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Proposal of a method for capturing and predicting cloud motion using omnidirectional camera images

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Abstract

Renewable energy is an energy source that contributes to the improvement of Japan's energy self-sufficiency rate due to greenhouse gas emission control. In Japan, photovoltaic (PV) regardless of the installation location is rapidly spreading for both residential and non-residential homes due to the introduction of Feed-in Tariff (FIT) and the reduction of the introduction price. On the other hand, PV is susceptible to the rapid weather changes, which may affect the balance of power supply and demand. Therefore, the electricity supplier needs to maintain the stability of the power while considering the photovoltaic power generation. The total amount of power generation is adjusted by between the dynamic PV power generation and demand. Thus, our research team has simulated the solar radiation simulation system considering the influence the shadows of buildings/trees using the Geographic Information System (GIS), superimposing a solar surface-based Digital Surface Model (with elevation information). Furthermore, this work combined the previous research with all-sky images taken by an omnidirectional camera using a fisheye lens. Consequently, it has been constructed a new method to capture the effects of clouds based on the amount of solar radiation. The purpose of this research is to propose a new method to predict clouds movement using an omnidirectional camera image.

Keywords: Geographic information system, digital surface model, photovoltaic, solar radiation forecast, omnidirectional camera

1. Introduction

Solar power generation is expected to solve the global warming and fossil fuel depletion issues. Therefore, the Japanese government has been proactively proposed a new policy related to this concern. In Japan, the surplus power purchase system was introduced in 2009, resulting in the rapid increase of domestic shipments of solar panels. Furthermore, since the Feed-in Tariff (FIT) was launched in 2012, the installed amount of non-residential solar system has also rapidly increased. In addition, the facility cost of photovoltaic power generation is decreasing due to technological development and the increase of the installed amount of solar systems [1]. The installed amount of solar power in Japan has increased, and will be reach 42.29 million kW by the end of fiscal 2016. On the other hand, the issue of solar power generation is influenced by the fluctuation of weather conditions. Electric power companies set supply quantity according to demand to maintain the stability of electric power while considering the fluctuation of photovoltaic power generation. In addition, new electric power companies have a smaller amount of generated electricity compared to the major power companies. So, it is difficult to achieve supply quantity according to demand. For this reason, the "30-minute simultaneous amount" is set so that the new power company can adjust the total output of the power plant and purchase additional power to coincide the lack

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within 30 minutes. The new power company tunes the supply within the short 30 minutes. However, since the photovoltaic power generation is prone to have the fluctuation, an additional mechanism is necessary to achieve the same amount of generation for 30 minutes simultaneously. One of the mechanisms is to predict the amount of solar radiation falling from the sun. If this amount of solar radiation can be predicted, the generated power from the solar system can be predicted. The electric power company can measure the generated power in advance, leading to adjustment of the balance between supply and demand. One of the conventional methods for predicting the amount of solar radiation is known as SOLASAT 8-Nowcast service using images taken by the weather satellites [2]. This method is suitable for predicting the solar radiation over a wide range (after 30 minutes to several hours). However, there are some technical concerns as follows; (1) the spatial resolution of SOLASAT 8-Nowcast is as low as 500m mesh; (2) the prediction method is based on an image viewed from the sky; (3) it is impossible to consider the influence of shadows based on buildings/trees and the influence of scattered sunlight based on clouds.

On the other hand, our research team has built a new simulation system based on solar radiation that considers the shadows of buildings/ trees using Geographic Information System (GIS) and Digital Surface Model (DSM) [3]. This system is simulated under weather conditions (sunny). In addition, our research team has established a new method to incorporate weather elements based on the data from a pyranometer [4]. Furthermore, the proposed system is combined with an omnidirectional image taken from an omnidirectional camera using a fisheye lens. In this way, it is constructed a new method to capture the effects of clouds considering the amount of solar radiation.

The purpose of this research is to develop a new method to estimate the movement of clouds from omnidirectional camera image, estimating the amount of solar radiation in the existing and future power systems.

