Satellite Imagery Resolution Enhancement for Urban Area Thermal Micromapping

Iryna Piestova, Mykola Lubskyi, Mykhailo Svideniuk, Stanislav Golubov, Peter Sedlacek

Abstract—The approach to urban area thermal micromapping is presented in this article. The temperature field calculation is performed using the higher spatial resolution thermal emissivity. Logical redistribution is used to equalize the multispectral satellite image bands spatial resolution. Comparison of the output temperature map and the long-wave infrared radiance distribution image is demonstrated.

Keywords— infrared satellite imagery, resolution enhancement, thermal micromapping, urban area.

I. Introduction

In recent decades, there has been an intensive expansion of urbanized landscapes. Industrial production enlargement and population migration from villages to large cities prompt the residential neighborhoods' development. At the same time, the urban landscapes create a specific microclimate, which is characterized by a higher air temperature due to the presence of large amount of areas that capable to accumulation the heat (asphalts, concrete, bitumin etc.). Low concentration of green plantations and significant air pollution, which also contributes the heat retention [1]. Thus, the space monitoring of the urban environment in the longwave infrared band of the electromagnetic spectrum (wavelength of 8-14 microns) is an effective approach for analyzing of the heat load of urban areas to the environment [2].

High heterogeneity is a characteristic feature of urbanized landscapes. Large several of objects and covers with different thermophysical properties are present here. Today, the Landsat-8 is the only one operating satellite, which supplies remote sensing data that allow heat fields mapping with a moderate spatial resolution. It provides data in two long-wave infrared bands (10.3-11.3 μm and 11.5-12.5 μm wavelengths). But, spatial resolution of 100 m is insufficient for a detailed study of the vegetation influence on the urban environment.

However, there are approaches to the use of the visible and near-infrared data, in order to increase the informative and accuracy of the terrestrial objects and covers temperature spatial distribution determining.

II. Concept and Methods

The proposed approach is based on the combined use of thermal imagery by Landsat-8 TIRS sensor (https://landsat.usgs.gov/) and multispectral imagery by Sentinel-2 MSI sensor (https://earth.esa.int/web/sentinel/missions/sentinel-2). Spatial resolution enhancement of the land surface temperature distribution is achieved using the higher spatial resolution thermal emissivity distribution [3]. The land surface thermal emissivities of various pavements are calculated through the data of multispectral imagery with spatial resolution equalization [4].

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A. Land surface temperature calculation

The end-product radiance data processing is the land surface temperature using inverse Planck's equation [5]:

$$T = \frac{c_2}{\lambda \ln\left(\frac{\varepsilon(\lambda)c_1}{\lambda^5 L_S} + 1\right)} \tag{1}$$

where L_s is the spectral radiance of land surface, $\varepsilon(\lambda)$ is the land surface spectral emissivity, c_1 and c_2 are the first and second radiation constants, λ is the thermal radiation's wavelength in band of sensor sensitivity, T is the land surface physical temperature.

Land surface spectral radiance is gained from the input satellite data by specific procedure of atmospheric correction that allow removing atmospheric influence on radiation [6]:

$$L_S = \frac{L_i - L_i^{\uparrow}}{\varepsilon_i \tau_i} - \frac{1-\varepsilon_i}{\varepsilon_i} L_i^{\downarrow} \tag{2}$$

where L_i is the top of atmosphere (TOA) radiance in i-th band; $L_i^{\uparrow}$ is the upwelling sky irradiance in i-th band; $L_i^{\downarrow}$ is the downwelling scattered radiance in i-th band; τ_i is the spectral atmospheric transmittance.

Determination of the land surfaces emissivity distribution can be performed using multispectral visible and near infrared (VNIR) remote sensing imagery.

Surface emissivity is determined by relationship between emissivity and normalized difference vegetation index (NDVI) distribution. The emissivity is a rather inert surface feature. It is possible to involve data obtained with some time interval relatively long-wavelength infrared imagery.

For soils and vegetation, this dependence is established through the projective vegetation cover fraction F, which is defined as follows [7]:

$$F = \left(\frac{NDVI - NDVI_0}{NDVI_\infty - NDVI_0}\right)^2 \tag{3}$$

where $NDVI$ is the value of the vegetation index in the current pixel; $NDVI_0$ is the maximum value of bare soil index; $NDVI_\infty$ is the vegetation index minimum value of the completely vegetated surface.

The emissivity calculation is carried out as follows:

$$\varepsilon_\lambda = \varepsilon_{v\lambda} \cdot F + \varepsilon_{s\lambda}(1 - F) + \Delta\varepsilon_\lambda \tag{4}$$

where ε_λ is the land surface emissivity in current pixel; $\varepsilon_{v\lambda}$, $\varepsilon_{s\lambda}$ are the emissivities for a surface completely covered with vegetation and bare soil or another surface, where there is no vegetation relatively; $\Delta\varepsilon_\lambda$ is an amendment that takes into account the irregularity of radiation due to rough surface (the typical value for a rough surface is approximately 0.005).

