Analysis on the temperature results of thermal infrared remote sensing based on a ground platform

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Abstract. Thermal infrared cameras have been widely used to measure temperature as a non-invasive measuring instrument recently. To assess the temperature results of thermal infrared remote sensing, we compared them with the temperature obtained by traditional contact temperature measuring method. A ground remote sensing platform was designed to obtain the thermal infrared temperature of the underlying surface. Meanwhile, the traditional contact method was used to obtain surface temperature synchronously. Afterward, the two kinds of temperature were compared and analyzed. Our results indicate that for the four kinds of underlying surface studied in this paper, the two kinds of temperature all have strong correlation. Furthermore, the mean temperature difference ranges between 0.46 ℃ and 1.79 ℃. Moreover, no significant difference can be observed between the two kinds of the temperature of grassland, tile, and permeable brick when the evaluation is at the level of P=0.001.

1. Introduction
Temperature is one of the most basic and important parameters in science and commerce [1]. According to the contact property between the measuring instrument and the measured solid, liquid or gas medium, various measuring techniques can be roughly divided into three categories: invasive, semi-invasive, and noninvasive [2]. Both invasive and semi-invasive methods may cause interference in the temperature field [2]. Besides, the invasive method can only be used to obtain the mean temperature of the contact area other than the high temperature appeared in a local area for a short time [3,4]. With no contact between the measuring device and the measured medium, noninvasive method, such as thermal infrared remote sensing, can avoid this kind of problem [5,6]. Furthermore, thermal infrared remote sensing can obtain the temperature data of an area and monitor the environment with systematic image characteristics repeatedly at a lower cost [7].

There is no strict physical definition of thermal infrared remote sensing. Lillesand Kiefer & Chipman defined the bands of thermal infrared remote sensing in the wavelength of 3-1000 μm [8]. H. Sheng et al. considered thermal infrared radiation as electromagnetic waves with wavelengths ranging between 3.5 and 20 microns μm [9]. According to the study by Sabins, the wavelength of thermal infrared radiation ranges from 3 to 14 μm [10]. What all definitions have in common is that thermal infrared remote sensing records emitted radiation information other than reflective radiation information.

Thermal infrared remote sensing is an important tool to measure temperatures and energy fluxes in landscape and environment studies [11,12]. Furthermore, thermal infrared remote sensing is of importance to assess the urban heat island and perform land cover classifications [13,14]. As can
identify urban hotspots at appropriate scales, thermal infrared remote sensing is a useful assessment of techniques for urban and rural planning [15].

The Building Environment and Energy Laboratory (BEEL) of State Key Laboratory of Subtropical Building Science has conducted several low altitude thermal remote sensing observations using unmanned airship and unmanned aerial vehicle [16]. However, the ground tests during the observations cannot provide a detailed comparison between the temperature results of thermal infrared remote sensing and the traditional contact temperature measuring method because the thermal infrared temperature data of each ground test point is not enough.

Generally speaking, the most accurate method of temperature measurement using current technology is contact temperature measurement. Thus, it is a good way to assess the temperature results of thermal infrared remote sensing by comparing them with the results of contact temperature measurement. In the urban and rural environment research, there are few studies on how the surface temperature results of thermal infrared remote sensing differ from those of traditional contact temperature measurement. In order to partly fill this knowledge gap, we compared the two kinds of temperature obtained in an outdoor environment experiment.

2. Study area and data

2.1. Study area

This study was conducted at the front square of Liwu Building, located in the Wushan campus of South China University of Technology (SCUT), Guangzhou, China. The study area contains several types of underlying surface, from which grassland, cement pavement, tile, and permeable brick were selected to conduct this study. The test points of these underlying surface are shown as point 1-4 in Figure 1, respectively.

![Figure 1](image)

Figure 1. The study area. Point 1-4 represent the grassland, cement pavement, tile, and permeable brick, respectively. This photo was taken at the top balcony of the Liwu building using the thermal infrared camera in the visible mode.

2.2. Data

2.2.1. Instruments. The thermal infrared data was acquired using the TH9260® thermal infrared camera (NEC, Japan) that has one band between 8 and 14 µm. This camera has a field of view (FOV) of 21.7°x16.4° and collects data with an image resolution of 640x480 pixels. The mean thermal sensitivity of the camera is 0.08 °C at 30 °C. The TH9260® camera has been calibrated when it was manufactured.
The contact temperature measurement was conducted using the BES-01 temperature acquisition recorder, which is developed by the Institute of Building Energy Conservation Technology, Harbin University of Technology, China. The recorder is an energy-saving instrument based on the single-chip technology of new generation. It can automatically test and record the temperature data. The range of temperature measurement of this recorder is between -50 and 120°C. The temperature measuring accuracy of this recorder is < 0.5°C.