2. System Construction

2.1. GIS utilization overview

GIS is a technology for modeling the real world on a computer. It is possible to comprehensively manage and process data (spatial data) with information on a location based on a geographical location for performing advanced analysis. 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 [5]. This layer consists of position information, attributing information. The Data Base Management System (DBMS) manages data using the setting key items on a table, linking the items. GIS also has a function of linking tables. In addition to this data, GIS has the feature for linking a table to a key. It is called "position" which can show the coordinates. These coordinates could not found in other DBMS [6]. Typical features and geospatial data of GIS are shown in Fig.2. The tracking function handles the trajectory of the acquired position using GPS. Spatial statistic functions aggregate the objects into the view. Geocoding is responsible for coding the text address. The 3D function handles the three-dimensional data. Network analysis function performs the analysis of the network data. Finally, the spatial analysis function analyzes the events, which might occur in the targeted area [7]. In this research, the 3D and Spatial Analysis functions are used. The data for GIS is divided into raster data and vector data. Raster data is a data format, which is suitable for expressing a phenomenon where the space changes continuously. Examples of raster data include aerial photographs, altitude data (DEM and DSM), results of solar radiation amount , and etc. The overview of raster data is shown in Fig.3. The vector type is a data format suitable for expressing features with the defined position and boundary. Vector data is roughly divided into (1) point, (2) line, (3) polygon [8]. The image of vector data is shown in Fig.4.

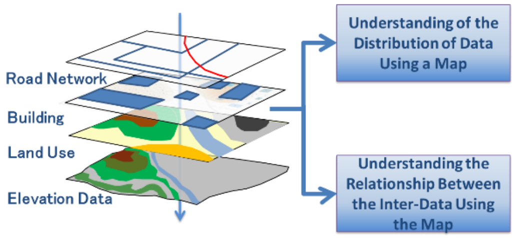


Fig. 1. The basic principle of GIS

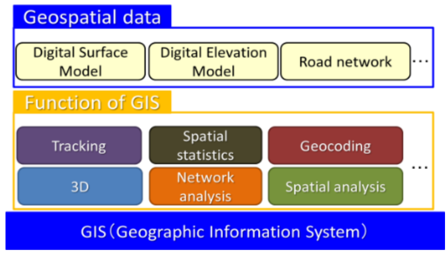


Fig. 2. Geospatial data-function of GIS

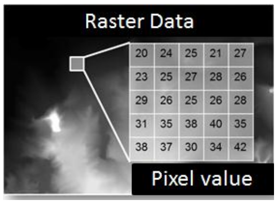
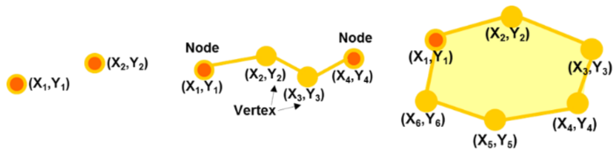


Fig. 3. The overview of raster data



(a) Point (b) Line (c)Polygon

Fig. 4. The image of vector data

2.2. Outline of previous research

Our research team has built a solar radiation system using GIS and Digital Surface Model (DSM) to analyze solar radiation considering the shadows of buildings and trees. Another elevation model handled by GIS is the Digital Elevation Model (DEM). Fig. 5 shows a schematic diagram of the DSM and DEM. The difference is that the DSM represents the elevation data with the height of buildings and trees, while the DEM represents the elevation data with only the height of the ground surface. It is possible to express the shadow of buildings and trees by superposing the solar orbit on the DSM, performing a solar radiation analysis. An example of shadow representation in 3D map is shown in Fig.6. In Fig.6, the red circles indicate the shadows [9]. The map of solar radiation amount of the whole Kitakyushu City, Fukuoka Prefecture, is created using this function as shown in Fig.7. In this map, the weather conditions are sunny, and the color represents the amount of annual solar radiation considering the effects of the shadows of buildings and trees. The red color indicates high solar radiation. The blue color indicates low solar radiation.

Then, a schematic diagram of the estimated solar radiation amount using a solar radiation simulation result and an omnidirectional camera is shown in Fig.8. This system is composed of two functions; ① all sky image function; ② estimated solar radiation function. Moreover, this system is comprised by five DB; that is, the whole sky image DB, solar position DB, solar radiation amount DB, solar radiation coefficient DB, and estimated solar radiation amount DB. The comparison of the estimated solar radiation value and measured value from 11:01 to 11:30, 2017.2.6 is calculated by this mechanism as shown in Fig. 9. In Fig. 9, the blue indicates the measured value using the pyranometer, the red indicates the estimated value of the system constructed in this study, and the black indicates the amount of solar radiation at the time of clear sky of 2017.2.3. Moreover, in Fig. 9, the red circle part is an actual measurement value, which is larger than the amount of solar radiation at the time of fine/clear weather. The estimated solar radiation has a similar trend. This method can capture the effects of scattered sunlight caused by clouds. Fig.10 shows the comparison diagram of the measured and estimated values from 11:31 to 12:00, 2017.5.1. It can be seen from Figs. 9 and 10 that the variation tendency of the amount of solar radiation is generally captured [10].

