International Journal of Smart Grid and Clean Energy

Establishing a support system for the installation of photovoltaic generation system considering historical cityscape and landscape using Geographical Information System (GIS)

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Abstract

The utilization of the photovoltaic systems is expected to spread worldwide, solving greenhouse gases (GHG) emissions and the problem of fossil fuel depletion. Therefore, the Japanese government has been implementing a concrete policy to promote the widespread utilization of photovoltaic systems, such as the introduction of feed-in tariffs. As a result, the penetration of photovoltaic power generation systems in Japan is rapidly increasing into multiple applications and infrastructures.

On the other hand, the photovoltaic system requires an area size larger than a certain size for installation. In addition, the photovoltaic system stands out from the surrounding landscape due to the reflection of sunlight. So the influence on the landscape such as historical townscape and natural environment is becoming a concern. For this reason, in Japan, it is necessary for local governments to take into consideration the landscape issues by establishing the ordinances aiming for a harmony between the landscape and the installation of solar power generation systems. So far, our research team has built a solar radiation analysis system that takes into consideration the influence of surrounding buildings and trees using the geographic information system (GIS) and digital surface model, in order to solve the problems of the photovoltaic power generation system that is affected by the surrounding buildings, tree shadow effects, and weather conditions. In addition, the solar radiation analysis system has also been constructed. It takes into consideration weather conditions in analyzing the solar radiation by correcting with the value of a solar radiation value meter and the value of solar radiation amount data, considering the past weather conditions.

The purpose of this research is to support the examination of installation of photovoltaic power generation system which can harmonize the installation of photovoltaic power generation system with the landscape, with a focus on a historical cityscape. Specifically, a system that can select roofs and lands that could obtain a lot of solar radiation while taking into consideration the scenery is constructed. Using this system, the photovoltaic power generation panel installation location could also be selected so that it cannot be seen from the walking course of the historical cityscape. The system is utilizing the solar radiation analysis system, which is the result of our previous research, and the skyline function of the geographic information system.

Keywords: Geographic information system, solar radiation analysis, digital surface model, photovoltaic, landscape, skyline, TIN model

1. Introduction

Solar power generation systems are expected to spread for reducing carbon dioxide and solving the problems of fossil fuel depletion. In Japan, the introduction of solar power generation systems has been spreading rapidly since the government implemented "Feed-in Tariff (FIT) for renewable energy" on July 1, 2012 [1].

On the other hand, solar power generation systems are influenced by shadows of buildings, trees and weather conditions. As a result, there are several cases that the installed solar power generation systems

* Manuscript received July 9, 2019; revised February 2, 2020.

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doi: 10.12720/sgce.9.2.375-382

cannot generate power as assumed before introduction. Therefore, our research team has constructed the amount of solar radiation simulation system using Geographic Information System (GIS) and Digital Surface Model (DSM) [2]. It became possible to analyze the amount of solar radiation considering the shadows of buildings and trees by introducing this simulation system. In addition, our research team has also constructed the amount of solar radiation simulation system that cooperates with this system and the solar radiation amount DB of New Energy and Industrial Technology Development Organization (NEDO) including the data of whole sky solar radiation meter that takes the past weather conditions into account. As a result, it became possible to incorporate weather conditions into GIS [3]. Furthermore, in order to develop solar radiation volume simulation service using cloud computing, our research team has constructed a method to make solar radiation analysis database [4]. Consequently, it has become possible to analyze how much amount of solar radiation can be obtained in the planned site before introducing the photovoltaic power generation system. In addition, there is also a case study to examine the recombination circuit that takes into account the effect of the shadow applied to the part of the solar power panel [5].

