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Solar radiation analysis on GIS considering influence of weather condition and partial shadow analyzed by high-resolution digital surface model

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Abstract

The use of photovoltaic (PV) systems is rapidly increasing worldwide as a source of renewable power generation. During operation, their power output is influenced by weather conditions. If the surface of the PV cell does not receive adequate sunlight due to shade or precipitation, less electricity will be generated. An optimal location for a PV system that receives enough solar radiation must therefore be determined by considering the influence of partial shadows. In this work, solar radiation data is analyzed using a geographic information system (GIS) and digital surface model (DSM). However, the resolution of the DSM provided by Kitakyushu City was not high enough to describe the necessary details of partial shadows. To overcome this problem, a method using a high-resolution DSM based on aerial photographs taken by a drone is proposed. The proposed high-resolution DSM was able to accurately reproduce the shape of the partial shadow and evaluate the detailed locations and shapes of partial shadows. Evaluating the solar radiation considering weather conditions by the data values obtained from a pyranometer indicated that a pyranometer could be used to correct the result of solar radiation analysis considering weather conditions.

Keywords: Geographic Information System, Digital Surface Model, Photovoltaic System, Solar Radiation, Partial Shadow, Weather Condition

1. Introduction

Using renewable energy can increase a country’s energy self-sufficiency and reduce their fossil fuel consumption. As such, the Japanese government has encouraged renewable energy utilization and renewable energy has increasingly penetrated the market since 2013. To reduce research and development costs, power system and rationalization controls have been promoted since 2016 [1]. In April 2017, the corporations among relevant government agencies pledged to increase renewable energy utilization by using feed-in tariffs, adjusting the power system, enhancing the efficiency of power generation equipment, and reducing costs [1].

As solar energy is abundant on Earth and does not depend on the area, photovoltaic (PV) systems offer a promising alternative for electricity generation. In addition, PV systems are more easily introduced than solar heat and wind power generation systems because their electric power generation and profitability are very influenced by their potential [2].

Given that the power output of PV systems can be influenced by weather conditions and shadows of buildings and trees, an estimation of their electricity outputs using solar radiation data considering the influences of shadows and weather conditions before construction would be beneficial. Additionally, weather patterns and partial shadows could cause a PV system to generate less electricity. Therefore, optimum locations containing suitable solar radiation values that consider the influence of partial shadows must be determined.

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Previously, a technique to analyze the amount of solar radiation using a geographic information system (GIS) and digital surface model (DSM) provided by Kitakyushu City was developed. However, while the DSM provided by Kitakyushu City was sufficient for selecting suitable PV system locations from a wide area, it does not provide a high enough resolution to describe partial shadows in detail.

Therefore, this this research aims to establish a technique to analyze solar radiation considering the influence of partial shadow by means of a high-resolution DSM developed from aerial photographs taken by a drone. Solar radiation data is then analyzed considering partial shadows and weather conditions based on data collected with a pyranometer.

2. Solar Radiation Analysis on GIS

2.1. GIS utilization

A GIS is used for the creation, management representation, search, analysis, and sharing of geospatial information and can virtually reconstruct real-world geospatial models, as shown in Fig. 1 (a) [3]. A GIS manages data in layers consisting of information on attributes and their positions. These layers are then superimposed to produce real-world models, as shown in Fig. 1 (b), making it possible to grasp the geographical distribution and relationship of GIS data [4].

The influence of partial shadows caused by buildings and trees should be considered when evaluating solar radiation on a PV system. As such, solar radiation was analyzed using Kitakyushu City's DSM (50 cm×50 cm mesh), shown in Fig. 2, which includes the heights of trees and buildings [5]. The DSM creates a surface by connecting the points of each mesh containing height data; a 3D DSM model overlaid with an aerial photograph is shown in Fig. 3.

2.2. Solar radiation analysis considering influence of weather conditions and partial shadows

Solar radiation data considering several weather conditions was acquired from New Energy and Industrial Technology Development Organization (NEDO) and was analyzed using GIS and DSM [6].

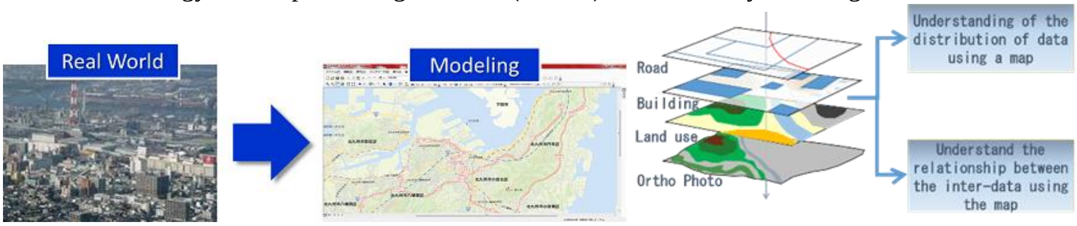


Fig. 1. GIS utilization: (a) GIS image and (b) GIS principle.

