Precise Inspection Method of Solar Photovoltaic Panel Using Optical and Thermal Infrared Sensor Image Taken by Drones

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Abstract. The inspection of the solar panel using the drone has already been put into practical use. However, this method requires an initial investment cost as compared with the conventional method, and it may take a cost such as image processing. In addition, there are challenges such as the ability to carry out the necessary maintenance of the law even if technically possible. Nowadays, the introduction of drones is proceeding in such a way as to check the points of abnormalities through simple flight. The advantage of this method is that safety enhancement and inspection speed are greatly improved compared to the case of performing the inspection by the conventional method. For companies, the use of drones and thermal infrared sensors for inspection can be used to reduce the population and to reduce the problems of recruitment, and to improve the efficiency and reduce the cost by simplifying the inspection procedure with fewer personnel will be. The purpose of this study is to develop a method to accurately detect abnormal points by making thermal infrared images of orthographic images by improving the inspection method through simple flight of drone. The study investigated whether it is possible to precisely check the point where the problem is located under the condition of insufficient solar radiation at the site installed by a small developer. We propose a method that can accurately distinguish between normal and abnormal panel points in images taken using drones and thermal infrared sensors, and how to accurately detect abnormal points by focusing on problem panels. Abnormal points were found to be very accurate and efficient to find and inspect panel more than the temperature range value of each panel.

Keywords: inspection, solar panel, drone, photovoltaic, thermal infrared.

1. Introduction
Global energy demand is growing rapidly with economic growth. Solar energy is growing as a renewable energy source for the realization of a sustainable society that respects the environment. Especially, the solar power generation that is introduced will last more than 20 years after installation, but it is very important to detect and respond to the problem immediately in order to maintain stable generation over the long term. In general, monitoring systems for detecting anomalies are introduced in various forms. So far, the monitoring system is predominantly the threshold value determination. For example, if the power generation falls below a certain value, it is determined that the power generation is abnormal, and the solar power generation manager is notified and checked. However, the amount of power generation depends on various factors such as the season, the time zone, the installation area, and the surrounding environment of the power plant. Therefore, most of the tasks that require analysis and judgment by humans based on the results of the anomaly are lacking in reliability. In this background, we tried to develop a monitoring system that can detect abnormalities by using measured temperature values using
drones and thermal infrared sensors and to identify the cause of abnormalities. When the power generation deterioration is detected, the cause (such as a fuse or a breaker, a shadow of a tree and a grass or a deterioration of the solar panel itself) is specified, and a check is made so that the abnormality can be immediately recognized.

Drones are a technique that utilizes the excellent accessibility of drones for surveying, and it solves the problem of workable days, economics and convenience which have been pointed out as problems of conventional aerial photogrammetry. Recognizing the utility of drones, the Korean government published an "Enactment of the Guidelines for Public Survey of Utilization of Unmanned Aerial Vehicles" in February 2018, and instituted institutional procedures to allow drones to be recognized as the outcome of public surveys. The principle of drones surveys is the same as the principle of aerial photogrammetry using the principle of "collinear conditional expression" which has been going on since 1849. However, the drones are characterized by the accuracy of interpretation due to the development of artificial intelligence mapping technique that produces unique economic, universality, accessibility, and interpretation of photographed images.

Photovoltaic (PV) facilities in Asia are often installed on a large scale in homes, factories, or large areas. Especially, 2/3 of Korea's land is composed of mountains, so there are many solar facilities utilizing hilly areas. These areas are disadvantageous in that accessibility such as inspection and repair is disadvantageous, and it is difficult to utilize the measuring equipment and expensive labour costs are incurred. In addition, ground observation is time consuming and efficient and accurate monitoring methods are required to be developed. Image processing methods using drones and thermal infrared sensors are emerging as solutions to these problems. Image processing technology using drones has been developed rapidly in recent years mainly in the field of surveying. These technologies have recently been rapidly applied to agriculture and have begun to be applied to solar power plant inspection [1].

The purpose of this study is to propose a method to detect the problem of solar power generation facility by using difference of thermal characteristics in response to sensor by acquiring high precision orthoimage by attaching optical and thermal infrared sensor to drone.

2. Materials and Methods

2.1. Study Area
In this study, a small scale solar power generation facility was selected as a study area. The study area was a power generation facility applied to a hill located in a rice growing area and consisted of two rows on a slight slope. Figure 1 shows the location of the study area at Ochang-eup, Cheongju, Chungbuk in Republic of Korea.

![Figure 1. Location of study site](image-url)
2.2. Materials
The drone used DJI's Inspire 2 (China). The Inspire 2 is a rotor drone that has good stability, long flight times, and payloads that can be equipped with optical and thermal infrared sensors. The optical sensor uses a DJI's Zenmuse X5s (Red, Green, Blue) model with a very high resolution of 5280×2970. The thermal infrared sensor is a product of FLIR’s Vue Pro R (USA) model with a resolution of 640 x 512. The two sensors were installed with different GPS devices with different resolution and reaction speed. Image processing was performed using Sensefly’s Fix4D Capture and Mapper and the images were processed using R, MATLAB, and GIS tool.

