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Observation of Urban Heat Island using Airborne Thermal Sensors

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***Abstract*— As a basic study on urban heat island, the surface temperature of the central Tokyo, Japan is investigated using images obtained by airborne thermal sensors. Thermographies were taken from a helicopter on August 7, 2007, both in the daytime and at night. Using these thermal images, the variation of surface temperature can be observed in a detailed manner. Although the road surface and building roofs shows very high temperature, vegetation and water bodies show much lower temperature. The temperature at night also shows significant variation depending on the surface material and the sunlight condition in the daytime. Ground based verification of surface temperature was also carried out using a handheld thermal sensor. Based on these observations, detailed variations of temperature on various urban earth surfaces were revealed.**

I. Introduction

Urban heat island is serious problem in large cities in the world. Because urban areas became to be covered with concrete and asphalt, the temperature does not go down even at night. Distribution of earth surface temperature can be observed by thermal bands of satellite sensors, e.g. Band 6 of Landsat 7, in a coarse resolution (e.g., 60m). However, due to the spatial resolution of satellite thermal sensors, detailed temperature distributions cannot be observed.

The present authors [1] recently proposed a method to extract rooftop greening using the near-infrared band of digital aerial images and GIS data as a first step to investigate the effect of rooftop greening from the thermal point of view. However, since the area of such vegetation is usually not so large, satellite thermal sensors cannot capture the detailed temperature distribution. Hence in this paper, airborne sensors are employed to assess a detailed surface temperature distribution in a central district of Tokyo, Japan. Using the thermographies obtained from the flights both in the daytime and at night, the surface temperature distribution is explained with respect to the surface material and the sunlight condition in the daytime.

Ground based verification of the surface temperature is also carried out in this study using a handheld thermal sensor. Based on these observations, detailed variations of temperature on various urban earth surfaces are provided as a fundamental dataset to evaluate urban heat island phenomena.

II. Airborne Survey Images of The Cetral Tokyo

A. *Airborne Thermograpy*

In order to capture a detailed temperature distribution in a dense urban area, thermographies were taken over the central part of Tokyo Metropolis, Japan from a helicopter on August 7, 2007, both in the daytime (13:00) and at night (22:00). The weather was partly cloudy with the maximum temperature 33.2°C and the minimum 25.8°C. The surveying flight was conducted by Skymap Co., Ltd. (http://www.skymap.co.jp/).

The thermal sensor onboard a helicopter is Termo Tracer TS7302, an infrared thermograpy sensor produced by NEC Avio Infrared Technologies Co., Ltd. (http://www.nec-avio.co.jp/en/index.html). The sensor measures the infrared band in the wavelength 8 μm - 14 μm and stores in 14 bit data file with 320（H）× 240（V）pixels in each time frame. The coverage temperature is between -40°C to 120°C with accuracy of ±2%.

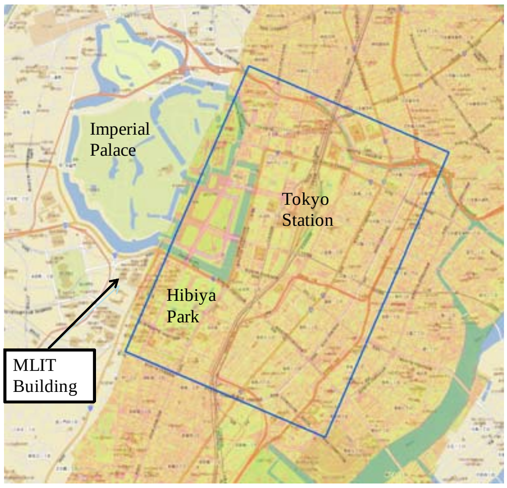


Figure 1. The central part of Tokyo: the area taken by aerial theromography on August 7, 2007 used in this study.

Figure 1 shows the main study area of this paper, observed by the helicopter-loaded thermal sensor from 610m above the ground. The area includes Tokyo Station, the front square of Imperial Palace, and Hibiya Park, all surrounded by many high-rise buildings. The area is the most important central business district in Japan.