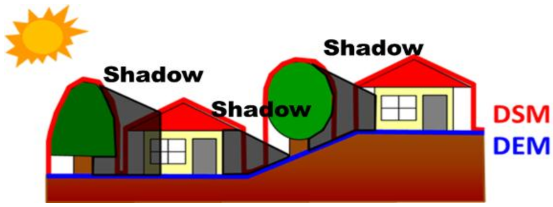


Fig. 5. The overview of DSM and DEM

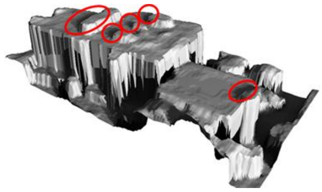


Fig . 6. Shadow representation in 3D map

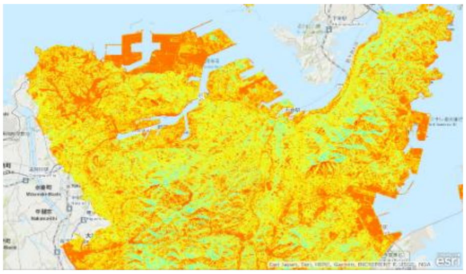


Fig. 7. Solar radiation map (Kitakyushu City)

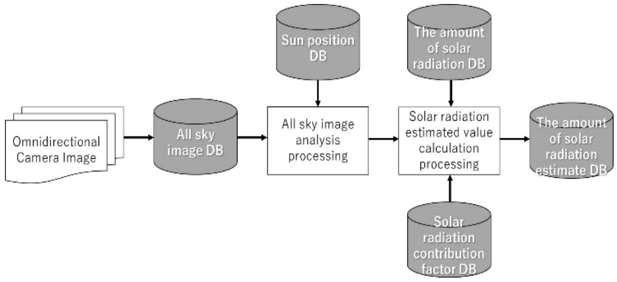


Fig. 8. System overview

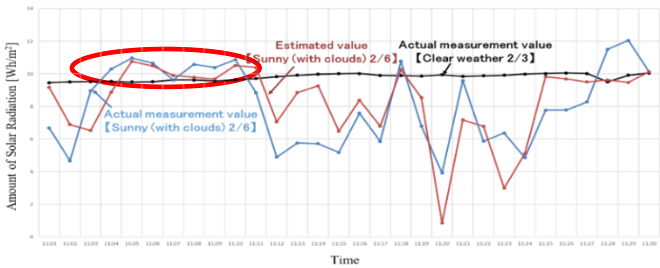


Fig. 9. Comparison of the actual and estimated values of solar radiation (2017.2.3 and 2017.2.6)

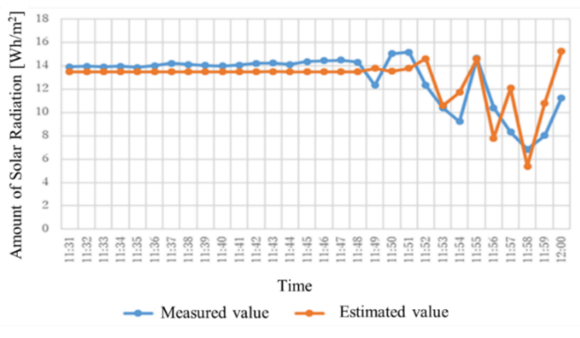


Fig. 10. Comparison of the actual and estimated values of solar radiation (2017.5.1)

2.3. Overview of the method for predicting cloud movement using the omnidirectional image

In this research, it has been developed the estimated solar radiation system built in the previous researches. This research also constructs a mechanism that can predict the solar radiation after a short time. The outline of the forecasted solar radiation system designed in this research is shown in Fig.11. The process surrounded by a red frame is a mechanism for capturing the movement of a cloud using an image captured by an omnidirectional camera. The functional diagram of the mechanism for capturing the movement of the clouds is shown in Fig.12.The function of this mechanism is composed of four functions.