2.2.2. Data acquisitions. The data acquisition time is between 9:30 a.m. on August 24 and 9:30 a.m. on August 25 in 2012. The TH9260® camera was put on a tripod and placed at the top balcony of Liwu Building with a height of around 40 meters high above the ground. The flat side of the BES-01 temperature acquisition recorder was attached to the underlying surface to measure the temperature. Furthermore, the thermal conductive silica gel was used to paste them to ensure the heat transfer process.

The temperature acquired by the TH9260® camera is recorded as Ti, whereas the temperature acquired by the BES-01 recorder is recorded as Tc. Ti and Tc represent the result of thermal infrared remote sensing and contact measurement, respectively. The time interval of data acquisition is 10 seconds. The data acquisitions of Ti and Tc were conducted synchronously using the automatic test and record mode.

3. Methods
First, Ti of the test point 1-4 was extracted from the thermal infrared images using the software Image Professor Pro2. The points were selected in the thermal images according to the locations where the BES-01 recorders were placed. Afterward, Ti and Tc data were sorted out by time to generate the temperature curves to show the variation trends of them.

Next, the regression analysis of Ti and Tc was conducted to study the correlation between them. At this step, the Kolmogorov-Smirnov(K-S) test was first carried out to verify if Ti and Tc are normally distributed [17]. According to the K-S test result of non-normal distribution, Spearman rank correlation coefficients were selected and calculated to evaluate the correlation between Ti and Tc.

Thereafter, the statistical characters of Ti and Tc were calculated to analyze the distribution of them. Furthermore, the temperature differences between Ti and Tc were assessed using both mean and median values, respectively.

Last, Welch's test and Games-Howell post hoc test were conducted to test the significance of temperature differences between Ti and Tc [18,19]. The fundamental purpose of this paper is to assess Ti by comparing it with Tc. Furthermore, the distribution and variation of Ti and Tc of grassland, cement pavement, tile, and permeable brick were analyzed as a reference and supplement to this study.

4. Results

4.1. Temperature Variation Trends
Figure 2 a-d show the Temperature Variation Trends of Ti and Tc of grassland, cement pavement, tile, and permeable brick. In general, the shapes and trends of the curves of Ti and Tc are basically the same. Furthermore, the curves of Tc are smoother than those of Ti generally.

4.2. Correlation
To evaluate the correlation between Ti and Tc, the coefficients of them are calculated. At this step, the K-S test was first conducted. The results of the K-S test (P=0) indicate that Ti and Tc are not normally distributed. Thus, the Spearman correlation coefficient r was selected and calculated. The results of r of the grassland, cement pavement, tile, and permeable brick are shown in Table 1.

The results indicate that r ranges between 0.994 (permeable brick) and 0.980 (grassland), whereas cement pavement (0.991) and tile (0.993) have the correlation coefficient within them. According to
the interpretation by Taylor [20], an extremely strong correlation can be observed between Ti and Tc from all the four kinds of underlying surface (r >0.9, p=0).

![Graphs of Ti and Tc temperatures](image)

Figure 2. The temperature variation trends of Ti and Tc. (a) grassland (b) cement pavement (c) tile and (d) permeable brick.

Table 1. The Spearman's correlation coefficients between Ti and Tc.

| Underlying surface      | Spearman's correlation coefficient r | p  |
|-------------------------|-------------------------------------|----|
| Grassland               | 0.980                               | 0  |
| Cement pavement         | 0.991                               | 0  |
| Tile                    | 0.993                               | 0  |
| Permeable brick         | 0.994                               | 0  |

4.3. Temperature difference

In order to study the difference between Ti and Tc, the box plot of them is generated, as shown in Figure 3. Furthermore, the statistical characteristics of them are calculated, as shown in Table 2. The results indicate that Ti ranges between 23.20°C (grassland) and 27.50°C (tile), whereas Tc ranges between 23.75°C (grassland) and 55.81°C (tile).

When using the mean values to assess the temperature, Ti is higher than Tc for the grassland, cement floor, and permeable brick. The temperature differences are 0.87 °C, 0.46 °C, and 0.97 °C, respectively; Ti is lower than Tc for the tile with the temperature difference of 1.79 °C. When using the median value to assess the temperature, the same trend can be observed: Ti is higher than Tc for the grassland, cement floor, and permeable brick. The temperature differences are 0.56 °C, 1.54 °C and 1.35°C, respectively; Ti is lower than Tc for the tile with the temperature difference of 2.06°C. Thus, for the four kinds of underlying surface studied in this paper, the mean values of temperature
differences range between 0.46 °C and 1.79 °C, whereas the median values of temperature differences range between 0.56 °C and 2.06 °C.

