Applications of UAS-obtained thermal images for vegetation coverage ratio monitoring of mudstone areas

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Abstract. Soil vegetation coverage is a crucial factor for those wishing to protect naked slopes. Thermal imaging enables monitoring of the changes in infrared temperature of a slope surface and calculating the vegetation coverage ratio (VCR). The VCR is an efficient method for determining infrared temperature changes in different slope lands, which include regions exposed to sunlight, vegetation areas, and shaded areas. The thermal images capture the infrared temperature distribution, boundary of vegetation of temperature, and barren vegetation areas. The VCR can be subsequently calculated. In this study, thermal images were obtained using an unmanned aircraft system (UAS) according to airline planning, frame size of an image, and overlapping of lateral and front images for taking pictures. Moreover, 3D images can compare the VCR by calculating the aggregation of the study area and vegetation area. A satisfactory agreement was obtained between the infrared temperature obtained through thermal imaging and the VCR. Thermal imaging can thus be used to monitor changes in the VCR of mudstone. Moreover, a 3D topographic map was created using the UAS-obtained images to overlap with the thermal images.

1. Introduction

Mudstone in Taiwan is a type of mudrock, which is a component of clayey materials of sedimentary rock. Mudstone has poor cementation and is prone to water-induced collapse, inducing mudflow. Taiwan is located in a track of typhoons, and the mudstone in southwestern Taiwan is prone to collapse when typhoons bring torrential rainfall. Weathered-mudstone soil contains highly soluble salts, causes soil layer dispersion, and is prone to erosion by rainfall. Vegetation is the primary measure used to prevent bald mudstone-induced disasters. The vegetation coverage ratio (VCR) is a crucial index indicating the degree of protection of mudstone slopes.

The southern aspect of a mudstone slope has the highest frequency of erosion among all aspects for mudstone in the southwestern area in Taiwan. The temperature changes in naked mudstone depend on the intensity of solar radiation. When the incident angle of sunshine is approximately equal to 90°, a mudstone slope receives the most solar radiation, which abruptly increases infrared temperature [1]. Figure 1 shows the maximum surficial temperature at different incident sunlight in mudstone area [2]. The normalized difference vegetation index (NDVI) is a simple graphical indicator used to analyze remote sensing images. The NDVI quantifies vegetation by measuring the difference between spectral reflectance in the near-infrared (NIR) region and that in the red light (RED) region. Vegetation strongly reflects NIR light but absorbs red light. The formula for calculating the NDVI is as follows [3].

\[ \text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})} \] (1)
The index’s value is between −1 and 1. The index is 0 for naked areas, indicating a reflection rate close to those of soil and rock. The NDVI value for vegetation areas is between 0 and 1 and increases with vegetation density. Nonvegetation areas such as areas of cloud, water, and ice have negative NDVI values.

Figure 1. Maximum surficial temperature at different incident sunlight in mudstone area [2].

NDVI interpretation of satellite images has coarse spatial resolution (20 m in SPOT images), and these interpretations are easily affected by clouds and shadows [4]. However, evaluating how the NDVI changes over time is impossible at this stage. This study aimed to monitor the NDVI by using unmanned aircraft system (UAS)-obtained thermal images for high precision and rapid interpretation, thus enabling determination of the VCR.

A thermal image presents energy transfer through imaging technology by detecting infrared thermal radiation and projecting the energy onto a detector by using a lens. The detector then converts the infrared energy into a digital signal, and a thermal image is obtained on a screen [5]. Testing using a thermal imager is a noncontact and nondestructive rapid testing methodology for detecting surficial infrared temperature changes in objects. Objects exposed to sunshine in the morning exhibit a surficial increase in temperature until noon, and temperature decreases during the night until sunrise. The use of thermal image technologies for infrared temperature monitoring has several advantages, including remote, large-area monitoring, high visibility, quick response, light weight, and digital operation [6].

The applications of thermal imagers range from military industries to medicine, science, and engineering. The technology of the thermal imager has been used for landslide monitoring and is combined with remote sensing [7]. Moreover, it is used for geologic investigation and shore cliff slope stability evaluation [8].

UASs have been used for military purposes since 1917. The two primary categories of UASs are those for fixed-wing planes and those for rotor-type planes. UASs have been widely used for the investigation of postdisaster events and disaster prevention monitoring. The systems are lightweight, small, highly mobile and safe, easy to repair, and low-cost. A UAS can be used in high-risk areas. UASs have been widely used in several fields, such as for search and rescue, forest soil and water conservation [9], and investigation of flood and debris-flow disasters [10–11]. UASs fitted with thermal imagers have been developed in recent years and could provide useful information for landslide monitoring and analysis.

2. Study area
The study area was located in the mudstone area in Tainan city, southern Taiwan (Figure 2), in the range between 22°55′33.3″ N and 120°24′19.5″ E. The area has been designed a special soil and water conservation area since 1998. The elevation of the study area is between 100 and 150 m.
Remote sensing images showed that the area had sparse vegetation between 2010 and 2013, resulting in erosion caused by torrential rains. The vegetation coverage increased in 2015; however, the increase was not substantial.

