperature we used ETM+ satellite image on 30 May 2006. For validation of results, used the statistics measured by the 10-year-old Alashtar weather station.
2.2 Calculate At-Sensor Radiance and Brightness Temperature

It is well known that any object will emit thermal electromagnetic energy as its temperature is above absolute zero (K). Based on this principle, the signals received by the thermal sensors (TM/ETM+) can be converted to at-sensor radiance.

\[ L_{sensor} = gain \times DN + bias \]  

where \( L_{sensor} \) is spectral radiance of thermal band in W/(m² sr mm); gain is the slope of the radiance/DN conversion function; DN is the digital number of a given pixel from a L1G product; bias is the intercept of the radiance/DN conversion function (Landsat Project Science Office, 2002). The gain and bias values can be found in header files of TM/ETM+ image.

Radiance values from the TM/ETM+ thermal band were then transformed to radiant surface temperature, namely top-of-atmosphere brightness temperature, using thermal calibration constants supplied by the Landsat Project Science Office (2002) according to Eq. (2):

\[ T_{sensor} = \frac{K_2}{\ln \left( \frac{K_1}{L_{sensor}} + 1 \right)} \]  

where \( T_{sensor} \) is effective at-satellite temperature (brightness temperature) in K. \( K_1 \) and \( K_2 \) are prelaunch calibration constants and they are pre-settled (For Landsat 7 ETM+, \( K_1 = 666.09 \) W/(m² sr mm), and \( K_2 = 1282.71 \) K; for Landsat 5 TM, \( K_1 = 607.76 \) W/(m² sr mm), and \( K_2 = 1260.56 \) K) (Landsat Project Science Office, 2002). Therefore, values of \( K_1 \) and \( K_2 \) are constant for ETM+, but the values of bias and gain values maybe different for different images (bias and gain values are fixed for TM band6).

The temperature calculated by Eq. (2) is not the actual LST, but the top-of-atmosphere brightness temperature. To obtain a reasonably high quality of LST, four steps of correction process may be required according to Voogt and Oke (2003): (1) spectral radiance conversion to at-sensor brightness temperature; (2) correction for atmospheric absorption and re-emission; (3) correction for surface emissivity; and (4) correction for surface roughness. The first step is just the calculation process of Eq. (2) described above. The second to fourth steps of correction process are usually very complicated. In order to simplify the correction process, Qin et al.’s (2001) mono-window algorithm and Jiménez-Munoz and Sobrino’s (2003) single-channel algorithm were proposed, respectively.

2.3 Qin et al.’s mono-window algorithm

Qin et al.’s (2001) mono-window algorithm was expressed as follows:

\[ T_s = \frac{a_6(1 - e_6 - d_6) + [b_6(1 - e_6 - d_6) + e_6 + d_6]T_{sensor} - d_6T_a}{e_6} \]  

where \( T_s \) is the land surface temperature in K, \( T_{sensor} \) is the brightness temperature in K computed from Landsat TM/ETM+ band6, \( T_a \) is the effective mean atmospheric temperature (K), \( a_6 \) and \( b_6 \) are constants with values of 67.355351 for \( a_6 \) and 0.458606 for \( b_6 \) when the LST is between 273.5 and 343.5 K. \( C_6 \) and \( D_6 \) can be calculated by the following equations:

\[ C_6 = \varepsilon T_6 \]  

\[ D_6 = (1 - \varepsilon)T_6 \]  

where \( \varepsilon \) is the ground surface emissivity and \( T_6 \) is the atmospheric transmittance. \( T_a, e, t_6 \) are the three parameters needed to convert the brightness temperature to LST. According to the work of Qin et al. (2001, 2003), \( T_6 \) could be estimated by atmospheric water content and \( T_a \) could be calculated by the linear equations corresponding to the four standard atmospheres (Eq. (6)).
\[ T_a = 17.9769 + 0.91715T_0 \quad (\text{For tropical}) \]
\[ T_a = 16.0110 + 0.92621T_0 \quad (\text{For mid – latitude summer}) \]
\[ T_a = 19.2704 + 0.91118T_0 \quad (\text{For mid – latitude winter}) \]

where \( T_a \) is the effective mean atmospheric temperature; \( T_0 \) is the near-surface air temperature.

