Journal Paper

“Remotely Piloted Aircraft System and Engineering Management: A Real Case Study”

- International Conference on Management Science and Engineering Management -

August 2018

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Cite as: Ramírez, I. S., Marugán, A. P., & Márquez, F. P. G. (2018, August). Remotely Piloted Aircraft System and Engineering Management: A Real Case Study. In International Conference on Management Science and Engineering Management (pp. 1173-1185). Springer, Cham.

Remotely Piloted Aircraft System and Engineering Management: A Real Case Study

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Abstract.

Photovoltaic energy is one of the most relevant renewable energy due to its fast growth in the last years. The sizes of the solar panels and the solar power plants are also increasing. Therefore, the modern solar plants require new maintenance techniques that ensure the efficiency and rentability. In this field, condition monitoring systems play an essential role because they can increase the reliability, reduce cost and, therefore, improve the operation of the solar plant. The goal of this paper is to develop a new monitoring system composed of an unmanned aerial vehicle fitted with a thermal camera. This paper studies the capability of the system to detect defects in the solar panels or external factors that affect to the optimal operation. Firstly, the system is tested in an experimental platform under controlled conditions and, then, some experiments in a real solar plant are carried out. The data provided by the system is analyzed and converted into useful information of the state of the panels. It is demonstrated that this system can detect some specific failures and elements that affect the normal condition of the panels.

Keywords: Thermography, Remotely Piloted Aircraft, Photovoltaic Solar Energy Management.

1. Introduction

Renewable energies are clean and unlimited sources of energy. Nowadays, solar energy is one of the most abundant and cleanest energy sources. In this field, photovoltaic (PV) energy is one of the most important energies due to its great availability and minimum environmental risks [1]. The main countries around the world are supporting renewable energies in order to fulfil political agreements, e.g. the 2020 Horizon in the European Union. Figure 1 shows the annual installed PV power for the biggest PV energy producers. Some of the leader countries are China with 15.2 GW, Japan with 11.4 GW, and USA with a total of 7.3 GW installed [2]. In addition, Australia, India and Indonesia show a very positive trend due to current government policies and lower prices of the photovoltaic panels. PV energy is expected to be around 280 TWh in 2030 [3].

Figure 1: World annual installed PV Power [2]

Despite its growth, photovoltaic energy is still a small fraction of world electricity production. The main reason is that the cost of PV energy generation due to the limited efficiency of PV panels. It is essential to reduce the production costs, and to invest in maintenance policies to increase the efficiency of the process and minimize downtimes [4,5]. Several factors, such as the impact of sedimentation (dust or dirt particles) can reduce the energy production about 7-15% per month in periods without rain or inspections [6], generating considerable economic losses. Therefore, it is essential to identify the critical parts of the conversion process in order to keep under control the involved components. For example, wind turbines are devices in the renewable energies field where a lot of components are usually monitored in order to detect breakdowns quickly and effectively [7-9].

The companies are managing the maintenance based on the Supervisory Control and Data Acquisition (SCADA). There are a large number of approaches employed in SCADA systems [10,11]. The operators take decisions according to analytics methods [5,12,13], where in fault detection and diagnosis have been studying novel techniques in the last few years [14-16].

It is crucial to obtain information through real-time monitoring systems. These systems employ different technologies to evaluate multiple parameters, e.g. vibration analysis, electromagnetic, acoustic emission and infrared thermography.

This paper is focused on the use of infrared thermography for inspection of solar power plants [17,18]. Nowadays, infrared thermography is one of the most common non-destructive tests (NDT) [17,19-21]. In general, NDT are employed to prevent failures and improve the maintenance efficiency without affecting the properties of the system [22]. Data acquisition using infrared thermography is an increasing technique used due to its speed, efficiency and non-destructive nature [23].

Infrared thermography is based on heat transmission by radiation [24,25]. The infrared radiation emitted by bodies at different levels of the electromagnetic spectrum is captured. The temperature is calculated from this radiation, therefore, there is no physical contact with the object, i.e. the properties or conditions of the system are not altered. Infrared emissions are invisible to the human eye and it is necessary to use special cameras or sensors. However, infrared thermography has several limitations, e.g. it is necessary to take measurements from suitable areas and improve the data collection process. The inspection of huge solar plants can result a very slow and complicate task. Remote Piloted Aircrafts (RPA) can be used to improve the efficiency of these inspections.

RPAs have multiple advantages such as speed, improved operational safety, operating costs and a big angle of view [26]. The aircrafts have been adapted for different application areas due to its high technical conditions. These aircrafts are mainly used for photography, thermography, safety and rescue. They are also used in renewable energies, specifically to analyze blades of wind turbines and PV panels [27]. The combination of drones and infrared thermography allows maintenance tasks to be optimized [24], achieving significant economic and operational advantages.