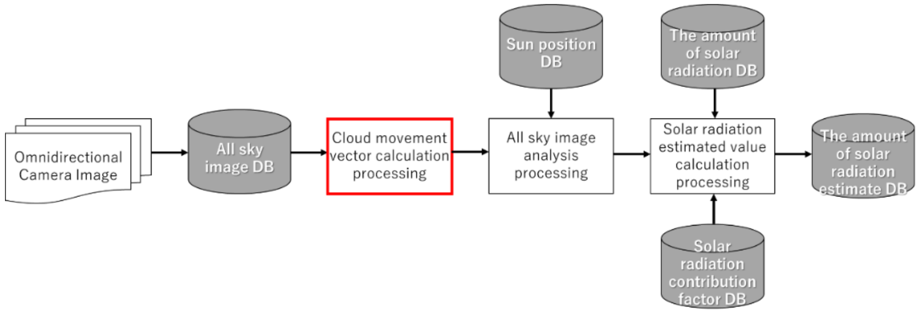


Fig. 11. Outline of the forecasted solar radiation system

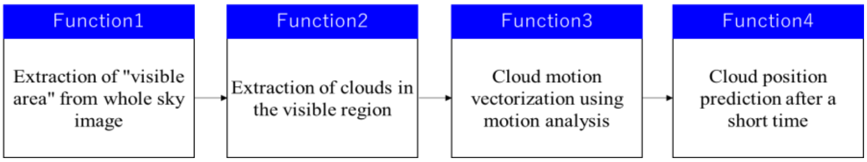


Fig. 12. Functional diagram of the mechanism for capturing the movement of clouds

2.4. Assumption of the demonstration area

In this research, an omnidirectional camera was installed on the roof of Kyushu Institute of Technology, Tobata Campus Research Building No. 10. In addition, the demonstration area was 2 km square area including the Kyushu Institute of Technology, Tobata campus. It is assumed that the distribution system area is 2 km square. The map of the demonstration area is shown in Fig.13. The demonstration area is located in the blue area in Fig.13. The red circle indicates the position of Research Building No. 10 equipped with an omnidirectional camera. The clouds move approximately 10 to 20 meters per second [11]. Therefore, in this area, it is necessary to capture the motion of the cloud until after 3-4 minutes.

Fig. 13. Demonstration area mechanism

2.5. Extraction of "visible area" from the whole sky image

It is extracted the visible area excluding buildings and trees around the place where the omnidirectional camera is installed. This extraction work at the place where the omnidirectional camera is installed was performed manually because it is sufficient to perform one operation. The extracted result is shown in Fig.14. The functions 2 and later are processed in this visible area.

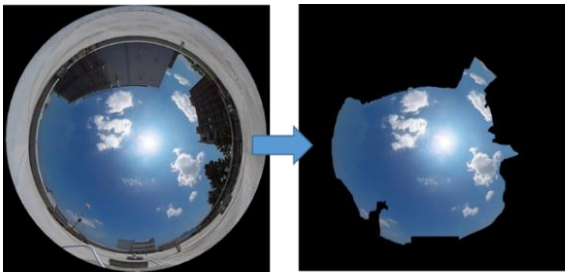


Fig. 14. Extraction result of the visible area mechanism

2.6. Extraction of clouds in the visible region

It is extracted the cloud under the following conditions using the RGB values, CMYK values and brightness values of the pixels.

①$220 \leqq \text{Red} \leqq 255$

②$0 \leqq \text{Red} \leqq 219$ and $33 \leqq \text{Cyan} \leqq 101$ and $0 \leqq \text{brightness} \leqq 199$

③$0 \leqq \text{Cyan} \leqq 32$

The extracted clouds are judged as one cloud by drawing a line at the boundary with other areas. The extraction result of the cloud is shown in Fig.12.