Qin et al. also estimate the atmospheric transmissivity from \( w \), the atmospheric water vapor content, for the range 0.4–1.6 g/cm\(^2\), according to

\[ \tau_5 = 0.974290 - 0.08007w \quad \text{high } T_0 \quad (7-a) \]
\[ \tau_6 = 0.982007 - 0.09611w \quad \text{low } T_0 \quad (7-b) \]

### 2.4 Jiménez-Munoz and Sobrino’s single-channel algorithm

In Jiménez-Munoz and Sobrino’s (2003) single-channel algorithm, the LST is given by the following equation:

\[ T_s = \gamma \left[ e^{-1} (\vartheta_1 L_{sensor} + \vartheta_2) + \vartheta_3 \right] + \delta \quad (8) \]

\[ \gamma = \left( \frac{c_1 L_{sensor}}{T_{sensor}} \right)^{\frac{1}{c_2}} \quad (9) \]

\[ \delta = -\gamma L_{sensor} + T_{sensor} \quad (10) \]

where \( T_s \) stands for the land surface temperature in K; \( \varepsilon \) is the ground surface emissivity; \( L_{sensor} \) is the at-sensor radiance in W/(m\(^2\) sr mm), \( T_{sensor} \) is the at-sensor brightness temperature in K, \( l \) is the effective wavelength in mm, \( c_1 = 1.1910^4*10^6 \) and \( c_2 = 14387.7 \). The atmospheric parameters of \( c_1, c_2 \) and \( c_3 \) can be obtained as functions of the total atmospheric water vapor content \( w \) according to the following equations particularized for TM/ETM+6 data:

\[ \vartheta_1 = 0.14714w^2 - 0.15583w + 1.1234 \quad (11-a) \]
\[ \vartheta_2 = -1.1836w^2 - 0.37607w - 0.52894 \quad (11-b) \]
\[ \vartheta_3 = -0.04554w^2 + 1.8719w - 0.39071 \quad (11-c) \]

### 3. EMISSIVITY PREPARATION

From above, it can be found that the ground emissivity is essential to both algorithms. In this paper, three methods are provided to calculate the emissivity and they are: (1) method based on classification image; (2) method based on NDVI image.

#### 3.1 Method based on classification image

This method is the simplest method, which refers to the land use/cover information and assigns an emissivity value to every land category according to its class ID value. The classification image and emissivity values for every land category are the key to this method. For landsat TM/ETM+ data, the classification image is generally created by image classification algorithm like Maximum Likelihood or K-mean’s method using the bands except band6. The accuracy of classification image would have a distinct impact on the final LST results. Approaches to acquire classification image from TM/ETM+ data can recur to image processing software such as RSI ENVI® (http://www.rsinc.com).

We use Maximum Likelihood method for image classification. For assignment emissivity factor to each class use the table 1.

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Features</th>
<th>Fractional Vegetation cover</th>
<th>NDVI</th>
<th>Emissivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Water bodies</td>
<td>0.000</td>
<td>0.070</td>
<td>0.989</td>
</tr>
<tr>
<td>2</td>
<td>Agricultural cropland</td>
<td>0.977</td>
<td>0.472</td>
<td>0.972</td>
</tr>
<tr>
<td>3</td>
<td>Dense vegetation (forest)</td>
<td>0.682</td>
<td>0.377</td>
<td>0.967</td>
</tr>
<tr>
<td>4</td>
<td>Sparse Vegetation (Grass)</td>
<td>0.507</td>
<td>0.320</td>
<td>0.957</td>
</tr>
<tr>
<td>5</td>
<td>Urban (built-up)</td>
<td>0.154</td>
<td>0.107</td>
<td>0.912</td>
</tr>
<tr>
<td>6</td>
<td>Waste land/bare soil</td>
<td>0.050</td>
<td>0.027</td>
<td>0.896</td>
</tr>
</tbody>
</table>

#### 3.2 Method based on NDVI image

An alternative, operative (easy to apply) procedure is to obtain the LSE image from the NDVI. Of the different approaches given in the literature (Sobrino & Raissouni, 2000; Valor & Caselles, 1996; Van de Griend & Owe, 1993), a modification of the last one has been used, the NDVI Thresholds Method—NDVI\(^{TM}\), which shows a good working in comparison to a reference method as the one based on the TISI indices (Becker & Li, 1990), as is pointed by Sobrino et al. (2001). The method proposed obtains the emissivity values from the NDVI considering different cases:

(a) \( \text{NDVI} < 0.2 \)

In this case, the pixel is considered as bare soil and the Emissivity is obtained from reflectivity values in the red Region.