On the other hand, photovoltaic power generation systems require a larger area than a certain area scale. It also stands out from the surrounding landscape by reflection of sunlight. Therefore, the influence on the landscape, such as the historical townscape and the natural environment of the photovoltaic power generation system must be concerned. As a result, in Japan, local governments are required to give consideration to landscapes, such as establishing ordinances aimed at harmonizing the landscape with respect to the installation of solar power generation systems [6]. Therefore, this research focuses on the historical cityscape. Thus, a solar panel installation support system that takes scenery into consideration so that solar panels cannot be seen from the city walking course of historical cityscape is constructed by utilizing 3D functions and DSM data of GIS. Furthermore, in cooperation with the solar radiation amount simulation system which is the result of research so far, a system that can select the roof and the land that can secure solar radiation while supporting the installation of landscape-conscious solar power generation panels is also constructed. In other words, it aims to support examination of installation of solar power generation system that can harmonize the landscape.

2. System Construction

2.1. GIS utilization overview

GIS is a technology for the creation, management representation, search, analysis and sharing of geospatial information [7]. Fig. 1 shows the ability of the system to construct a model for the real world on the computer. GIS manages data in a film called a layer. This layer consists of position information and attributes information. As shown in Fig. 2, GIS constitutes the real world model by superimposing layers. This makes it possible to grasp the geographical distribution and geographical relationship data. Therefore, it is possible to grasp the geographical distribution and geographical relationship of GIS data. Data used in GIS is called geospatial data, with the existence of a very big data. Moreover, GIS has a variety of functions. Typical features and geospatial data of GIS are shown in the following Fig. 3. In this figure, Digital Surface Model (DSM) considers the height of trees and buildings, while Digital Elevation Model (DEM) represents the ground surface and road network, providing roads details. The overview of DSM and DEM is shown in Fig 4. As shown in this figure, the DSM makes it possible to consider the shadows of buildings and trees. Tracking function handles the trajectory of the acquired position information by GPS. Spatial statistic functions aggregate the objects in the view. Geocoding is responsible for coding the text address. 3D function handles the three-dimensional data. Network analysis function performs the analysis of the network data. Finally, Spatial analysis function analyzes the events, which might occur in the targeted area [8]. The data that is used for GIS is divided into raster data and vector data. Raster data is a data format suitable for expressing a phenomenon in which space changes continuously [9]. Examples of raster data include aerial photographs, altitude data (DEM and DSM), results of solar radiation amount simulation, and etc. The overview of raster data is shown in Fig5. Vector type is a data format suitable for expressing features with definite position and boundary [9]. Vector data is roughly divided into (1) point, (2) line, (3) polygon. The image of vector data is shown in Fig 6.