![Figure 3. The scatter plots of Ti and Tc of the grassland, cement pavement, tile, and permeable brick.](image)

| Underlay surface | Temperature type | Mean/°C | Medium/°C | Std. dev. | Min./°C | Max./°C |
|------------------|-----------------|---------|-----------|-----------|---------|---------|
| Grassland        | Ti              | 30.77   | 28.00     | 40.00     | 23.20   | 44.10   |
|                  | Tc              | 29.90   | 27.44     | 26.83     | 23.75   | 40.81   |
| Cement pavement  | Ti              | 38.38   | 36.60     | 48.30     | 29.60   | 52.80   |
|                  | Tc              | 37.92   | 35.06     | 58.20     | 29.44   | 53.38   |
| Tile             | Ti              | 37.76   | 34.50     | 70.55     | 27.30   | 54.40   |
|                  | Tc              | 39.55   | 36.56     | 66.84     | 29.50   | 55.81   |
| Permeable brick  | Ti              | 35.36   | 33.10     | 41.94     | 27.20   | 48.20   |
|                  | Tc              | 34.49   | 31.75     | 42.92     | 27.50   | 48.38   |

According to the results of the Levene test (F (2,11360) =113.006, P=0) and K-S test (p=0), the data have different variances and are non-normal distributed. Thus, we choose the Welch’s test and Game-Howell post hoc test to test the significance of the temperature differences between Ti and Tc.

The significant coefficients P of grassland, cement floor, tile, and permeable brick are 0.002, 0.000, 0.706 and 0.009, respectively. Thus, when using the level of P = 0.001 to assess the significance, Ti
and Tc are not significantly different for the grassland, tile, and permeable brick. The significant difference can only be observed between Ti and Tc from the cement pavement.

5. Discussion and conclusion
This study compares the temperature results of near-ground thermal infrared remote sensing and contact measurement method. Furthermore, the variation trends, correlation, statistical characteristics of the two kinds of the temperature of grassland, cement pavement, tile, and permeable brick are analyzed. Our results indicate that for the four kinds of underlying surface, the curves of thermal infrared temperature Ti and contact measuring temperature Tc are basically similar. The fluctuation of Ti is larger than that of Tc. In general, the temperature differences between Ti and Tc are not large. The mean temperature difference ranges from 0.46 °C to 1.79 °C, whereas the median temperature difference ranges from 0.56 °C to 2.06 °C.

Few studies of the temperature difference between low altitude thermal infrared remote sensing and contact temperature measurement have been conducted in the urban environment. However, there are some similar studies in body temperature measurement. Teran et al. have found that the mean difference between the non-contact infrared temperature measurement and the contact temperature measurement was 0.029 ± 0.01 °C [21]. According to the study by Buono et al. [22], the difference between the non-contact infrared temperature measurement and the contact temperature measurement was 0.17 °C. Two factors can potentially contribute to the higher temperature difference in our study.

First, unlike their studies, our study was conducted in the outdoor environment. The results can be affected by the sunlight, atmosphere, wind and other environmental factors. Second, the observation objects are different. In the studies by Teran et al. and Buono et al., the objects are the human body which is stable in temperature [21,22]. In our studies, the objects are the underlying surface which is variable in temperature. Thus, our study has a higher temperature difference is understandable.

In the correlation analysis, extremely strong correlation can be observed between Ti and Tc of all the kinds of underlying surface. In contrast, the correlation between Ti and Tc of grassland was the weakest. One reason might be the photosynthesis and transpiration. Due to the combined influence of these two functions, the process of heat dissipation and warming is more complex, resulting in a relatively weaker correlation between Ti and Tc. This finding corroborates the studies by Teran et al. and Buono et al., who also find strong positive correlation between non-contact infrared temperature measurement and the contact temperature measurement [21,22].

Furthermore, no significant difference can be observed between Ti and Tc of grassland, floor tile, and permeable brick when the evaluation is at the level of P=0.001. That’s to say, the temperature result of thermal infrared remote sensing and traditional contact temperature measurement for the three kinds of underlying surface are similar. Thus, the near-ground thermal infrared remote sensing has high accuracy in the temperature results. It can be a good way to obtain temperature data in urban and rural environment research. In addition, as a supplement and extension of the research content, this study also reveals the temperature distribution of grassland, cement floor, floor tile and permeable brick, which provides a reference for the study of the urban thermal environment.

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