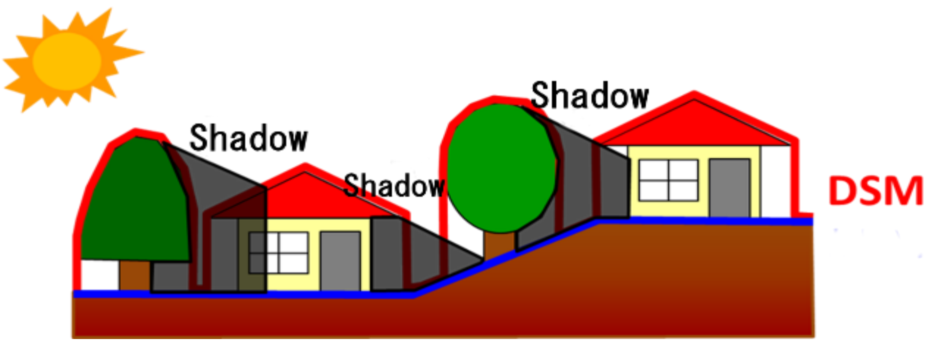


Fig. 2. DSM image

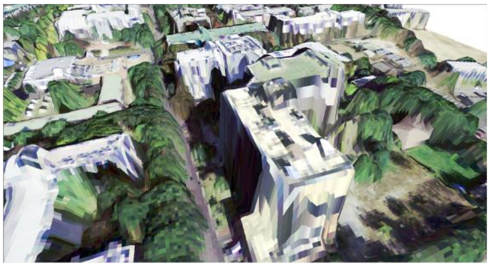
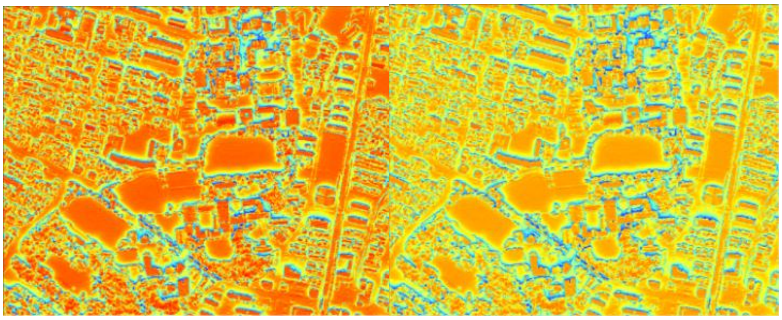


Fig. 3. 3D model of DSM overlaid with an aerial photograph



(a) (b)

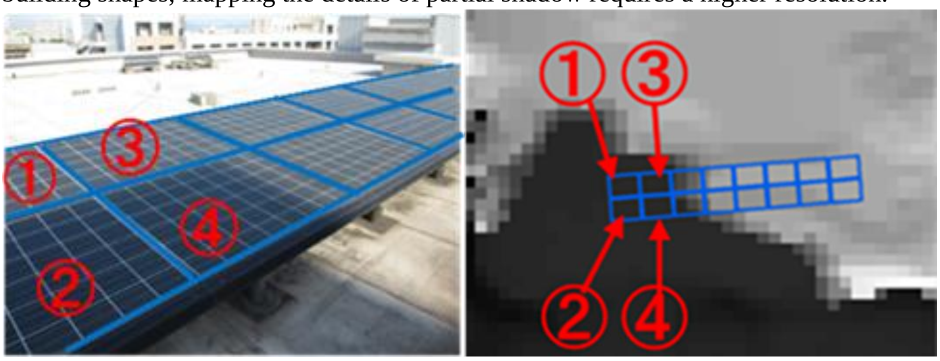
Fig. 4. Correction of Solar radiation map by the use of NEDO: (a) basic solar radiation map and (b) solar radiation map corrected by the use of NEDO.

The original and corrected solar radiation maps of [] are presented in Fig. 4, where a redder color indicates higher levels of solar radiation.

A database creation method from analysis results was also developed to offer services via cloud computing [4].

2.3. Gaps in partial shadow evaluation using Kitakyushu City's DSM

Partial shadows blocking PV system's access to solar radiation were evaluated using Kitakyushu City's DSM; results are shown in Fig. 5, where the blue frame indicates PV panel area. Here, although no partial shadows covered them, the solar radiation analysis indicated that panels 1 and 3 were covered. A 3D DSM model created with a 50 cm × 50 cm mesh is shown in Fig. 6, where PV systems are installed over the yellow buildings and the red zone creates a shadow. As the low resolution of the DSM provided inaccurate building shapes, mapping the details of partial shadow requires a higher resolution.