Fig. 1. GIS image

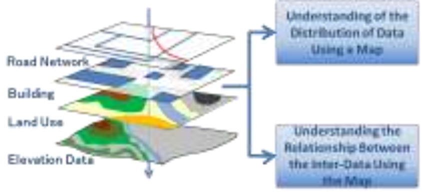


Fig. 2. The basic principle of GIS

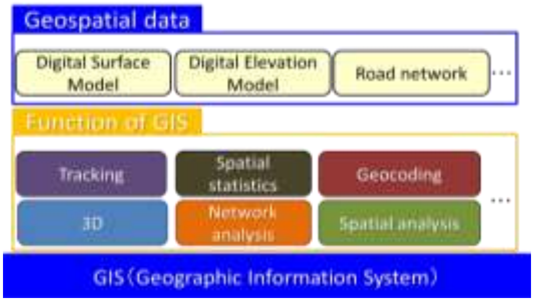


Fig. 3. Geospatial data-function of GIS

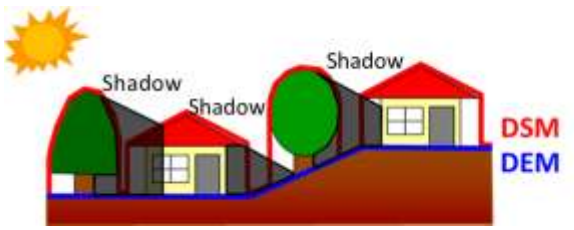


Fig. 4. Overview of DSM and DEM

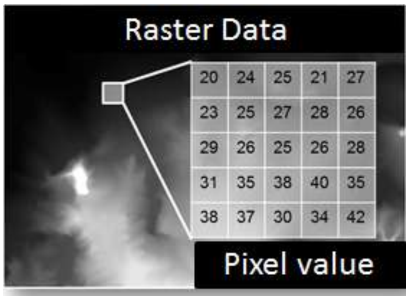


Fig. 5. The overview of raster data

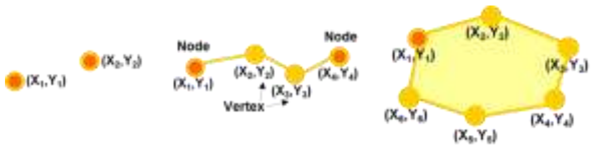


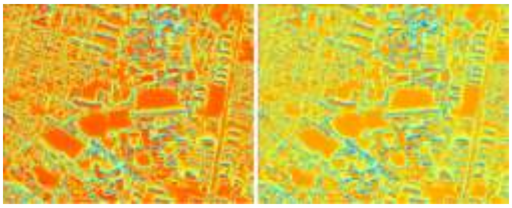
Fig. 6. The image of vector data

2.2. The amount of solar radiation simulation system using GIS

So far, our research team has constructed the amount of solar radiation simulation system with clear weather conditions by combining the GIS function of Spatial Analysis and DSM which is elevation data holding the height of buildings and trees. In this system, shadows of buildings and trees can be considered. The representation of the shadow in this system is shown in Fig.7. In Fig. 7, portions surrounded by red circles represent shadows. In our research team, GIS applications are used ArcGIS. The simulation results are released from the regional information portal site “G-motty” using a map. Fig. 8 shows the solar radiation simulation map released from the regional information portal site G-motty. In this map, red indicates that the amount of solar radiation is large and blue indicates that the amount of solar radiation is small. Also, in order to attract the user's interest, the user moves the circle in Fig. 8 to confirm the amount of solar radiation using the application called spy glass [9]. With this amount of solar radiation simulation, it becomes possible to extract the land and the roof from which the amount of solar radiation can be obtained topographically. However, as weather conditions are clear and weather factors are not taken into consideration, there is a divergence from the actual amount of insolation. Therefore, a correction method with the value of the solar radiation amount DB of New Energy and Industrial Technology Development Organization (NEDO) considering past weather conditions [3] has been constructed. Fig. 9 shows the solar radiation simulation results before and after correction.

Fig. 7. Representation of shadows of buildings and trees

Fig. 8. The solar radiation map published from the regional information portal site G-motty



(a) (b)

Fig. 9. Comparison of the amount of solar radiation analysis results and the corrected results by the value of NEDO (Annual amount of solar radiation) : (a) Analysis results thus far (b) As a result of correcting the value of NEDO

2.3. System overview

The proposed model using GIS that was constructed in this research is composed of the following three functions.

1. Creating TIN model and checkpoints data with height from DSM.
2. Executing Skyline processing.
3. Extracting roof and land that can secure efficient solar radiation while maintaining historical landscape.

The flowchart diagram of this model is shown in Fig.10.

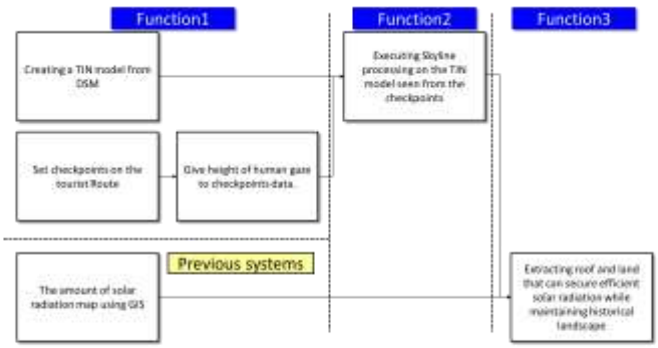


Fig. 10. Function of the model and flowchart diagram

2.4. The demonstration area of this research

In this research, focusing on the historical cityscape, the influence on the landscape by solar panels is considered. The demonstration area was Koyanose-area of Yahatanishi-Word, Kitakyushu-City, Fukuoka-Prefecture, Japan. With the establishment of the 1635 participation interchange system, the Tokugawa shogunate developed news stations in all over Japan, with the main road of Edo (current