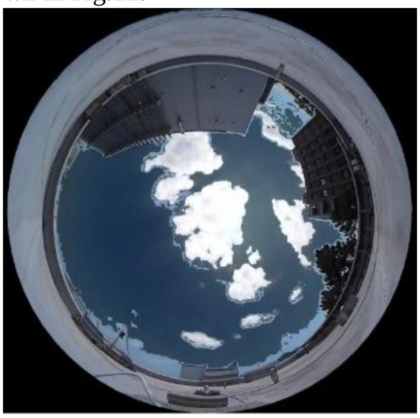


Fig. 15. Cloud extraction result

2.7. Cloud motion vectorization using the motion analysis

In this research, it is obtained the movement vector of the clouds using the motion analysis and optical flow. An optical flow is a appearance movement pattern of an object among consecutive frames caused by the movement of the object or camera [12]. In the optical flow, the analysis was performed under the following two assumptions as follows. ①the brightness on the images of the objects do not change among one continuous frame, ②The adjacent pixels behave similarly. Under these assumption, the movement of the object (the movement amount of XY axis) among adjacent frames (caused by the movement of the object) is calculated for each pixel. In this research, it is used "optical flow" in the image library named opencv. The dense optical flow is determined using the "algorithm of Gunnar Farneback (function name: calcOpticalFlow Farneback)" using the cloud extraction image of one minute ago and the current cloud extraction image. Further, the calculated result corresponding to the coordinates of the top part of the current cloud contour is taken as the movement amount of the vertex [12]. After that, the movement average of contour vertices of the entire cloud is determined. This is used as the movement vector of the entire cloud. In this research, one minute of movement vector is calculated. The flow of processing is shown in Fig.16.

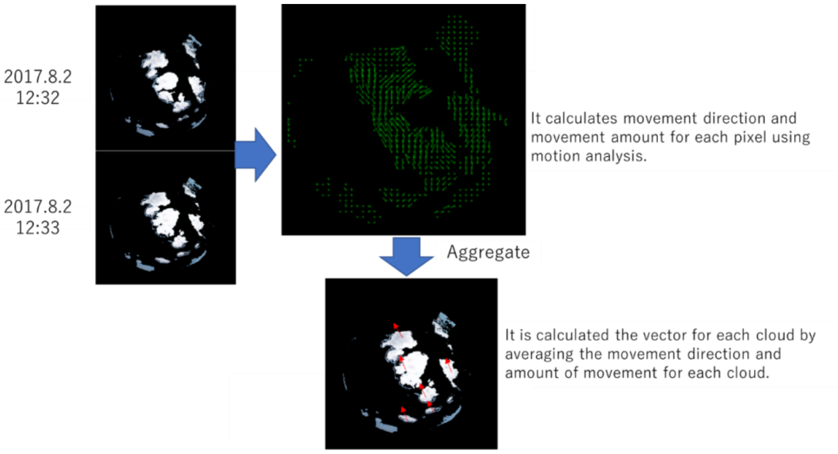


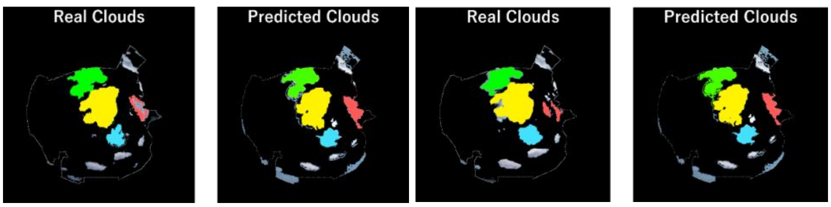
Fig. 16. Outline of the vectorization method of the cloud movement direction and movement amount using the motion analysis

2.8. Cloud position prediction after a short time

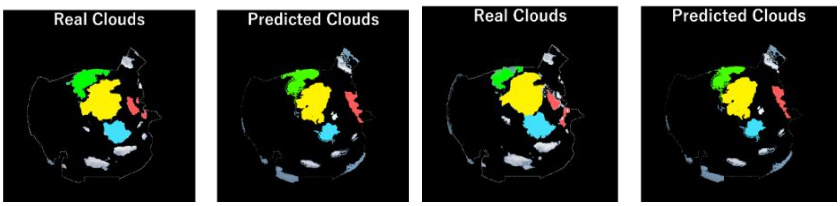
Regarding the one-minute movement vector calculated by the function 3, the length of the vector is p [pixel], and the angle formed with the x axis is α [°]. An equation for obtaining the length P of the movement vector for predicting the position of each cloud after n minutes using this vector is set as equation (1).

$$P[\text{pixel}] = n \times p \qquad (1)$$

The vector after n minutes is calculated, and applied to a cloud extracted from the whole sky image at the current time, moving to predict movement of the clouds. In this research, it is decided that the color and shape of the cloud did not change. The comparison diagram of the predicted clouds and actual clouds using this mechanism is shown in Fig.17. Focusing on four clouds in Fig.17, those clouds are colored green, yellow, light blue, and red, respectively, for easy to understand. In this research, it is focused on the capture of the cloud movement up to 4 minutes after, since it is assumed 2km square area. It can be understood from Fig.17 that the position of the clouds is approximately at the predicted position by comparing the actual and the predicted clouds. However, it turned out that focusing on the yellow and light blue clouds after 4 minutes cannot cope with the change in cloud size. As a future subject, it is necessary to apply the mechanism, which can respond to the change of the cloud size.