(a) (b)

Fig. 5. Comparison: (a) partial shadow actually covering PV panels and (b) indicated partial shadow coverage by solar radiation analysis.

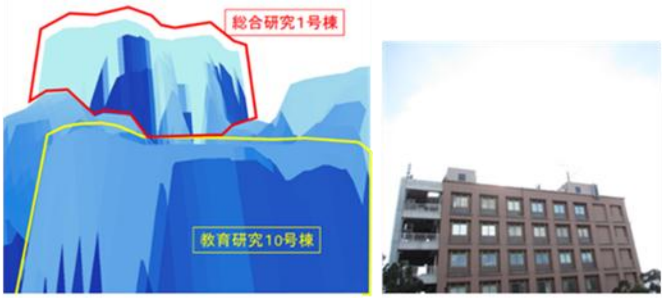
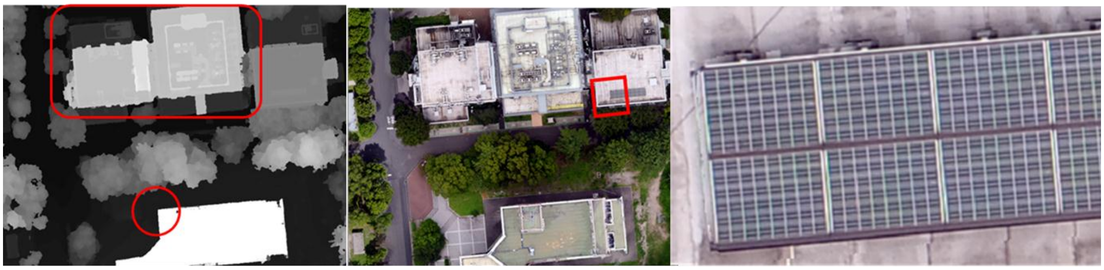


Fig. 6. 3D DSM model of buildings created using a 50 cm × 50 cm mesh and a photograph of the buildings

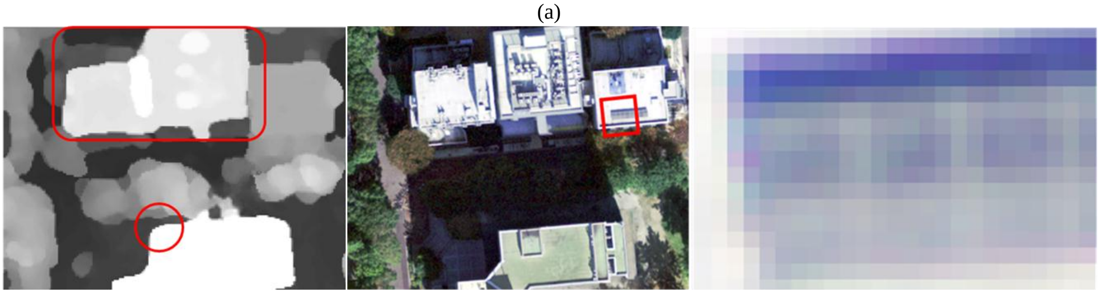
3. Solar Radiation Analysis on GIS Considering Influence of Weather Condition and Partial Shadow Analyzed by the High-Resolution DSM

3.1 High-resolution DSM created by aerial photograph using a drone

To overcome the problems caused by a low-resolution DSM, a drone was used to take high-resolution aerial photographs and thus create a high-resolution DSM [7]. The airplane used to collect data for the DSM created by Kitakyushu City photographed at about 3,000 meters above the ground; photographs were taken from about 100 meters above the ground by the drone used here. The resulting aerial photographs and DSMs are shown in Fig. 7. The aerial imaging by the drone clearly captures small cells of panels, whereas the photograph taken of the same panels by an airplane is unclear. Moreover, the resulting DSM accurately reproduced the corners of buildings; those produced by Kitakyushu City's DSM are rounded. Overall, the 1.6 cm×1.6 cm mesh of the proposed DSM is more accurate than the 50 cm×50 cm mesh of Kitakyushu City's DSM.



(a)



(b)

Fig. 7. Comparison between the high-resolution DSM and Kitakyushu City's DSM: (a) the high-resolution DSM and (b) Kitakyushu City's DSM.