(b) \( \text{NDVI} > 0.5 \)

Pixels with NDVI values higher than 0.5 are considered as fully vegetated, and then a constant value for the emissivity is assumed, typically of 0.99. It should be noted that the samples considered in the paper are not included in cases (a) or (b).
In this case, the pixel is composed by a mixture of bare soil and vegetation, and the emissivity is calculated according to the following equation:

$$\varepsilon = 0.004 P_v + 0.986$$  \hspace{1cm} (12)

where \(\varepsilon_v\) is the vegetation of the emissivity and \(\varepsilon_s\) is the soil emissivity, \(P_v\) is the vegetation proportion obtained according to (Carlson & Ripley, 1997):

$$P_v = \left[ \frac{NDVI - NDVI_{\text{min}}}{NDVI_{\text{max}} - NDVI_{\text{min}}} \right]^2$$  \hspace{1cm} (13)

\(NDVI_{\text{max}} = 0.5, NDVI_{\text{min}} = 0.2\)

The term \(d_e\) in Eq. (8) includes the effect of the geometrical distribution of the natural surfaces and also the internal reflections. For plain surfaces, this term is negligible, but for heterogeneous and rough surfaces, as forest, this term can reach a value of 2% (Sobrino, 1989). A good approximation for this term can be given by

$$d_e = (1 - \varepsilon_s)(1 - P_v)F\varepsilon_v$$  \hspace{1cm} (14)

where \(F\) is a shape factor (Sobrino et al., 1990) whose mean value, assuming different geometrical distributions, is 0.55. Taking into account Eqs. (8) and (10), the LSE can be obtained as:

$$\varepsilon = m P_v + n$$  \hspace{1cm} (15)

with

$$m = \varepsilon_v - \varepsilon_s - (1 - \varepsilon_s)F\varepsilon_v$$

$$n = \varepsilon_s + (1 - \varepsilon_s)F\varepsilon_v$$  \hspace{1cm} (16)

In order to apply this methodology, values of soil and vegetation emissivities are needed. To this end, a typical emissivity value of 0.99 for vegetation has been chosen. The choice of a typical value for soil is a more critical question, due to the higher emissivity values variation for soils in comparison with vegetation ones. A possible solution is to use the mean value for the emissivities of soils included in the ASTER spectral library (http://asterweb.jpl.nasa.gov) and filtered according to band TM6 filter function. In this way considering a total of 49 soils spectra, a mean value of 0.973 (with a standard deviation of 0.004) is obtained. Using these data (TM6 soil and vegetation emissivities of 0.97 and 0.99, respectively), the final expression for LSE is given by:

$$\varepsilon_{\text{TM6}} = 0.004 P_v + 0.986.$$

4. RESULT AND DISCUSSION

Results of implementation of two algorithms are shown in following figures.
Figure 3 shows the results of the Qin algorithm based on the NDVI coefficient. Emissivity ranges between 26 to 46 °C shows more vegetation in areas with more homogeneous results visible. Figure 4 shows the results of the Qin algorithm based on the Emissivity coefficient from the classification method. Ranges between 31 to 51 degrees and the surface shows a red area (areas with high temperatures that face the sun) it is more. Figure 5 shows the results of the Jemenez algorithm based on NDVI emissivity coefficient. Ranges between 26 to 46 °C and shows its ability to detect smaller differences in areas with dense vegetation. Figure 6 shows the results of the Jemenez algorithm based on the results of the emissivity coefficient from the classification method. Ranges between 28 to 47 degrees shows red area in this image is more than other images.

In both algorithms when we use classification for calculating emissivity, the distance between the maximum and minimum temperatures and surface areas increased with temperature between 40 and 50 degrees was more. One of the differences between the two methods is their sensitivity to changes in atmospheric parameters. Qin algorithm sensitivity to parameters such as atmospheric water vapor is more than Jemenez algorithm. It showed that if any detailed information about atmospheric water vapor be available, the performance of the two algorithms will be improved. Emissivity coefficient has a significant impact on the results. By changing the size of the emissivity of 0.1, the results of 2 to 3 degrees would change.

5. VALIDATION

Regarding to lack of land surface temperature measured by weather stations as well as the unavailability of air temperature at the time of imaging for the validation results using the Earth’s surface temperature data from 10 years following one variable experiment regression equation was obtained.

\[ y = 0.995x + 5.211 \]

Where \( y \) is a land surface temperature and \( x \) is a air temperature.

Rate correlation coefficient results in the following diagrams are shown.
5. CONCLUSION

In this paper, two methods to retrieve the land surface temperature (LST) from thermal infrared data supplied by band 6 of the Enhanced Thematic Mapper plus (ETM+) sensor onboard the Landsat 7 satellite are compared. The land surface emissivity (LSE) values needed in order to apply these methods have been estimated from a NDVI based method and classification method. The results show that the Qin algorithm using NDVI Emissivity factor it had obtained better results than other states in the study area. Sensitivity analysis performed on the algorithm showed that the sensitivity of results to small changes emissivity coefficient is very high level and highly values the land surface temperature will affect. Results are influenced by various errors, each of them carefully putting the final impact. For best results coming to the following two options are suggested,(i) using precise information, especially the amount of atmospheric water vapor (ii) Calibration parameters of the two algorithms using ground-based measurements accurately.

References