As a first step of the image analysis, the thermal image with 2m spatial resolution, shown in Fig. 2, was co-registered on a GIS map (DM 2,500) produced by Geographical Survey Institute of Japan. Based on this superposition, the detailed temperature distribution can be correlated with the ground surface characteristics. The registration to the GIS map was carried out for both the daytime and nighttime temperature images. Hence, by subtracting the temperature values between the two images, the change of the temperature can be obtained.

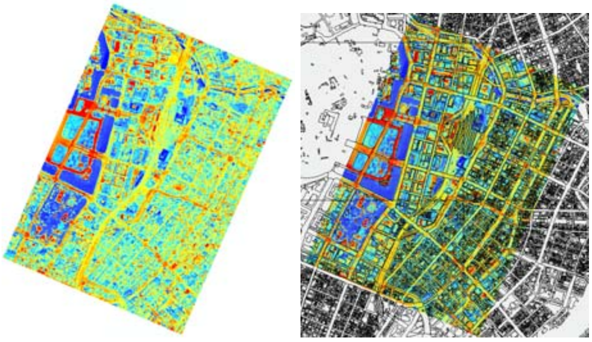


Figure 2. The thermal map (left) and its superposition on GIS data.

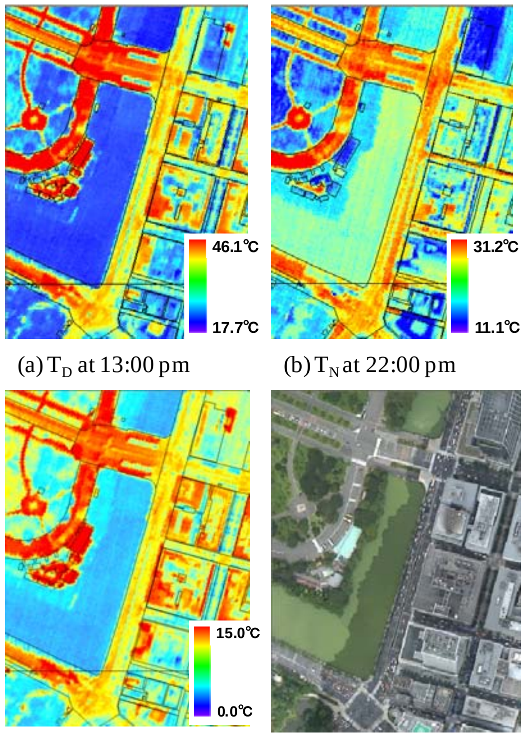
B. Comaprison of day and night temperatures

Using the temperature data obtained by the airborne thermal sensor, the difference of temperatures in the early afternoon (13:00pm) and at night (22:00pm) was calculated as shown in Figure 3, for the moat and the front square of Imperial Palace. It is observed from the figure that the surface temperature is very high, over 40°C, on the pavement of asphalt road, especially at widely opened locations. The surface temperature of the heated pavement continues to be high, over 30°C, even at 22:00pm. The difference of daytime and nighttime temperature shows that the difference (T_D-T_N) is the largest, about 15°C, in the most heated surface.

The surface temperature of the asphalt road by the moat is not so high because high-rise buildings are standing along it, and thus the road surface had been in shadow in the morning. The sunlight condition is considered to be an important factor to determine surface temperatures.

The water surface temperature of the moat was the lowest, about 17°C at 13:00pm, although the maximum air temperature of the day was 33.2°C. The difference of the day and night temperature is seen to be the smallest for water among various surfaces in the figure. It is well known that water has the largest specific heat value among almost all the materials, and hence water is difficult to heat up nor to cool down.