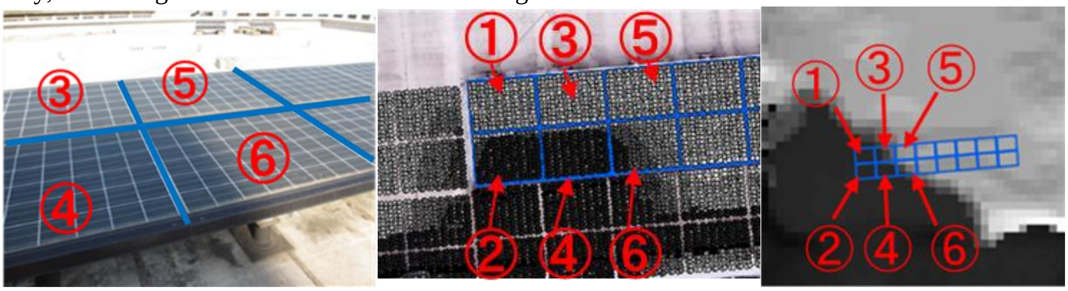
3.2 Solar radiation analysis considering influence of partial shadow by using the high-resolution DSM

Due to the increased number of data points, the high-resolution DSM required about five days to finish the analysis using the area solar radiation tool on ArcGIS [8]. Therefore, the DSM was analyzed using the points solar radiation tool instead, in which only the points plotted on panels of a PV system were analyzed, allowing for analysis to complete in only two minutes. Their points are then stored in the database. Therefore, the database can carry out real-time and high-speed processing.

A partial shadow found from the solar radiation analysis obtained from the high-resolution DSM is compared with the one obtained from Kitakyushu City's DSM in Fig. 8, where the black areas indicate shadows. Clearly, the high-resolution DSM more accurately reproduced the partial shadow by showing shadow coverage on panels 2, 4, and part of 6, and not on panels 1 or 3, as was indicated by Kitakyushu City's DSM. Thus, the developed high-resolution DSM was determined to accurately evaluate the detailed location and shape of partial shadows.

3.3 Solar radiation analysis considering weather condition using a pyranometer

Using data from NEDO and a pyranometer can correct solar radiation analysis by considering weather conditions. The pyranometer used to correct of solar radiation values is shown in Fig. 9. The measured value from the solar radiation analysis-based GIS was used as the correction coefficient. The corrected solar radiation values are shown in Fig. 10, where redder regions have higher values of solar radiation. Clearly, correcting solar radiation levels considering weather conditions.



(a) (b) (c)

Fig. 8. Solar radiation analysis using developed high-resolution DSM: (a) actual partial shadow, (b) solar radiation analysis using the high-resolution DSM and (c) solar radiation analysis using Kitakyushu City's DSM.

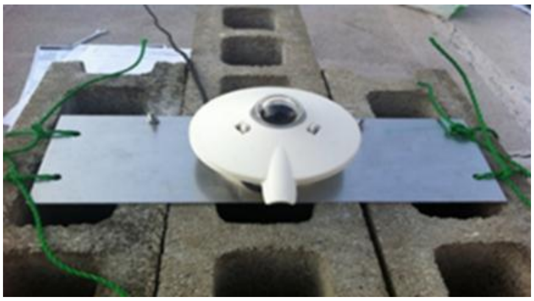
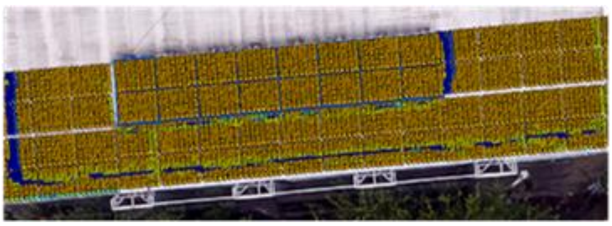


Fig. 9. Pyranometer



(a)

(b)

Fig. 10. Correction for weather conditions using a pyranometer: (a) solar radiation analysis before correction and (b) solar radiation corrected for weather conditions using correction coefficients.

4. Conclusion

A more-precise solar radiation analysis method considering partial shadows and weather conditions on PV systems was proposed. An evaluation of the influence of the partial shadows covering PV systems using Kitakyushu City's DSM that the resolution provided by Kitakyushu city's DSM, although sufficient to find locations with suitable solar radiation levels over a wide area, it was not accurate enough to describe the partial shadows in detail. Therefore, a high-resolution DSM was developed using high-resolution aerial imaging via drone to more accurately capture partial shadows. Although the increased resolution required more computing time using the area solar radiation tool on ArcGIS commonly used, using the points solar radiation tool on ArcGIS was able to significantly reduce this added time.

The high-resolution DSM was found to accurately evaluate the detailed locations and shapes of partial shadows. Solar radiation values were also accurately mapped after being further corrected with weather conditions acquired via NEDO or a pyranometer. Future work should consider PV operation estimated by solar generation analysis.

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