AN ANALYSIS ON PV RESOURCE IN RESIDENTIAL AREAS BY MEANS OF AERIAL PHOTO IMAGES

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ABSTRACT: This paper presents a method for estimation of photovoltaic systems potential by using aerial photographs. Rooftops have good conditions for PV system installation. Then, installation areas were assumed as roofs of residences and buildings. This estimation calculated from extracted roof area by image analysis. Authors have added new processes to previous roof-extraction method. The new processes are to update training data, to set priority of classification categories, and to apply geographical data. In the result, authors get accuracy improvement of the analysis. By utilizing this method, PV installation potentials in Koganei city in Tokyo have been analyzed. The estimation had shown that 216.1 MW PV can be installed in 1.44 km^2 of rooftop spaces. This result suggested that the potential of rooftop PV is large.
Keywords: PV System, Rooftop, Aerial Photograph

1 INTRODUCTION

To install photovoltaics (PV) in cities is predictably-effective. Because of low energy density of sunlight, PV systems require large space to generate enough electricity. There are not empty areas in cities basically. However, most of the rooftop of residences and commercial buildings might be unused area and will have good condition for PV systems. Moreover, the place of rooftop is near the demand.

In Japan, residential PV systems have been installed over 80% of total installation. The “Japan’s PV roadmap 2030 (PV2030)” in Ref. [1] was developed. PV2030 outlines possible development routes leading to 102GWp of PV in 2030. It targets the installation of 45-60GWp residential PV systems in 2030. Scheduled installations of natural energy have planned by local governments.

It is important for the target volumes to estimate the PV installation potential. The estimation could be guessed the scale and the effect of PV installation.

Earlier studies have investigated the PV installation according to only statistical data concerning the construction and land use. However these estimations cannot grasp the potential distribution. Furthermore the analysis ranges is limited because the data are also limited.

This study developed PV potential estimation by means of aerial photographs. The method solves the problems of the distribution and the limit. Automatic program to extract available area for PV installation have been developed by Taguchi et al. in Ref. [2], [3]. This study is aimed at accuracy improvement by adding a new process to previous method.

In this study, all roofs including buildings are defined as available area for PV installation. The developed program extracts roofs from aerial photographs. Resolution of using photographs is 25 x 25 cm/pixel.

On test sites, the accuracy of available area by updated method has been verified. PV installation potential has been estimated in Koganei city in Tokyo.

This paper consists of analysis-flow, new process’s content, accuracy verification, assessment and conclusion.

2 ANALYSIS METHOD

The analysis consists of 5 steps including preparation. Process flowchart is shown in Figure 1.

Preparation:

10 training data are selected per class in order to classify into land-cover classes by color appearance. The 8 classes are shown in section 3.2. Each data is 10 x 10 pixels. Authors select the data evenly by eyes. See Figure 2.

Each color appearance of each data has calculated. Hue and saturation have been adopted to the classification in order to exclude the effect of photograph’s tone.

Step 1:

An aerial photograph is divided into regions by color density difference. Each region is labeled. The color appearance is transformed from RGB model into HSI model.

Step 2:

The divided regions are classified into 8 classes by Maximum Likelihood Classifier (MLC). MLC is based on the training data of Step 1. Moreover the regions are classified into Roof areas, Vague areas, and Non-roof areas. These 3 categories are determined by possibility that the region is roof area. See section 3.2 for details.

Step 3:

This step target Vague areas at Step 2. It matches the regions with geographical data. Then, the regions can be judged whether the regions are roof area. See section 3.3 for details.

Step 4:

The regions that formally decided as roof area are the following 2 patterns. One is the regions that the highest possibility of roof area at Step 2, the other is the regions that judged as roof area at Step 3. These roof areas are treated by dilation and erosion. The processes help the result image smooth. Moreover, total roof areas are counted.

Final:

Roof-distribution image areas and total roof area are shown.