Relationship for other types of covers is estimated by the regressive dependence between artificial surfaces spectra taken from ASTER Spectral Library (http://speclib.jpl.nasa.gov) and NDVI index outside its range that corresponds to the vegetation cover and open soil. Based on the obtained spectra a point cloud of dependence of the averaged emissivity of each of the typical spectra from NDVI index is expressed through the sensor-registered values in red and

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near infrared (NIR) bands. The resulting cloud of points is averaged quasi-optimally over both axes and then the spline-approximation of the dependence is performed through the obtained knot points.

B. Multispectral imagery spatial resolution equalization

Land surface emissivity distribution obtaining is most effective with the VNIR data obtained by Sentinel-2 series satellites of the in combination with the long-wavelength infrared data provided by the Landsat-8 satellite.

The interpolation for Sentinel-2 MSI sensor spectral bands ground sampling distance (GSD) equalizing must be carried out before analysis. The first step is 20 m spectral bands resampling up to 10 m one. Such procedure generates four identical subpixels. It is necessary to reallocate band signals [8] in these subpixels properly to enhance the overall image actual resolution taking into account the surrounding area context. Selected reallocation matrix is a tool for reclassification [9] of current subpixel after analysis. Its class is considered jointly with near neighborhood, and resulting decision is made to save this one or change it to another class from a set of surrounding subpixels. After additional image adjustments are conducted [10], the Sentinel-2 data acquires an unified 10 m spatial resolution, compared to 30 m for Landsat-8.

This interconnection for other types of land covers is estimated by the regressive relationship between the artificial surfaces spectra taken from the ASTER spectral library and the NDVI index beyond its range corresponding to plant cover and open soil. This technique for obtaining the emissivity distribution of is most effective with the visible and NIR data derived by Sentinel-2 satellites.

C. Emissivity spatial resolution enhancement

Besides extracting land surface temperature from radiance data emissivity distribution, obtained using VNIR data, allow to significantly enhance the spatial resolution of resulting spatial distribution of temperature.

Also we can derive further spatial resolution enhancement by subpixel processing of pair of multitemporal emissivity distributions with subpixel displacement one relatively to another. In this case the initial distributions must contain time-invariant data. Because the emissivity is rather inertial feature of land surface, or absolutely unaltered, so the pair of one's distributions with short time difference (up to 2 weeks) can be engaged.

Subpixel displacement is calculated by relative function between source images using special software [11]. Also it is necessary to create a noise distribution image joint for both input ones, which characterizes a homogenous surface, where any value deviation can be explained as noise. Then fusion of low-resolution input images into a joint resampled image by interlaced scan over the higher resolution grid, taking into account the subpixel's offset and noise matrix is conducted. Next procedures are: the estimation of the inverse operator matrix, enhanced resolution image restoration, and iterative image reconstruction to eliminate irregularities and suppress noise.

