PV Resource Survey for Urban Areas by means of Aerial Photographs

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ABSTRACT: In this paper, we present a method for estimating the introduction potential of photovoltaic power generation systems (PV systems) in urban areas. Most PV systems are installed on building roofs as roofing systems in urban areas. Therefore, by using the information about roofs obtained from aerial photographs taken from an airplane, we can estimate the introduction potential of PV systems in an area of interest. The introduction potential of PV systems is basically estimated according to the total area of roofs. In order to obtain the information about roofs, the recognition and extraction of roof from aerial image is a necessary process. In this study, automatic approach for house roof extraction based on characteristics of surface features is proposed. An experiment of roof extraction is carried out and the result of our extraction method is compared with the manually extracted roofs to conduct an accuracy assessment. Finally we estimate the introduction potential of PV systems based on the experimental results.
Keywords: PV system, Roofing systems, Aerial photogrammetry

1 BACKGROUND AND OBJECTIVE

Escalations of global climate change, various environmental issues, and resource depletion have focused on PV as one of the renewable energy technologies alternative to fossil fuel. Furthermore, from the perspective of energy security, PV is expected as major future energy source in Japan where energy resources are limited. Under such circumstance, the “Japan’s PV roadmap 2030 (PV2030)” was developed [1]. PV2030 outlines possible development routes leading to 100 GWp of PV in 2030. It targets the installation of 45-60 GWp residential PV system in 2030. It is important for the target volumes to estimate the introduction potential of PV systems. Moreover, the estimation of the introduction potential is necessary as a guideline for regional energy plans.

Earlier studies have investigated promising sectors for the introduction of PV systems and their introduction potential of PV systems according to statistical data concerning the construction of buildings and land use [2] [3] [4] [5]. Such studies based on statistical data cost a great deal of money and time for data collection and reduction. Therefore, inexpensive and efficient estimation methods are needed. Aerial Photographs have the potential to provide information that can help us understand where the suitable place for introduction of PV systems. In addition, aerial photograph is easily-available.

The objective is to develop an efficient method for estimating introduction potential and power generation of PV systems by using information obtained from analysis of aerial photographs. This paper aims to define a technique for extracting roof from an aerial photograph and estimating the area of roofs. The technique targets roofs of an independent house.

2 THE ESTIMATION METHOD

In earlier studies, statistical data has been used for estimating the introduction potential of PV systems. In this study, on the other hand, focusing on that many PV systems are installed on roofs of residential, commercial and public facilities in urban areas, an efficient estimation method using aerial photographs is proposed. With high resolution aerial imageries, it is possible to identify the small-scale features such as buildings and roads. In our method, automatic image analysis process on recognition and extraction roofs is important to obtain detailed information about roofs. The detail of image analysis process is described in next section.

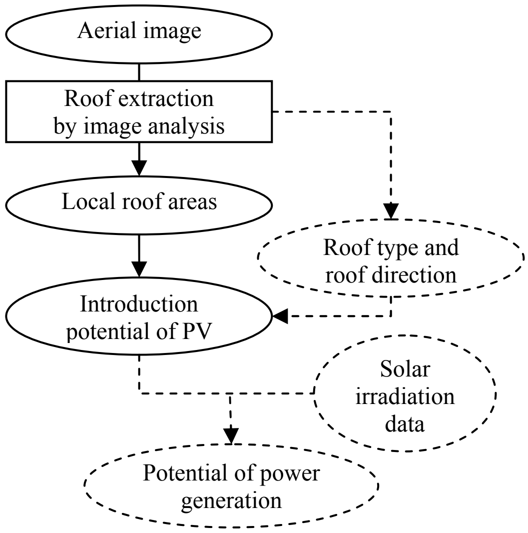


Figure 1: A flow diagram of estimation process. This paper focuses on the full line parts.

3 IMAGE ANALYSIS

In this section, the process of extracting roof regions from aerial image is presented. Automated building extraction in urban areas is one of most difficult problems in image understanding and photogrammetry. A variety of approaches have been suggested for the extraction of building from aerial imageries. Several approaches integrated the image analysis with other data sources, map, digital elevation models or Geographical Information System data. Meanwhile, an approach using multiple images is described in [6]. Some of these approaches gave notable results. However, In order to supply the requirement cheaply and efficiently, we employ a method using one image to extract roof regions. Extraction algorithm is consisted of 3 steps.