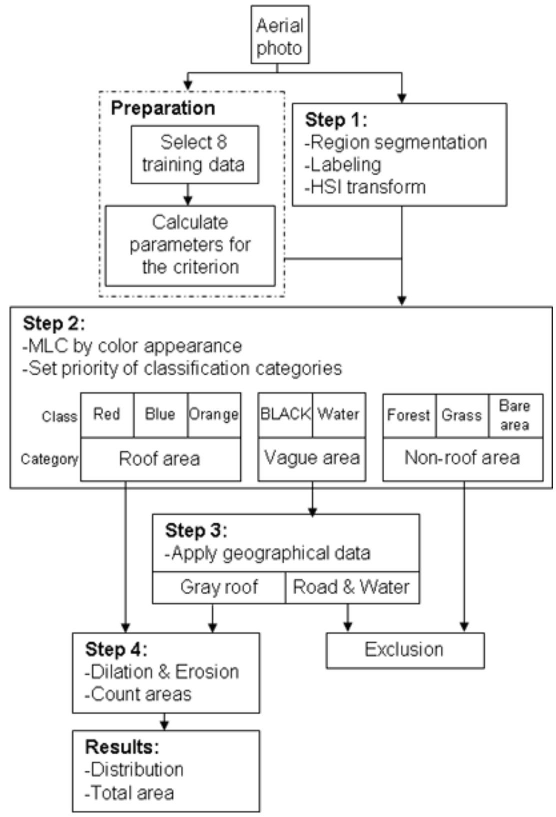


Figure 1: Process flowchart for roof areas extraction

3 NEW ANALYSIS PROCESSES

3.1 Update training data

Gray and black color training data were updated. The training data had been selected at Preparation. Gray color and black color are treated with same color because they are not related to intensity. These colors are called BLACK. BLACK include roof area and road (parking) area. Then, roof area isn't distinguished from road area at this step. To divide into roof area and road area by color difference is very difficult.

The training data of BLACK had been selected from a road area on previous method in Ref. [2]. Road area is not suitable for residential PV systems. Then, BLACK have been data to extract unavailable area in this analysis. This time, BLACK are updated as the data to extract available area because training data of BLACK were replaced by the data from black and gray roofs.

The 3 data patterns readied data from only road area, from both of road and roof area, and from only roof area in order to decide best of BLACK data. The analyzed results by these 3 data patterns were compared. The extracted image using data from only road area is the worst extraction of roof area. The others are similar results and good extractions.

In order to make easy analysis method, the data from only roof area are applied. These data help to decrease wrong extraction.

3.2 Set priority of classification categories

8 classes have been set for land-cover classification. 8 classes are red roof, blue roof, orange roof, BLACK, water (dark navy), forest (green), grass (light green), and bare area (beige). It defines the following 3 categories. Roof area is that area of red roof, blue roof, and orange roof. Vague area is that area of BLACK and water. Non-roof area is that area of forest, grass, and bare area.

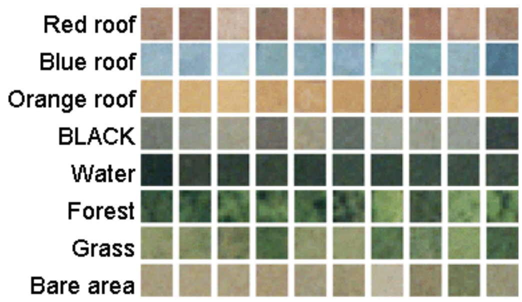


Figure 2: Training data

Each region which is divided at Step 1 is classified into the 8 classes by MLC. Moreover, the regions are classified into Roof areas, Vague areas, and Non-roof areas. Roof areas are used as available area for PV installation at Step 4. Vague area is matched with geographical data at Step 3. Non-roof area is excluded.

This additional process decrease errors of the extraction.

3.3 Apply geographical data

Vague area at Step 2 is classified using geographical data. The classification is means to distinguish roof area from road and water area. The geographical data include data of road's center lines with several widths, and of water regions.

Figure 3: Geographical data

It matches vague area and the geographical data. If the pixels of vague area have overlapped 400 pixels with the object-pixels of geographical data, the region including these pixels is determined as road or water area. The other areas are determined as roof area. These roof areas are as available area for PV installation at Step 4.

4 ACCURACY VERIFICATION

4.1 Verification methodology

5 test sites have been selected from residential area for the verification. Each site is 500 x 500 pixels, and that is equivalent to 125 x 125 m. In these test sites, roof

area images of recognition by eye are defined as correct images.

Result images compared with correct images. Hitting roof area shows extracted roof area exactly. Error area of surplus shows extracted non-roof area as roof area. Error area of shortage shows un-extracted roof area. Hitting area of non-roof shows the other area; non-roof area exactly.