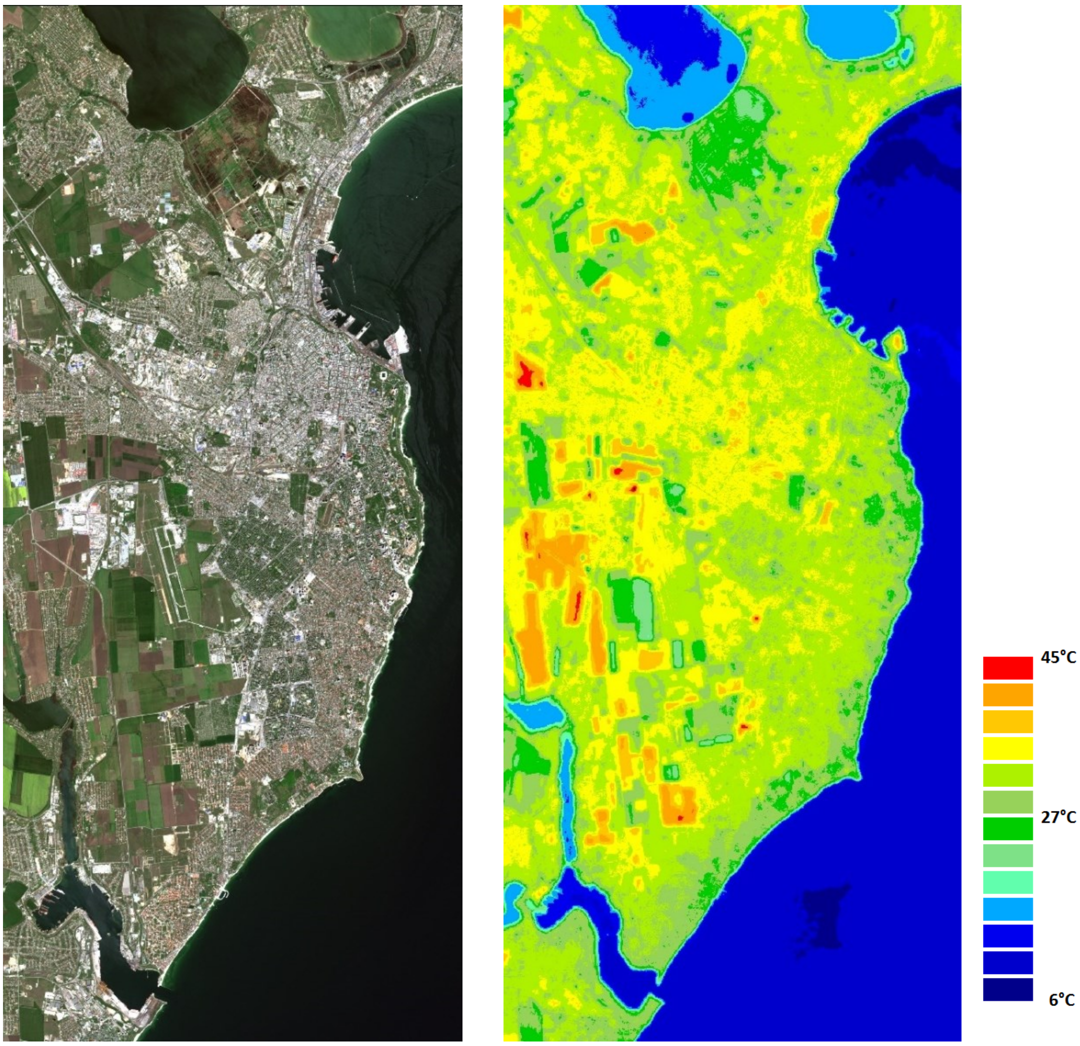
Obtained emissivity distribution of enhanced spatial resolution is included into inversed Planck's equation (1) instead of the low spatial resolution one.

III. RESULT AND DISCUSSION

Odessa city territory was chosen as the object for presented technique validation. The thermal infrared image of Landsat-8 TIRS sensor (23.04.2018, 100 m spatial resolution) and two multispectral images of the Sentinel-2 MSI sensor (28.04.2018 and 30.04.2018, 10 m spatial resolution) were processed.

Multispectral images were used to obtain the distribution of the emissivity. Thermal infrared image was used directly to obtain the enhanced resolution land surface temperature field. The corresponding software has been developed to perform the procedure for restoring the enhanced resolution image [11].

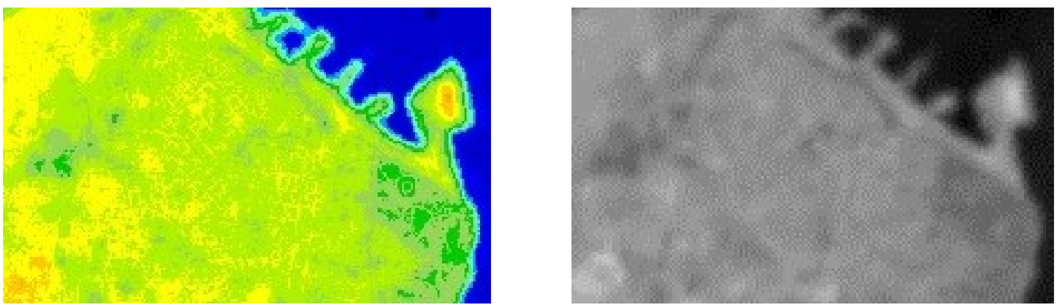
Fig. 1 shows a comparison of the Sentinel-2 satellite multispectral image and the derived temperature distribution map.



a *b*

Fig. 1 Input data and processing result: *a*) Sentinel-2 satellite multispectral image (Odessa city, 28.04.2018, 10 m spatial resolution), *b*) enhanced resolution temperature distribution map

Area of interest covers various land surfaces and a significant building area. Fig. 2 demonstrates a comparison of the output temperature map and the long-wave infrared radiance distribution image obtained by the TIRS sensor.



a *b*

Fig. 2 Thermal field of enhanced detaility (*a*) in comparison with the original TIRS image (*b*)

Enhanced spatial resolution and more fined details are clearly visible. It is also proved that the vegetation areas have a lower temperature than the surrounding buildings and stand out well on the temperature map.

IV. Conclusion

Vegetation mapping with analysis of thermal distribution is a very important for the overall assessment of biomass and its seasonal influence on thermal fields. The moderate resolution satellite imagery was chosen for testing the proposed technique, one of the forthcoming long-term time series analysis.

Subsequent temperature distribution analysis will provide an opportunity to build a time series and to extract the trends of temperature change, as well as the influence of green zones. Which allows to develop a scientific basis for further recommendations to city local authorities and climate change impact mitigation for the urban population.

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