3.1 Image segmentation

In the first step, a digital image of aerial photograph is partitioned into connected regions by grouping neighboring pixels of similar intensity levels. The difference in value is calculated between two adjacent pixels. If the difference is less than the threshold, the adjacent pixels are connected as a same region. Otherwise, if the difference is larger than the threshold, the adjacent pixels are determined as a part of boundary.

3.2 Classification based on color texture

In the second step, the segmented regions are classified into five main types (forestland, grassland, bare surface, water, and artificial construction) by the use of Maximum Likelihood Classifier (MLC) based on their color texture. A region having roof-specific color (blue, orange, etc.,) is classified as a roof region in this step. MLC is widely used as a classification technique.

$$L(x,c) = \frac{1}{(2\pi)^{K/2} |{}_cV|^{1/2}} \exp\left\{-\frac{1}{2} d^2{}_M(x,c)\right\} \quad \text{equation 1}$$

c : classification class

$L(x,c)$: likelihood

$d^2{}_M(x,c)$: Maharanobis distance

${}_cV$: covariance matrix

Parameters used in MLC are HSI (Hue, Saturation, and Intensity) values. HSI is one of the many color spaces. HSI values are calculated based on RGB (Red, Green, and Blue) values by using following equations.

$$I = \max\{R, G, B\} \quad \text{equation 2}$$

If $I = 0$, S and H are defined by equation 3

$$S = 0$$
$$H = indefiniteness \quad \text{equation 3}$$

If $I \neq 0$, S is defined by following equation

$$S = \frac{(I - i)}{I} \quad \text{equation 4}$$

Where i is $\min\{R,G,B\}$

Next r, g, and b are defined as follows.

$$r = \frac{(I - R)}{(I - i)}, \quad g = \frac{(I - G)}{(I - i)}, \quad b = \frac{(I - B)}{(I - i)} \quad \text{equation 5}$$

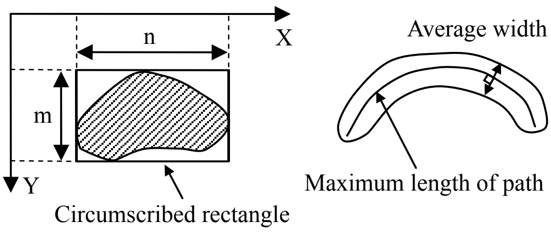
Finally H is defined as follows.

$$H = \begin{cases} \frac{\pi}{3}(b - g), & for\ R = I \\ \frac{\pi}{3}(2 + r - b), & for\ G = I \\ \frac{\pi}{3}(4 + g - r), & for\ B = I \end{cases} \quad \text{equation 6}$$

3.3 Classification based on shape characteristics

In the third step, the regions recognized as artificial constructions in the second step are classified into roofs and roads by use of shape characteristics. A contour of projected independent house roof has a similar shape to square. On the other hand, roads have an elongated shape and connecting each other. Therefore, shape characteristics of artificial objects, such as length, width and size of a region are important information to distinguish roof regions from roads.

Parameters of shape characteristics are calculated based on each segmented region and the circumscribed rectangle [7]. The circumscribed rectangle is defined as the smallest axis parallel rectangle when axis of coordinate rotated by a unit of 10 degrees.



(a) Fit ≥ 0.5 (b) Fit < 0.5

Figure 2: Segmented region and parameters of shape characteristics. **n:** A length of the long side of the smallest circumscribed rectangle. **m:** A length of the short side of the smallest circumscribed rectangle. The definition of FIT is described in Table 1.

Definition of Shape characteristics are described in Table 1. A region having moderate characteristics as a roof shape is distinguished from roads.