Tokyo) as the main road [10]. In the Kiyase area, a post office town called "Koyanose-shuku" was set up, buildings of white walls are still present and the walking course of the historical cityscape is set so that tourists can watch as they walk around the building at the time there. Fig. 11 shows the cityscape of the Koyanose-area.

Fig. 11. Townscape of Koyanose

2.5. Function of creating TIN model and checkpoints data with height from DSM (Function1)

In order to execute Skyline processing in GIS, it is necessary to use the elevation model. However, in that process, raster data cannot be used. The data that can be used in this process is the vector data or the surface model, such as TIN data. Therefore, it is necessary to convert from DSM which is raster data to vector data or TIN data. However, in the case of using vector data, in order to execute Skyline processing, it is necessary to truncate the decimal part of the elevation data, and accuracy deteriorates. For this reason, it is decided to adopt TIN data for this research. The TIN data is data formed by triangle from the observed point cloud data, and is mainly used as altitude data. Since TIN data is data created from point data unlike raster data of a group of cells (pixels) organized in rows and columns, the larger the number of points, the smoother the surface can be represented [11]. In this research, TIN data was prepared from DSM of 50 cm mesh. The created TIN data is shown in Fig.12.

Next, it is necessary to set a checkpoint to execute Skyline processing. The total of 29 checkpoints was set the intersection and before sightseeing spots on the town walking route. The checkpoint was set at a height of 1.5 m according to the viewpoint of tourists. The number of checkpoints was designed to be able to increase or decrease depending on the situation of the area to be verified. In addition, the height of checkpoints is designed to freely change the height freely, such as matching the viewpoint of children. Fig. 13 shows a map in which a street walking route (blue line) and a checkpoint (pink circle) is superimposed on an aerial photograph in which the TIN data is three-dimensioned as a reference altitude.

Fig. 12. TIN data of Koyanose area

Fig. 13. Tourist routes and checkpoints on the 3D aerial photograph

2.6. Function of executing Skyline processing (Function2)

The Skyline process is a process of generating a 3D polyline representing a sky and a line, separating the surface and features around each observation point [12]. In this research, 29 points of checkpoint and TIN data in Skyline processing is used, and spatially grasp the place seen from 29 checkpoints. Fig. 14 shows the result of executing Skyline processing at one checkpoint. In Fig.14, portions visible from a pink checkpoint is an area indicated by the red line. Fig. 15 shows the verification results of Skyline processing. Fig. 15 (b) shows a picture taken north from the checkpoint. ① in (a) and (b) in Fig. 15 shows the same roof. It can be seen that a solar power generation panel is installed on the roof of ① in Fig. 15 (b). Fig. 15 (a) shows that a part of the roof can be seen also by the Skyline processing result. In other words, Skyline processing shows the same result as the real world. In addition, Fig.16 shows the verification result of another checkpoint. In picture (b) of Fig. 16, the roof of the second floor cannot be seen except for the building of ②. The Skyline processing in (a) of Fig.16 also shows the same result.