2.3. Causes, Faults and Accidents Occurring in PV Power Generation Facilities

2.3.1 Broken part of panel. In the case of PV generation in the field, wild animals may collide with bases when they are installed in mountainous areas or places with little humanity. Animals such as deer and fox, as well as birds, may collide. There are also cases where the birds are dropped as well as the shit, by dropping them on the panel. There are cases where wild animals eat cables connecting panels and equipment, so you should not install fences or anything.

2.3.2 Discoloration of panel appearance. If there is a scratch that can be seen by the outline, the panel is faintly brown or dark color, so it is often visible to the naked eye. The reason for discoloration is that the developed heat passes through the part well and the heat accumulates. The portion where this heat is piled up is called "hot spot". Hot spots due to poor connection of electrical circuits and wiring in modules and systems. Hot spot caused by adhesion of bird droppings and fallen leaves. The hotspots are hot at around 90 degrees, and when viewed with an infrared camera, they are reddish, so you can find unexplained failures in the naked eye [2].

2.3.3 Snail trail (Snail-like shape) phenomenon. The Snail trail phenomenon occurs only in silicon solar panels. Small damage (microcracks) that are hard to find with the naked eye. Even if the snail trail occurs, the generation does not go down, so observation is necessary. Micro cracks are known to occur when installing or transporting solar cells and placing heavy objects on the panels.

2.3.4 Solar power plant fire. Solar power generation systems can cause fires due to electrical leakage or shorts due to various factors. The following may be considered as factors that cause a fire. Aging due to age deterioration, initial failure, mounting failure. Fire caused by insulation failure at the end of wiring. Discharge due to wiring touching metal parts such as module mounts. These problems caused by human errors such as "inappropriate area development", "inappropriate design" and "inappropriate construction" are widely confirmed regardless of low or high pressure. In addition, weeds with strong fertility and the effects of plants with a high degree have been reported in many cases, and several cases of fires have been reported among the failure cases.

2.3.5 Necessity of new abnormal phenomenon identification technology. As mentioned above, problems caused by various causes have been grasped by ground observation. If part of the cell connection in the panel is broken or weak, the voltage balance will be broken and the current will be partially concentrated and generate heat. This is called a hotspot. Hot spots are difficult to see visually and are very difficult to see from the back, so we use a thermographic camera to find out where the heat is rising locally. The difficult part of this inspection is that if the sunshine intensity is weak, the degree of heat generation of the hot spot is low, and it is not only difficult to detect the failure point, but sometimes it cannot be said as defective even if the heat generation point is found. This means that it is necessary to make a decision based on basic knowledge about the operation of the PV system.

2.4. Methodology
The research process proceeded as follows.
First, select the study area and establish a drone flight plan. Secondly, we monitor the time of inspection through simulation flight to the image shooting point. Thirdly, we use the optical and thermal infrared sensor at the same time to find the altitude and resolution for obtaining the optimal orthographic image. Fourth, by using a drones and a thermal infrared sensor, it is possible to capture the time available for shooting even if the insufficient amount of solar radiation is available. Fifthly, the captured optical and thermal infrared sensor images were analysed by orthoimaging. Sixth, we proposed a method to find the abnormal panel accurately using statistical values through the orthoimage. In the seventh, we proposed a method to accurately locate the problematic points for the abnormal panel found.

![Figure 2. Procedure and application method of research](image)

3. Results and Discussions

3.1. Orthoimages by Optical and Thermal Infrared Sensor
When a PV panel is photographed using an optical and a thermal infrared sensor mounted on a drone, it is possible to construct a topographic map having three-dimensional coordinate information by analysing a plurality of overlapping points. The shooting altitude in the image production process is a factor that greatly affects the resolution of the captured image [3]. Although images with high resolution Ground Sample Distance (GSD) are acquired at low altitude, the length of the flight path and the number of photographic images required for shooting the same area are excessively increased. Therefore, this case greatly affects the photographing operation and the mapping of the images. In this study, the performance of the sensor installed in the drone, the limitation on the current aviation safety law, and the condition of obtaining the optimal image in various flight conditions were investigated at the altitude of 30m. Drones photogrammetry gave vertical and lateral redundancy as high as 85% due to instability of drone posture due to light weight.

Mapping works in the following order. Initial Processing, (2) Point cloud generation, (3) GCP input and correction, (4) Mesh generation process, (5) Orthoimage by optical and thermal infrared sensor, it corrects the geometric distortion such as height difference and tilting of the photographed image, and matches all inputted images, and it is made into an image photographed at right angles to the ground in the air (Figure 3).