Table 1: Shape characteristics and their definition

Shape characteristics	Definition
Area	This intends the size of a region. It is based on the total number of pixels within a region.
Fit	This denotes whether a region is a rectangle. This is calculated by equation 7.
Length	This denotes the length of a region. If Fit is not lower than 0.5, then Length is equal to the length of long side of the smallest circumscribed rectangle. If Fit is less than 0.5, then Length is dased on the maximum length of path.
Width	This denotes the width of a region. If Fit exceed 0.4, then Width is based on the length of short side of the smallest circumscribed rectangle. If Fit is not over 0.4, then Width is based on the average width which is at right angles to the longest path.
Elong	This indicates whether a region is elongated. It is based on the caluculation elongation. Elong is calculated by equation 8.

$$Fit = \frac{Area}{Area\ of\ the\ circumscribed\ rectangle}$$

equation 7

$$Elong = \begin{cases} Length / Wedth, & for\ Fit > 0.4 \\ Maximum\ length\ of\ pass / Average\ wedth, & for\ Fit \leq 0.4 \end{cases}$$

equation 8

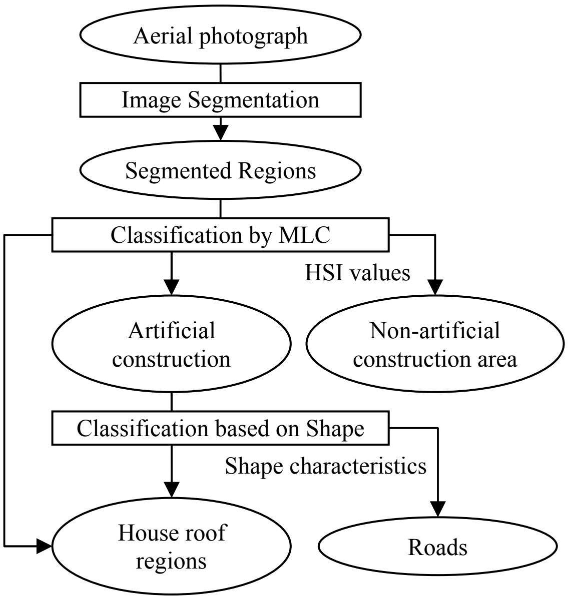


Figure 3: The flow chart of image analysis

By integrating the results of two classification processes, roof regions are extracted from the aerial image. Further estimation of introduction potential of PV systems is conducted based on the extracted regions of image analysis result.

4 EXTRACTION EXPERIMENT

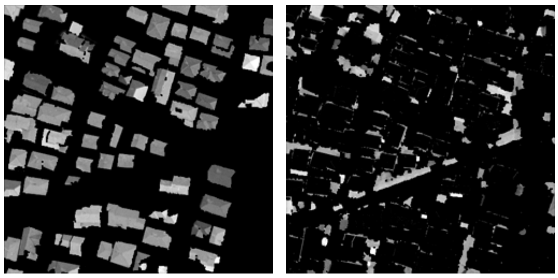
We experiment with the above mentioned method in residential area (Figure.4 (a)). The spatial resolution of the aerial image used in experiment is 25cm. The original photograph of the image was taken during the period of May to August, 2002.

The result of extraction experiment is shown in Figure 4 (b). As a result, almost all visible roofs shown in Figure 4 (a) are appropriately extracted by presented method. The study area contains approximately 82 roofs, 76 of which are almost completely extracted. The remaining roofs, or portion of them, are actually hypothesized that the roofs having great color variation in its roof surface. The experiment result includes extraction of non-roof regions correspond to roads adjacent to a gray roofed house. These false extractions are caused by the lack of a continuous color boundary between a rood and a roof. There are also false extractions of red colored sidewalks. This is because of that red is an unusual color for a sidewalk.

Our method uses color characteristics to classify surface features. However, the color of a feature will vary with the seasons and/or the places. This is especially true in the color of vegetations. The green color is the most effective parameter to distinguish vegetation regions from other regions. Hence, it is advisable to use aerial photographs which taken during a summer term when vegetation is green.