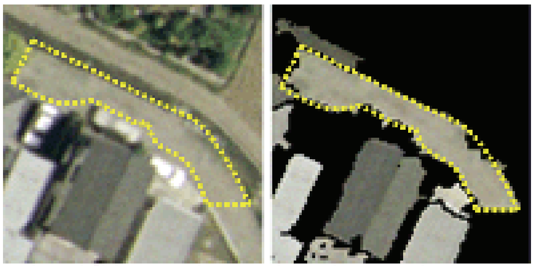


Figure 4: Extraction error (surplus)

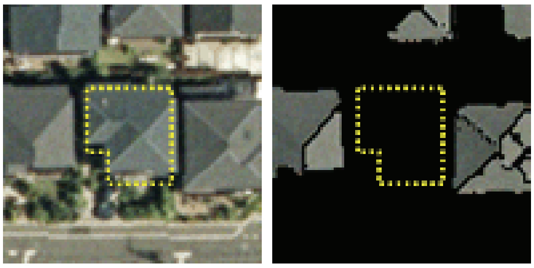


Figure 5: Extraction error (shortage)

Measure for verification is 2 kinds. One is the ratio that both of roof area and non-roof area are classified exactly. It is called Class Ratio.

$$ClassRatio\,[\%] = \frac{HittingArea(Roof + NonRoof)[pixel]}{TotalArea\,[pixel]} \times 100 \qquad (1)$$

The other is the ratio that is total extracted area to total correct roof area. It is called Area Ratio.

$$AreaRatio[\%] = \frac{TotalExtractedArea[pixel]}{TotalCorrectArea[pixel]} \times 100 \qquad (2)$$

4.2 Result of accuracy verification

These ratios have been calculated. Averages of 5 test sites were improved from 78.0 % to 83.0 % of Class Ratio, and from 73.2 % to 103.9 % of Area Ratio. This results show accuracy enhancement of this analysis method by adding new processes.

Figure 6: A test site image

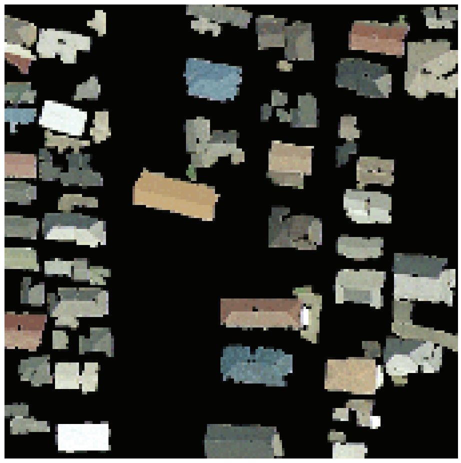


Figure 7: Result image of the test site of Figure 6

5 PV POTENTIAL ASSESMENT

5.1 Roof area estimation

The potential area was estimated in Koganei city in Tokyo. Koganei city is located in the center of Tokyo, and about 25 km from city core. Area of Koganei city is 11.33 km^2. About 110,000 people live there. There are residences and parks mainly without tall buildings.

Extracted roof area in Koganei city was 2.36 km^2. This area shows that about 20 % in Koganei city is roof area as shown in Figure 8. Red color areas describe roof area in Figure 8.

5.2 Assumption of PV installation

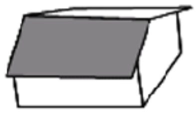
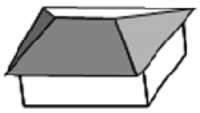
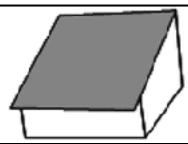
There are the following 3 assumptions for estimation of the potential of residential PV systems. First pattern is that PV systems are installed in 100 % of roof area. Second pattern is that PV systems are installed in 50% of roof area. Third pattern is that PV systems are installed by application of parameters according to statistics of construction.

- Assumption 1: All roofs are pent roof. Therefore 100 % of roof area is available. Filling factor is 100 %. The inclinations are 30°. The surfaces face south.
- Assumption 2: All roofs are gabled roof. Therefore 50%

of roof area is available. However available area is actual 45% as filling factor set 90 %. The inclinations are 30°. The surfaces face south.

- Assumption 3: A ratio of all roofs depends on statistics of construction. See the following and Table 1 for detail.

Table 1: Roof shapes and available areas (Assumption 3)

Roof shape	Installable ratio [%]	Available area (gray)
Gabled roof	50.0	
Hipped roof	62.5	
Pent roof	100.0	

- Inclination of roofs; 20° (40%) and 30° (60%)
- Orientation of roofs; 0° (48%), 45° (15%), 90° (9%), 270° (9%), and 315° (19%)
  Note that 0° shows south.
- PV surface facing south, southeast, east, west, and southwest are installed.
- Filling factor are all 90%.