2.1. Geologic and hydrologic conditions
The geological strata of the watershed are primarily sandy yellow soil and mudstone and were created during the Gutingkeng Formation between the Late Miocene epoch and the Pleistocene (Figure 3). The primary contents of the formation are fine granules of grey mudstone and loose bedding sandstone and interbedded limestone. The mudstone is impermeable and the land became badlands after the mudstone underwent weathering.

Taiwan is located in a subtropical area and has frequent typhoon landings. It experiences monsoon-rain-induced disasters. The rainfall starts to increase in May and is highest in August. January to March is the dry season.

3. Method
NEC F30W was the thermal imager used in this study. The size of the imager was 100 × 65 × 45 mm³, and its weight was 300 g. The UAS fitted with the NEC F30W thermal imager could measure infrared temperatures between −20 and 350°C. The two global positioning systems (GPSs) of the UAS had an autopilot function and predefined flight path planning (Figure 4).

A postprocessing package was used for thermal image analysis. The package provides thermal image emissivity correction, image correction, autocalculation of the emissivity of the entire area, partial enlargement, 90° rotation, multipoint temperature measurement, and graphic demonstration. The figures provided by the package include the regional thermal distribution curve, isotherm diagram,
profile thermal curve, dynamic thermal curve, and 3D thermal trend diagram. The study used multiple regions and single-region thermal image analysis for determining the highest, average, and lowest infrared temperatures (Figure 5).

4. Results and discussion

4.1. Field monitoring by UAS taken of thermal images
Thermal images were obtained by the UAS on 16 August, 2017, at 13:00 at an elevation of 51 m by using a positioned GPS. Figure 6 shows overlapped UAS-obtained thermal images and satellite images (Google Earth) in the study area.

Figure 6. Overlap of UAS-obtained thermal images and satellite image (Google Earth) for the study area.

A threshold infrared temperature was employed to separate vegetation and naked areas. In general, the infrared temperature was between 30°C and 50°C in the study area. For example, image T00911 shows that the vegetation area had an infrared temperature less than 36°C and thus this temperature is suitable for separating the naked and vegetation areas (Figure 7). This temperature was thus used in the analysis. Equations should be centred and should be numbered with the number on the right-hand side.

Regional temperature analysis was performed on the UAS-obtained thermal images separated at 36°C for the following aerial images of the study area: T00874, T00885, T00900, T00907, T00909, and T00911 (Figure 8).

A histogram of the number of grid points in the thermal images was created after performing the single-region thermal image analysis. Each thermal image was separated by the threshold infrared temperature (36°C) into naked and vegetation areas. The VCR was calculated using the number of grid points below 36°C divided by the total number of grid points in the thermal image.

The study separated images using the infrared temperature of 36°C and the distribution of temperature by using the number of points in the thermal image. The histogram was separated into two parts: those of temperature 35.99° or lower and those of temperature 36.00°C or higher. The obtained histogram is presented in Figure 9. The number of grid points in image T00874 at 35.99°C or lower and at 36.00°C or higher were 6957 and 12243, respectively. The corresponding VCR was thus 36%.

Similarly, the VCR for the thermal images T00885, T00900, T00907, T00909, and T00911 (Figure 8) were 3%, 47%, 15%, 57%, and 48%, respectively.

In this study, 295651 grid points were below 36°C and 180725 grid points were above 36°C. The number of grid points below 36°C divided by the total number of grid points is the VCR, which was 62.1% in the study area.
4.2. Vegetation area calculation using a digital terrain model

A 3D digital terrain model (DTM) was constructed in this study by using Pix4D (professional drone mapping and photogrammetry software). The study area and vegetation cover area were directly calculated for VCR estimation. The UAS-obtained thermal images were overlapped with the remote image obtained from Google Earth (Figure 6). The 3D study area, naked area, and vegetation cover area were 24,443, 8,359, and 16,084 m², respectively. The VCR in the study area was 65.8%.

5. Conclusion

This study used UAS-obtained thermal images for monitoring the vegetation ratio in the study mudstone area. The thermal images show distinct infrared temperature differences between naked and vegetation areas. Moreover, the eroded gully and ground crack areas show a lower infrared temperature than other areas. The thermal images clearly separate nonvegetation and vegetation areas, with these areas having different infrared temperatures, thus enabling calculation of the VCR.
The VCR in the study area, obtained using thermal image interpretation, was 62% and comparable to the 65.8% calculated using the UAS-obtained thermal images in the studied area. Thermal images can be effectively used to estimate the VCR in mudstone areas. This study provides another approach for monitoring changes in the VCR in real time. UAS-obtained thermal images provide the VCR with high precision, which is required in the regional area.

Acknowledgments
Financial supports under contract MOST 107-2625-M-415-001 of Ministry of Science and Technology in Taiwan are appreciated.

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