![Figure 3. Orthoimages by optical sensor and thermal infrared sensor](image)
3.2. Examination of Inspection Method of Solar Panel

For the precise inspection and diagnosis of the PV panel, it is necessary to use the photographed images to accurately identify the problematic points and take countermeasures. First, the PV panels were numbered in the same way from the top right to the bottom as shown in Figure 4. Statistical analysis was applied to find the problems in each row of panels. The measured panel data and statistical values of each panel are listed in Table 1, and the problematic panel has a large range value. The range is the value that indicates the spread of the temperature data, minus the minimum value. If the temperature is distributed at a low level, it is confirmed that the temperature at the boundary of the solar cell such as the boundary part is low, or when a problem corresponding to 2.3.1 or 2.3.3 occurs. In these cases, the corresponding arrays are A7 and A17 as shown on the Table 1.

Table 1. The results analyzed by applying the statistical method

| vars | n   | mean | sd  | median | trimmed | mad  | min  | max  | range |
|------|-----|------|-----|--------|---------|------|------|------|-------|
| A1   | 1   | 9736 | 0.25| 20.28  | 20.26   | 0.48 | 17.96| 25.79| 7.82  |
| A2   | 2   | 11604| 0.7 | 22.14  | 22.21   | 0.63 | 19.83| 23.84| 4     |
| A3   | 3   | 13755| 0.51| 21.69  | 21.68   | 0.53 | 18.75| 23.14| 4.39  |
| A4   | 4   | 13333| 0.39| 21.68  | 21.66   | 0.36 | 15.61| 22.68| 7.07  |
| A5   | 5   | 13527| 0.45| 21.35  | 21.3    | 0.34 | 16.76| 29.98| 13.22 |
| A6   | 6   | 13451| 0.36| 21.11  | 21.1    | 0.27 | 11.92| 22.8 | 10.88 |
| A7   | 7   | 13407| 0.44| 21.16  | 21.14   | 0.29 | 14.09| 30.26| 16.17 |
| A8   | 8   | 12951| 0.31| 21.36  | 21.33   | 0.23 | 19.25| 22.75| 3.51  |
| A9   | 9   | 12753| 0.4  | 20.84  | 20.81   | 0.25 | 19.2 | 25.36| 6.16  |
| A10  | 10  | 13364| 0.48| 20.67  | 20.68   | 0.29 | 19.63| 31.31| 11.68 |
| A11  | 11  | 13589| 0.35| 20.43  | 20.43   | 0.24 | 18.97| 25.09| 6.12  |
| A12  | 12  | 13642| 0.39| 19.95  | 19.95   | 0.27 | 17.26| 26.15| 8.89  |
| A13  | 13  | 13235| 0.36| 19.72  | 19.68   | 0.34 | 18.67| 24.85| 6.18  |
| A14  | 14  | 13482| 0.4  | 19.48  | 19.44   | 0.3  | 18.14| 24.49| 6.35  |
| A15  | 15  | 15789| 0.36| 19.23  | 19.23   | 0.32 | 17.18| 24.03| 6.85  |
| A16  | 16  | 15738| 0.35| 18.97  | 18.98   | 0.35 | 17.23| 21.31| 4.08  |
| A17  | 17  | 18176| 0.8 | 18.85  | 18.85   | 0.47 | 12.56| 22.92| 10.37 |
| A18  | 18  | 18395| 0.58| 18.72  | 18.74   | 0.41 | 11.69| 25.63| 13.94 |
| A19  | 19  | 17836| 0.51| 18.41  | 18.44   | 0.43 | 15.35| 22.64| 7.29  |
| A20  | 20  | 19936| 0.53| 18.43  | 18.45   | 0.51 | 17.39| 22.36| 4.98  |
When the maximum value of the temperature range is very high, it is found that it corresponds to 2.3.2. and 2.3.5. The study site is located at the point where two years have elapsed since the installation, but it is found that A5, A7, A10 among the target panels are in these cases.

3.3. Precision Review of Abnormality Panel
Figure 5 shows the comparison between the optical and the thermal infrared image for the abnormal panel obtained through the statistical analysis. Normal operating panels exhibit a homogeneous temperature distribution, but conditions 2.3.1 and 2.3.3 indicate that the panel has a lower temperature distribution than the surrounding panels. The panel corresponding to the hot spot corresponds to the condition of 2.3.2 and 2.3.5, which is relatively higher than that of the normal panel as shown in Figure 5. As described above, the range of the problematic panel, such as abnormal panel, was analysed to indicate 10 or more. Therefore, it is analysed that precise inspection should be performed on panels with a range of 10 or more.

4. Conclusion
Precise inspection and diagnosis of solar panels is a very important part of the solar power generation industry, which is in rapid demand and supply. The existing labour-intensive methods are costly, time-
consuming, and dangerous, requiring the integration of new technology needs that combine the fourth industrial revolution technology. The purpose of this study was to investigate the problems of solar panels using drones, optical and thermal infrared sensors. As a result of the study, it was analyzed that the thermal image taken by the drone can accurately identify the problematic point and can take corrective action. In particular, the abnormal panel has a very large range of statistical values compared to the normal panel. Therefore, it is concluded that intensive close inspection should be performed on panels with a range of 10 or more.

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