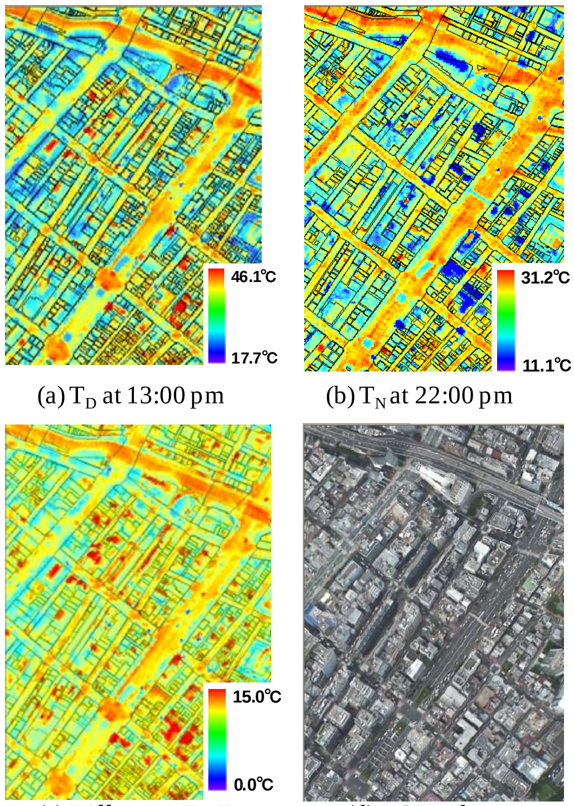
It is also noticed that the surface temperature of tree leaves is as low as water in the daytime and even lower than water at



(a) T_D at 13:00 pm (b) T_N at 22:00 pm

(c) Difference T_D-T_N (d) RGB color

Figure 3. The temperature distribution of the moat and the front square of the palace and its surrounding area.



(a) T_D at 13:00 pm (b) T_N at 22:00 pm

(c) Difference T_D-T_N (d) RGB color

Figure 4. The temperature distribution of Ginza area.

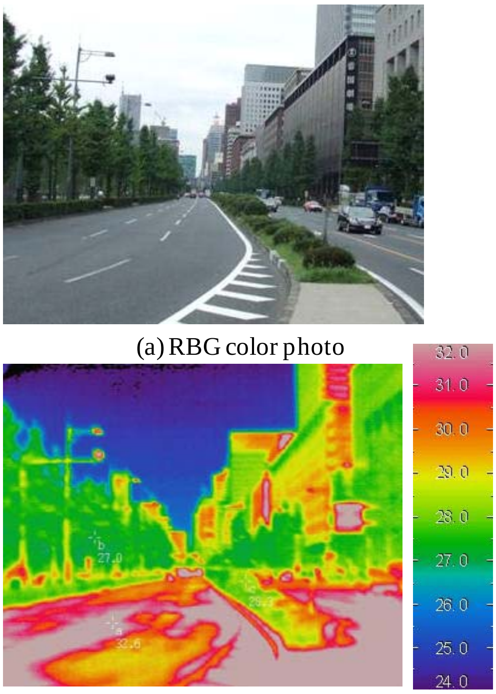
night. This observation can be explained by the fact that leaves have, in general, a very large specific heat value, next to water.

The temperature distribution was also examined for Ginza, one of the most fashionable shopping areas in Tokyo, as shown in Fig. 4. The surface temperature in the daytime is highest on the surfaces of an elevated urban expressway and a wide main street. The surface temperature is much lower for narrow streets because they are in the shadow of buildings in most of the daytime. The temperature of major intersections looks higher than other parts of the road, probably due to the sunlight condition.

C. *Ground-based termal imaging*

The ground based thermal sensing was also conducted to obtain validation data of the airborne thermal sensing. The infrared thermal imager used for the field survey is Termo Tracer TH9100, produced by NEC Avio Infrared Technologies Co., Ltd. This sensor is a newer product than TS7302, used in the aerial survey.

Figure 5 shows a sample thermal image taken at 12:45, August 27, 2008 at the south-east corner of the moat. Comparing the temperature image with the visual image, a detailed temperature distribution could be observed. The surface temperature of road-side trees and road-center plants are seen to be much lower than those of the road pavement and the building walls. Due to the difference of temperature for different surfaces, the shapes of man-made structures and vegetation can be estimated from the thermal image.