From the above, it can be seen that the roof of the building entering the sight can be extracted by Skyline processing. Therefore, Skyline processing was executed for 29 checkpoints in the same way. The processing result is shown in Fig.17. Fig.18 shows the roof that can be seen partly from the checkpoint by Skyline processing. The area shown in orange in Fig. 18 is the roof visible from the checkpoints. As mentioned above, the roof visible from the checkpoint on the walking course of the historical cityscape has been extracted. Buildings what roof cannot be seen even in buildings along the walking course of the historical cityscape have not been extracted. Also, the roofs which are away from the walking course of the historical cityscape but are visible from the check points have been extracted. If this method is not used, the municipalities must restrict the solar power generation panels to not be placed on all the buildings along the walking course of the historical cityscape. By using this method, it becomes possible to regulate the minimum necessary building which can be seen from the walking course of the historical cityscape.

Fig. 14. Result of Skyline processing

(a) (b)

Fig. 15. The first verification of skyline processing: (a) Processing Skyline (b) Photo taken from checkpoint

(a) (b)

Fig. 16. The second verification of skyline processing: (a) Processing Skyline (b) Photo taken from checkpoint

Fig. 17. Result of Skyline processing at 29 checkpoints

Fig. 18. Royles seen from checkpoint as a result of Skyline processing

2.7. Function of extracting roof and land that can secure efficient solar radiation while maintaining historical landscape (Function3)

Function 3 is a function that superimposes an annual solar radiation simulation map constructed by our research team and the roofs visible on the walking course of the historical cityscape on the GIS. With this function, it is possible to visualize the roof where the solar power generation panel cannot be seen from the walking course of the historical cityscape and the amount of solar radiation rushes much. The result of superimposing is shown in Fig.19. The area shown in black in Fig. 19 is roofs visible from the checkpoints of the walking course of the historical cityscape. In addition, the color of the other areas indicates that the annual amount of solar radiation is large for red, and the yearly amount of solar radiation is small for blue. As a result, in Fig. 19, the red or orange area can be regarded as a roof capable of securing the amount of solar radiation without affecting the landscape of the historical cityscape.

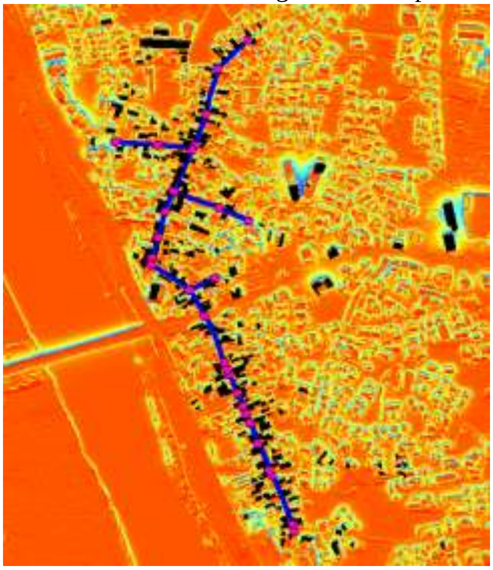


Fig. 19. Superposition result with solar radiation map

3. Conclusion

In this research, focusing on the historical cityscape, it has been conducting research aiming at building a power generation panel installation support system utilizing GIS 's three - dimensional function and DSM to consider the scenery so that the solar power generation panel can not be seen from the walking course of the historical cityscape.

In 3D function, TIN data was created from DSM. Furthermore, it has been executed to extract the roof visible from the checkpoint set on the street walking route by Skyline processing using TIN data. Furthermore, by combining with the research results so far, it has been possible to extract the roof where the amount of solar radiation falls considerably while paying attention to the landscape of the historical townscape, and the purpose of this research could be achieved.

In the future, our research team is planning to apply the results of this research to support installation of photovoltaic power generation system that taking into account the landscape of the natural environment.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Atsushi Shiota carried out the research. Atsushi Shiota, Thongchart Kerdphol and Yasunori Mitani analyzed the data. Atsushi Shiota wrote the paper. All authors had approved the final version.

Acknowledgements

I would like to thank the staff of Kitakyushu city who provided DSM for this research. I also thank you for all the students in the laboratory who carried out research together.

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