(a) After one minute (b) After two minutes



(c) After three minutes (d) After four minutes

Fig. 17. Comparison of the predicted and actual clouds

3. Conclusion

This research proposes an estimated solar radiation method using an omnidirectional camera constructed in the previous researches. This research proceeds with the goal to predict solar radiation amount in the near future. Therefore, in this research, it is constructed a mechanism that the images of the clouds are analyzed using the optical flow motion analysis, calculating the vector of cloud motion based on the extracting clouds from the omnidirectional camera. In addition, it is assumed that the area of the distribution system is 2 km square, thus, the movement of the clouds has been compared with the result of predicted movement of the cloud after 3-4 minutes (when the cloud passes through the area). The movement of the clouds has been able to be captured in general. Therefore, it could achieve the purpose of this research. In further research, since the change in the size of the cloud cannot be caught properly, it is planned to construct a new method to capture changes in the cloud size and shape.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Atsushi Shiota carried out the research. Atsushi Shiota, Ayumi Tada, Shuhei Yamada, Kokichi Yokozawa, Thongchart Kerdphol and Yasunori Mitani analyzed the data. Atsushi Shiota wrote the paper. All authors had approved the final version.

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References

[1] Ministry of Economy, Trade and Industry Resource and Energy Agency, "Annual report on energy in 2017 (Energy White Paper 2018)," Ministry of Economy, Trade and Industry Resource and Energy Agency, 2018.

[2] Japan Meteorological Association, "Insolation forecasting service using satellite dataSOLASAT 8-Nowcast," [Online]. Available: https://www.jwa.or.jp/service-business/service/797.html. [Access date: 1. 2. 2019].

[3] Atsushi S, Yuuki K, Kiyotaka F, Yasunori M, and Yaser Q. Development and public release of solar radiation map for effective use of solar energy based on gis with digital surface model. *International Journal of Electrical Energy*, 2015; 3(3): September 2015, 169-173.

[4] Atsushi S, Gai F, Kokichi Y, Thongchart K, Yasunori M. Construction of solar radiation simulation DB and solar radiation simulation system using GIS. *International conference on Electrical Engineering,* 2017, Weihai, 201702070000008.

[5] Atsushi S, Gai F, Yuki K, Yusuke K, Kenta T, Yaser Q, Yasunori M. guide construction of an efficient inspection, maintenance and asset management of photovoltaic power generation system using GIS. *Elsevier Energy Procedia,* 2016; 100: 69-77.

[6] Shiota A. Utilization of GIS in power system Master's thesis at Kyushu Institute of Technology, Japan, 2014.

[7] Atsushi S, Thongchart K, Yasunori M. Establishing a support system for the installation of photovoltaic generation system considering historical cityscape and landscape using Geographical Information System (GIS). *International Conference on Smart Grid and Green Energy (SGGE 2019)* , J5001 IJSGCE, 2019.

[8] Shiota A, Tanoue K, Mitani Y, Qudaih Y, and Fuji K. Construction of transporting system the electric power by using EV as mobile battery system in during black out of power grid by disasters. in *Proc. International Conference on Electrical Engineering (ICEE),* ICEE15A-160, 2015

[9] Atsushi S. Research on application of Geographic Information System (GIS) to electric power and energy field and contribution to the society with disaster prevention and mitigation, Doctor's thesis at Kyushu Institute of Technology, Japan, 2017

[10] Kokichi Y, Atsushi S, Yasunori M. Construction of the system that estimates the amount of solar radiation by analyzing all-sky image on GIS, The Institute of Electrical Engineers of Japan, 2018

[11] Kokichi Y. Construction of Solar Radiation Forecasting Method Using Geographic Information and Whole Sky Image, Master's thesis at Kyushu Institute of Technology, Japan, 2018.
[12] OpenCV, "Optical flow," [Online]. Available: http://labs.eecs.tottori-u.ac.jp/sd/Member/oyamada/OpenCV/html/py_tutorials/py_video/py_lucas_kanade/py_lucas_kanade.html. [Access date: 16. 2. 2019].