(a) RBG color photo

(b) Temperature by thermal sensor

Figure 5. Ground-based photograph (a) and its thermal image taken at 12:45, August 27, 2008 by Thermo Tracer TH9100 at the south-east corner of the moat in Fig. 3.

III. Effects of Vegetation

A. *Urban Greening Policy in Japan*

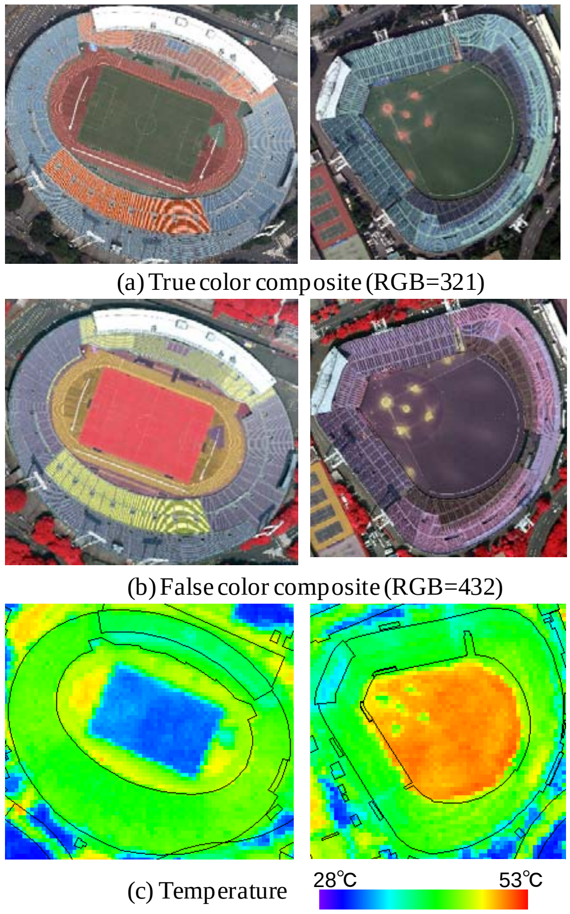
As the method to ease urban heat island, the abundance of vegetation is one of the most effective factors [2]. However, it is not so easy to increase parks and trees in a dense city like Tokyo. Hence, rooftop greening and wall greening are recommended by the central and local governments in Japan.

Tokyo Metropolitan Government recently announced "Basic Policies for the 10-Year Project for Green Tokyo" [3] in June 2007. As one of four basic policies, "Use ingenuity to create and conserve greenery" was declared. "Create a total of 400 ha of green space by greening rooftops, wall surfaces, railroad areas, parking lots and all other possible urban spaces" is one of the action plans toward the goal.

To promote this plan, Tokyo Metropolitan Government issued the regulation in April 2004 that the 20% of the rooftop should be covered by vegetation for the newly built or renovated buildings on the land area larger than or equal to 1,000m^3 (250 m^3 for public buildings).

B. *Vegetation seen from digital aerial images*

Airborne remote sensing is an effective way to detect vegetation in dense urban areas. Since digital aerial cameras



(a) True color composite (RGB=321)

(b) False color composite (RGB=432)

(c) Temperature

Figure 6. Comparison of digital aerial camera images and thermal images for a natural lawn stadium (left) and a manmade lawn ball park (right).

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recently developed and introduced to aerial surveying have a near infrared (NIR) band as well as RGB visible bands, they can be conveniently used to detect vegetation areas. The study area was taken by UltraCam-D digital camera [4] on August 4, 2006, by Geographical Survey Institute (GSI) of Japan.

Figure 6 compares digital aerial camera images and thermal images for a natural lawn stadium (National Stadium) and a manmade lawn ball park (Jingu Ball Park). Although the both lawns look green in the natural color composite, (RGB= 321), the false color composite (RGB=432) shows the difference. The natural vegetation is seen to be in red color due to high reflectance in the near-infrared region, which is unique to vegetation. On the contrary, the manmade green does not have such a characteristic and thus it is not so red in false color.