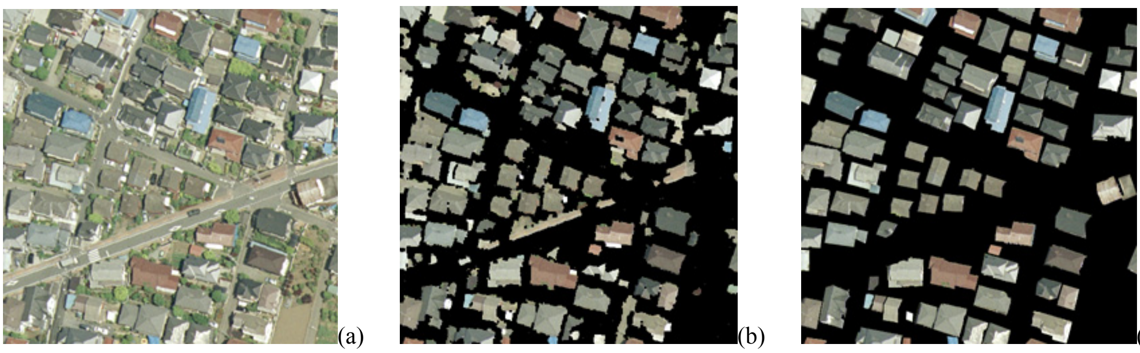
5 EVALUATION OF ACCURACY

The extraction result of study area was compared with the manually extracted roof image (Figure 4 (c)) to conduct the accuracy assessment. The roofs shown in Figure 4 (c) extracted according to Visual Evaluation Standard. If a pixel extracted in both images, we defined the pixel as the pixel extracted correctly. In the meantime, if a pixel extracted only in processed image, we defined the pixel as the pixel extracted incorrectly. Figure 5 (a) shows the correct extracted regions, and Figure (b) shows regions defined as incorrectly extracted regions.



(a) (b)

Figure 5: Comparison results (a) Correct extracted Regions. (b) Incorrect extracted Regions.



(a) (b) (c)

Figure 4: (a) Aerial image of study area (May to August, 2002, Hino, Tokyo). Spatial resolution is 25cm and image size is 500pixels by 500pixels (b) Result of experiment (c) Manually extracted roofs according to Visual Evaluation Standard

We calculated the extraction rate which defined as the percentage of correctly extracted pixels over total number of pixels in each roof region (Table 2). The middle column shows the number of roof extracted between the extraction rates shown in left column. As shown in table 2, approximately 73 percent of total number of roofs was extracted with high extraction rate (more than 80 percent). Therefore, sufficient results were obtained.

Table 2: Extraction rate

Extraction rate:	Number of roof:	Percentage:
90 - 100%	26	31.7
80 - 90%	34	41.5
60 - 80%	15	18.3
40 - 60%	5	6.1
20 - 40%	2	2.4
0 - 20%	0	0.0
Total	82	100.0

6 ESTIMATION OF INTRODUCTION POTENTIAL

The total area of roof regions can be calculated by multiply the number of extracted pixels by the resolution of the aerial photograph. Based on the extraction result, the total projected area of roofs in study area is calculated to be 6353 square maters. Of course the areas of roofs should be calculated in consideration of roof tilt angle. However, it is very difficult to know the tilt angle precisely through analysis of one aerial image. On the other hand, the tilt angle of ordinary independent house roof is set to around 20 - 30 degrees in Japan expect for a snowy district [8]. Hence, the areas of inclined roof can be approximate by assuming the proper angle. Based on the assumption that the tilt angle of all roof is 25 degrees, the areas of inclined roofs is calculated to be approximately 7000 m2. Finally, the installable capacity in the study area is estimated to be 1050 kWp under the rated output is set as 0.15 kW / m2.

7 CONCLUSION AND FUTURE WORKS

In this paper, an automatic house roof extraction approach for estimation of the introduction potential of PV systems has been presented. The roof extraction approach uses characteristics of surface features in order to distinguish roof regions from non-roof regions. The extraction algorithm is consisted of 3 steps. In the first step, a digital image of aerial photograph is segmented into connected regions. In the second step, calculate HSI values (attributes of the color appearance system) and classify the regions based on the HSI values by use of MLC. In the third, calculate the shape characteristics of each region and recognize the house roof regions. The proposed approach has been used in residential area to extract independent house roofs and showed good results. As a result, the possibility of presented approach to estimate the introduction potential of PV systems by means of aerial photograph analysis is suggested.

There are several problems are still exist in our approach. The roof extraction process uses color characteristics to classify surface features. However, the color of a feature will vary with the seasons. This is especially true in the color of vegetations. Moreover, color characteristics will vary from one site to another depending on the sun angle, the flight conditions and the weather. In addition, a power generation from PV systems is dependent on a roof shape and a roof direction. Therefore, future works will focus on: color calibration, understanding of roof structure.

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