2. Objectives and resources

The main objective of this paper is to evaluate the capacities of a proposed condition monitoring system consisting on a RPA with an infrared equipment. The paper is divided into two stages: Firstly, an experimental phase under controlled conditions in order to determine whether the proposed system is suitable for solar panel inspections and a test phase in a real solar plant. In the second stage, the system is used in a real solar plant and real data of the panels are acquired. Figure 2 shows a schematic design of the proposed system.

Figure 2: Schematic picture of the full system.

Specifically, the system is composed of:

- *A DJI S900 RPA.* This drone is a high stability hexacopter with the capacity of following automatic routes. This aircraft fulfils the initial requirements for aerial inspections of solar panels due to its reduced weight, high flight range and advanced control system.
- *Thermographic equipment:* The thermographic camera is a Workswell WIRIS model. It is a professional instrument for high precision thermographic inspections. This equipment has been chosen for its light weight, excellent storage and data processing capacity, with the advantage of combining thermographic and digital camera.
- *Processing software:* The data obtained must be processed after the measuring stage. For this purpose, CorePlayer software is employed in this system. This software allows all measurements to be stored and processed pixel by pixel. Regions of interest, data histograms, 3D mapping, comparison, etc. can be developed by this software.

3. Experiments under controlled conditions

A set of experiments are carried out on solar panels under controlled conditions to analyze the effectiveness of the proposed system. The specific objectives of these experiments are:

- To establish optimal routes.
- To evaluate the influence of altitude and orientation for optimal panel detection.
- To determine if the system is suitable for its use in real solar parks.

Two types of experiments are conducted for this purpose:

3.1 Detection of panels and influence of orientation

As aforementioned, altitude and orientation are key factors in the thermographic analysis of solar panels. In this experiment, two solar panels are placed 50 meters apart from each other. Figure 3 shows the initial configuration of both solar panels. The purpose is to check if the proposed system can detect both panels at a certain flight height. In first place, images will be taken from Position 1 (Panel A). Then, the drone ascends until the Position 2. Finally, the drone is approached until Position 3 (Panel B).

Figure 3:Description of the operation. Influence of the altitude

Figure 5 shows a thermogram taken at 60 meters (Position 2) in the first stage. The image shows a line (line of interest) that connects both panels providing the temperature values. Specific forms associated with the presence of a panel (red circles) are detected. This image shows that it is feasible, by mean of artificial vision algorithms, to locate panels from different heights. In this case, the orientation is not correct because the thermogram shows a marked variation of the panel temperature in transverse direction.

Figure 4: Thermogram taken at 60 meters.

Figure 5 shows two thermal images where the orientation of the panel has been modified. In addition, the histogram of temperatures is shown considering the panel as the region of interest. It can be observed that the change of orientation in the panels produces a variation of the temperatures.

Histograms have a similar distribution. However, temperature values vary around two degrees Celsius at all points.

Figure 5: Influence of altitude (left) and orientation (right).

3.2 Determination of the surface condition

In this experiment, some defects are caused on the surface simulating the presence of dirt, broken cells and water. The main objective is to analyze if the system can detect these defects. The panels are separated around 2 meters from each other. Figure 6 shows the configuration of the experiment. Different measurements of the three panels are taken at the same time to make comparisons between them. Lateral flights are also performed in order to measure each panel individually.

Figure 6: Distribution of panels.

Figure 7 shows that it is possible to detect the three panels. It can be observed that the temperature is different on each panel. Panel A presents the highest temperature, followed by B and C. This is because no changes have been caused on the surface of panel A. Panel C has been altered by pouring water at room temperature over its surface. Consequently, a drastic reduction of the temperature has occurred.

Figure 7: Panels analysed at high distance

They are individually analyzed when the panels have been identified. Firstly, the wet panel C is studied. The water was thrown from the top of the panel to perform this experiment. The inclination of the panel causes that the water molecules move downwards. It explains why the top of the panel begins to warm up earlier, causing a temperature gradient in the vertical axis. Figure 8 shows a gradient of 21°C (from 45°C to 24°C).

Figure 8: Thermogram of panel C and the line of interest.

To obtain a more accurate image, the temperature data for each pixel in Panel C has been exported to MATLAB. Figure 9 shows a 3D image of the temperature data. The temperature gradients show the water paths along the panel surface.

Figure 9: 3D graph of panel C

Panel B is examined when the analysis of Panel C is completed. This panel has been partially covered with sand to evaluate the effect of extreme soiling on surface temperature. A thermographic image of this experiment is shown in Figure 10.