The thermal image of these areas (Fig. 6 (c)) was taken and provided by PASCO Co., Ltd. TABI 320 thermal band imager (http://www.itres.com/TABI_320) onboard a airplane was used in thermal sensing from 1,078m above the ground at 13:25pm, August 7, 2006. The weather of the day was sunny with the maximum temperature 34.3°C and the minimum temperature 26.3°C. It is interesting to see that the surface temperature of the chemical lawn is much higher than the natural vegetation although these two stadiums are located in a short distance. Hence natural lawn grounds are much better in order to keep the local temperature cool.

C. *Effects of rooftop greenings*

There are several rooftop greenings in the central Tokyo. Ministry of Land, Infrastructure and Transport (MLIT) has been conducting the pilot project of rooftop greening on the rooftop of its headquarters [5]. Figure 7 shows a temperature distribution of this rooftop greening measured by Thermo Tracer TS7302 from a helicopter at 13:00, August 7, 2007.

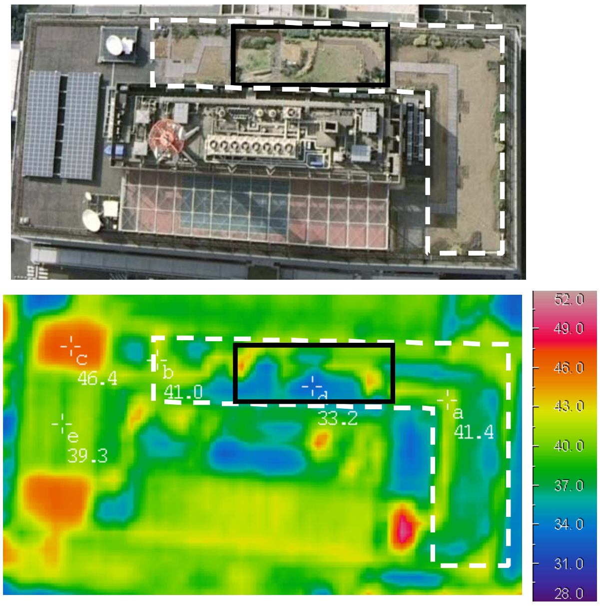

Figure 7. True color aerial image (top) and its thermal image (bottom) of the rooftop of MLIT building taken at 13:00, August 7, 2007 by Thermo Tracer TS7302.

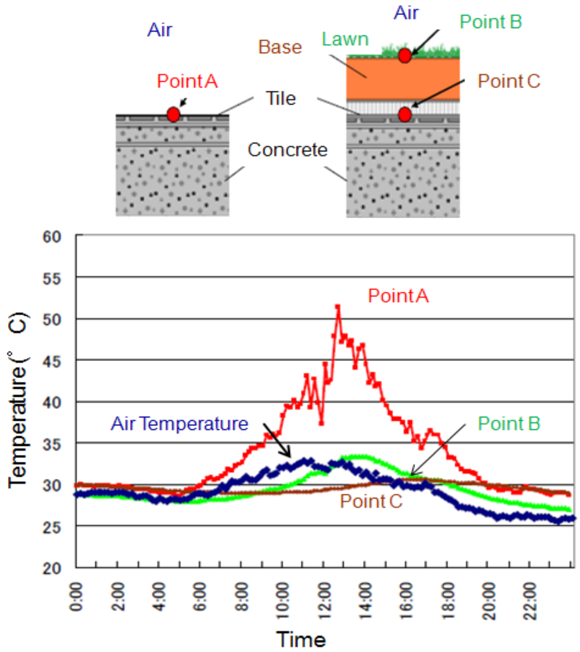

Figure 8. Measured temperatures on the rooftop of MLIT building on August 9, 2008 with the air temperature in central Tokyo [5].

Comparing with its aerial true color image, a detailed surface temperature distribution can be observed.

Observing the thermal image, the highest temperature is located on the bare tile surface, 46.4°C. The area with greening shows more than 10°C lower than the heated tiled roof. Figure 8 shows the measured temperatures on the rooftop of MLIT building on August 9, 2008 with the air temperature in central Tokyo at Japan Meteorological Agency (JMA). Although the date and year of the observation is different for Figs. 7 and 8, the weather conditions of the days were rather similar. Hence the temperature time histories shown in Fig. 8 are considered to be consistent with the temperature distribution in Fig. 7.