PV conversion efficiency is 150 W/m^2. PV possible capacity is calculated by the following.

$$PossibleCapacity[W] = RoofArea[m^2] \times 150[W/m^2] \quad (3)$$

Annual output energy at STC is calculated the following.

$$E_p = P_A \times \left(H_A / G_S\right) \times K \quad (4)$$

Where each parameter is;

E_p: Annual output energy [kWh/year]
P_A: PV capacity [kW]
H_A: Annual in-plain irradiation [kWh/m^2/year]
G_S: Irradiance at STC; 1.0 kW/m^2
K : Performance ratio; 71.6 % based on Ref. [5].

5.3 Results of estimation

PV potentials have been estimated according to 3 assumptions. See Table 2.

Table 2: Results of estimation

Assumption	1	2	3
Total roof area [km^2]	2.73	2.73	2.63
Available area [km^2]	2.73	1.23	1.44
Possible capacity[MW]	409.5	184.5	216.1
Annual output energy [GWh]	453.6	204.4	225.7

The estimation of assumption 3 will be close to actual potential.

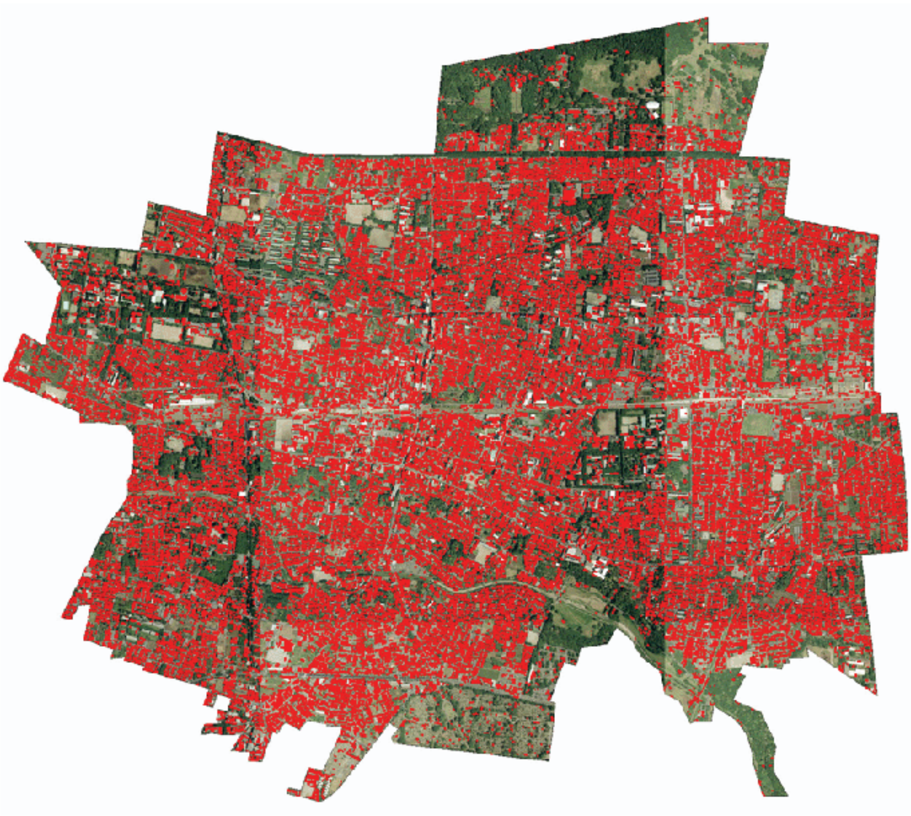


Figure 8: Result image in Koganei city

6 CONCLUSION

This paper presented to add new processes to previous method. The new processes are to update training data, to set priority of classification categories, and to apply geographical data. In the result, we get accuracy enhancement of analysis.

PV installation potential in Koganei city was analyzed. In the case of assumption by statistics of construction, the estimation has been obtained that 216.1 MW PV would be installed in 1.44 km^2. Annual output energy is 225.7 GWh/year. This amount is able to cover about 62,000 households on the assumption of 3,621 kWh/house/year. This presentation showed that the potential of rooftop PV is large.

Authors are going to apply the method to 23-wards in center of Tokyo. Then, potential of the rooftop PV in big cities including tall buildings and broad streets will be shown.

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