Figure 10: Thermogram of panel B and 3D picture.

The areas where sand is accumulated can be clearly distinguished. The specific heat of sand is very low (290 J/Kg K), and, therefore, low energy is enough to increase its temperature. Therefore, the sand absorbs heat from the surface, reducing the temperature in the adjacent areas. It is verified that the panel reach higher peaks of temperature when it is covered with sand, but the average temperatures remain similar. Figure 10 (right) is obtained by making a 3D graphic with MATLAB. This figure shows that the center of the areas with sand has a higher heat absorption. For this reason, the heat dispersion structure is cone-shaped. It is demonstrated that the sand or dirt reduces solar radiation absorbed and cools the panel due to the thermal conductivity of the sand.

4. Case study on a real solar plant

Once the feasibility of the monitoring system has been determined, it is tested in a real solar plant. The solar power plant is located in Spain. These panels are grouped into modules with one-axis solar tracker. Each module is composed by ten panels. Due to these characteristics, the solar plant is very attractive to be inspected by the proposed system.

The main objectives of this experiment are:

- To analyze remotely the panels. remote sensing and panel analysis.
- To consider the influence of panel orientation with respect to the drone and the direction of maximum solar irradiance
- To optimize the route followed by the aircraft

The knowledge and techniques applied in the previous experimental stage are used to execute this flight. The experiments will initially be carried out at a high altitude (100 meters) and, then, if any incidence is detected, the aircraft will go down to a closer altitude in order to analyze the faults in detail.

Figure 11 shows that a damaged solar panel was detected when the data was analyzed. Using the processing software, the affected module (PG2 in red) and a bordering module without any defect (PG3 in blue) are chosen as regions of interest (ROI).

Figure 11: Regions of interest.

The processing software shows automatically the maximum and minimum values and verifies that there is an important difference between the maximum values (76.7°C versus 49.9°C). This difference is caused by the presence of hot spots on the damaged plate. Figure 12 shows the temperature histogram of the ROI regions (PG2 and PG3). It is demonstrated that the distribution of values is very different in both panels.

Figure 12: Histogram and iteration of the data.

The healthy panel displays a leptokurtic distribution, more centralized and accumulated in its most repeated value. However, the damaged panel has a platykurtic distribution, with a low degree of concentration around the center values due to the temperature peaks provided by the damaged cells. Therefore, it is possible to detect hot spots by analyzing the thermal distribution.

The altitude fly of the drone is increased to validate the influence of altitude on the hot spot detection quality. Figure 13 shows the image obtained at a higher operational altitude. ROIs are selected and processed as above-mentioned. The distributions remain similar in both cases, only the quantity of data changes because the resolution decreases and therefore there is less number of pixels in the ROIs. Despite the higher altitude, it is still possible to identify the distribution associated with the presence of a hot spot.

Figure 13: ROIs hot spot analysis with high altitude.

Two adjoining solar modules were identified with hot spots of different size during the flight, layout and shape. Figure 14 shows the areas of interest PG4 (red) and PG5 (blue) selected for further analysis.

Figure 14: Both regions of interest with hot spots.

Figure 15 shows a 3D mapping of the hot spots presented in Figure 14. Hot spots with their corresponding gradients are clearly visible. The accuracy is adequate to detect these phenomena, despite the distance, see Figure 15.

Figure 15: ROI data map: PG4 (left) y PG5 (right)

5. Conclusions

This paper presents a study of the capacities of a proposed system for inspecting solar power plant. The system is a condition monitoring system formed by a remotely piloted aircraft fitted with an infrared thermography equipment. Several experiments have been developed in order to evaluate the goodness of the system. Firstly, a set of experiments are carried out under controlled conditions. Some defects are induced in the solar panels and the effect of these defects is analyzed. Secondly, an inspection on a real solar plant has been carried out. These experiments have demonstrated that the orientation, altitude and distance to the measurement target are crucial factors. This paper shows that an altitude of 40 to 50 m is favorable for an appropriate compromise between the accuracy of hot spot detection and the number of panels that can be inspected. Regarding to the orientation, measurements will be wrong and must be discarded if the angle of measurement coincides with the angle of maximum solar radiation. During the analysis, comparison between measurement dispersion were made. It is concluded that hot spots have the effect of dispersing values of the panel temperature histogram, i.e. the kurtosis is smaller when the number of hot spots increase. Finally, the system has been proved to be reliable and fast.

Acknowledgements

The work reported herewith has been financially supported by the Spanish Ministerio de Economía y Competitividad, under the Research Grants RTC-2016-5694-3 and DPI2015-67264-P.

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