The surface temperature of the lawn (point A) is almost the same level as the air temperature and a time lag (about 2 hours) was seen till the surface temperature caught up with the air temperature. Under the base (manmade light soil) of lawn (point C), the temperature was lower than the lawn surface. On the contrary, the tile surface temperature (point A) reached over 50°C in the afternoon. Hence the rooftop greening at MLIT building could demonstrate its effectiveness to prevent the roof to be very hot in summer.

Another interesting observation of rooftop greening is that on the roof of I-hotel in front of Hibiya Park. Figure 9 shows the digital aerial image taken on August 4, 2006 by UltraCam-D digital camera. Since the camera has the visible bands (RGB) and near-infrared band, the normalized vegetation index (NDVI) can be calculated.

$$NDVI = (NIR - R) / (NIR + R) \qquad (1)$$

where R and NIR are the digital numbers of the red and near-infrared bands, respectively. The rooftop vegetation shows a high NDVI value, representing the vegetation is active.

The thermal image taken by TABI 320 on August 7, 2006 is also plotted in Fig. 9 (d), where the vegetation shows rather high temperature comparing with the surrounding roof. It was found in the field survey and an interview with the manager that the vegetation is a kind of cactus, which needs not to water regularly. It is considered that since the surface of the plant is rather dry, the surface temperature went up high, not like ordinary plants. Hence if rooftop greening is placed for the purpose of reducing the surface temperature, this kind of plant is not suitable although it is maintenance free.

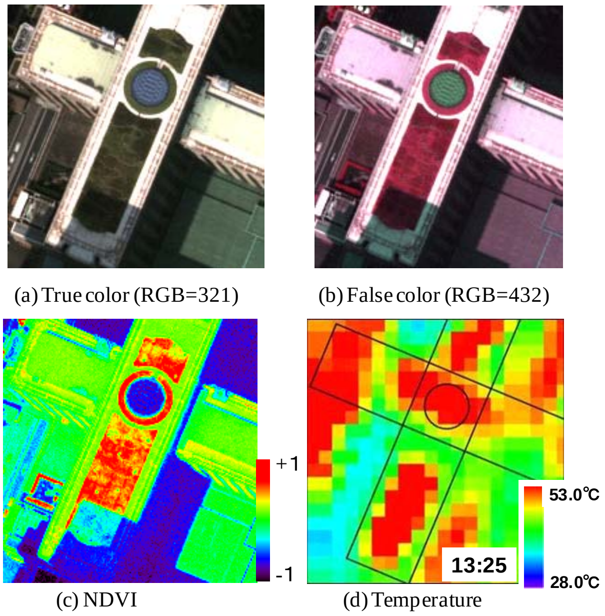

Figure 9. True color image (a), false color image (b), and NDVI image (c) by digital aerial camera, and the thermal image (d) of the rooftop of I-Hotel taken at 13:25, August 7, 2007 by TABI 320.

IV. CONCLUSIONS

As a basic study on urban heat island, the surface temperature of the central Tokyo, Japan was investigated using thermal images obtained by airborne thermal sensors Thermographies were taken from a helicopter on August 7, 2007, both in the daytime and at night. Using these thermal images, the variation of surface temperature was observed in a detailed manner. Although the road surface and building roofs shows very high temperature, vegetation and water bodies show much lower temperature. The temperature at night also shows significant variation depending on the surface material and the sunlight condition in the daytime. Ground based verification of surface temperature was also carried out using a handheld thermal sensor. Based on these observations, detailed variations of temperature on various urban earth surfaces were revealed. The effectiveness of rooftop greening in reducing the roof surface temperature was observed for several buildings, but some kind of plants, like cactus, were found not so effective.

ACKNOWLEDGMENT

The digital aerial images taken by UltraCam-D were provided from Geographical Survey Institute (GSI) of Japan. The thermal image taken by TABI 320 was provided from PASCO Co., Ltd.

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