3D MODEL CONSTRUCTION OF NUCLEAR POWER PLANT WITH UAV

Yukiya TANIGUCHI, Masayuki TSUTSUI, Takashi NAGAFUCHI, Susumu OGAWA
Civil Engineering and Environmental Department, Nagasaki University
E-mail. bb35515021@ms.nagasaki-u.ac.jp, ogawa_susumu_phd@yahoo.co.jp

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ABSTRACT: On March 11, 2011, in Fukushima Daiichi nuclear power plant, some accidents, core melting and hydrogen explosions, occurred by the Great East Japan Earthquake. Pollution simulation was already carried out by a particle model. But, 3D models of the nuclear power plant were not obtained at that time. In the future, 3D models are required for pollution simulation of nuclear power plant accidents in each place. In this study, 3D models of Sendai nuclear power plant in Kagoshima prefecture was constructed with UAV. Phantom 4 Professional was used in this study. In Civil Aeronautics Act, at the flight of UAV over nuclear power plants, access within 300 m from the site boundary and more than 150-m altitude flight are prohibited. Therefore, UAV route maps were created under the condition of 300 m away from the site boundary with 150-m altitude. *Litchi for DJI Mavic / Phantom / Inspire / Spark* was used as an automatic navigation software. Furthermore, all camera directions faced to the nuclear reactor. RGB and IR images were taken as shooting conditions. Finally, using PhotoScan, image editing software, 3D models in RGB and IR were constructed from the aerial images.

1. INTRODUCTION

On March11, 2011, in Fukushima Daiichi nuclear power plant, some accidents, core melting and hydrogen explosions, occurred by the Great East Japan Earthquake. For nuclear accidents, pollution simulation of radioactive materials diffusion is required. For this pollution simulation, a three-dimensional model of a nuclear power plant should be obtained. When an accident of Fukushima Daiichi Nuclear Power Plant occurred, the 3D model did not exist. For a 3D of a nuclear power plant, photogrammetry has to be done. On the other hand, in recent years, the spread of UAV progressed rapidly. UAV became popular in various fields such as earth science and archeology [1]. Compact digital cameras mounted on UAV are much higher resolution than aerial photographs of traditional aircrafts. The shooting can be repeated spatially [1]. UAV can be piloted for a long flight by general users in high performance of batteries, the weight reduction of aircrafts, and higher precision of GPS [2]. Photogrammetry with automatic navigation can be done in complicated terrains. The aerial images become three-dimensional using an SfM-MVS software. High-resolution terrain images were obtained and analyzed [1]. Ortho mosaic images and DSM of several-cm-level spatial resolution were obtained from 3D models [3]. In this study, 3D models of RGB and IR for Genkai and Sendai nuclear power plants in Saga and Kagoshima prefectures were constructed. The broad overviews of Genkai and Sendai nuclear power plants are shown in Figure 1.

Figure 1. Genkai and Sendai nuclear power plants.

Figure 2. UAV route map of Sendai nuclear power plant. Figure 3. UAV route map of Genkai nuclear power plant

2. METHODS

2.1. UAV route map

In this study, *Litchi for DJI Mavic / Phantom / Inspire / Spark* was used to create automatic navigation route maps around Genkai and Sendai nuclear power plants. A UAV route diagram of Sendai nuclear power plant is shown in Figure 2. Another UAV route map of Genkai nuclear power plant is shown in Figure 3. In Civil Aeronautics Act, at the flight of UAV over nuclear power plants, the access within 300 m from the site boundary and more than 150-m altitude flight is prohibited. Then, the altitude was fixed at 150 m each. All routes were more than 300 m away from the site boundary. For Sendai nuclear power plant, the departure and arrival point was made to the coast about 1.5 km south from Sendai nuclear power plant. The total flight distance was 7.2 km, while the flight time was 21 minutes. On the other hand, for Genkai nuclear power plant, the departure and arrival points were set in the paddy

fields located south from Genkai nuclear power plant. The total flight distance was 5.2 km, while the flight time was 15 minutes. *Litchi* has a function called POI (Point Of Interactive). With this function, a UAV in flight automatically heads to the direction of the defined center point. To head the camera face to the nuclear power plant all time in flight, a center point was set on the nuclear reactor. The created route map was shown in Figures 2 and 3.
Figure 2. UAV route map of Sendai nuclear power plant. Figure 3. UAV route map of Genkai nuclear power plant

2.2 *Phantom 4 Professional*

Phantom 4 professional was used in this study (Figure. 4). The spatial resolution is 20 million pixels, and the angle of views is 94 degrees. In the survey of Sendai nuclear power plant, on May 8, 2017, Phantom 4 Professional flew from the coast using *Litchi*. The near infrared images were acquired by attaching *Fuji Film's* IR 76 filter (Figure. 5) inside the UV filter of UAV camera (Figure. 6). In both RGB and IR, the images were taken manually every second. In the survey of Genkai nuclear power plant, on September 18, 2017, Phantom 4 Professional flew from the paddy field designated by *Litchi*. Both RGB and IR images were taken automatically every two seconds.

Figure 4. Phantom 4 Professional.

Figure 5. Near infrared film (IR76).

Figure 6. UV filter.

2.3. Three-dimensional model

2.3.1. Sendai nuclear power plants

PhotoScan is an image editing software. This software was used to create 3D models. 32 images of RGB and 26 images of IR 76 were selected from images obtained by Phantom 4 Professional. 3D models for RGB and IR were created from these aerial images. In the case of RGB, the alignment and high-density cloud construction were set to "high", while the blend mode for texture construction was set to "average". On the other hand, in the case of IR, image blurring is large and synthesis for figures may not be well if accuracy is "high". Therefore, alignment and high-density cloud construction were set to "medium". Blend mode was set to "mosaic (standard)". In other settings, the shape in the mesh construction was "3D shape", the maximum number of polygons was 90,000, and the mapping mode for texture construction was set to "general purpose".

2.3.2. Genkai nuclear power plants

As well Sendai nuclear power plant, PhotoScan was used to create 3D model of Genkai nuclear power plant. 62 RGB images were selected every ten seconds. 44 IR images were selected every 14 seconds. Both of RGB and IR, the alignment, high density cloud construction was set to "high". The blend mode in texture construction was set to "average".

2.3.3. IR gradation images

From UAV IR images, in both of Sendai and Genkai nuclear power plants, IR gradation images were created using PhotoShop to obtain the temperature spatial distributions of the nuclear power plants.

3. RESULTS

A 3D model of RGB is shown in Figure 7. Another 3D model of IR is shown in Figure. 8. In the RGB 3D model, relief on the ground and the arrangement of the structures were converted to three dimensions as actual power plants. However, the shape of two nuclear reactors were partly dimpled. For IR 3D model, the distortion occurred in the entire constructures. The RGB 3D model of Genkai nuclear power plant is shown in Figure 10, and the 3D model of IR is shown in Figure 11. In RGB, the relief and arrangement of the structure were three-dimensional as actual Sendai nuclear power plant. Figures 9 and 12 show the gradation images obtained from IR images for UAV acquired at Sendai and Genkai nuclear power plants, which mean temperature spatial distributions.

Figure. 7 RGB 3D model of Sendai nuclear power plant.

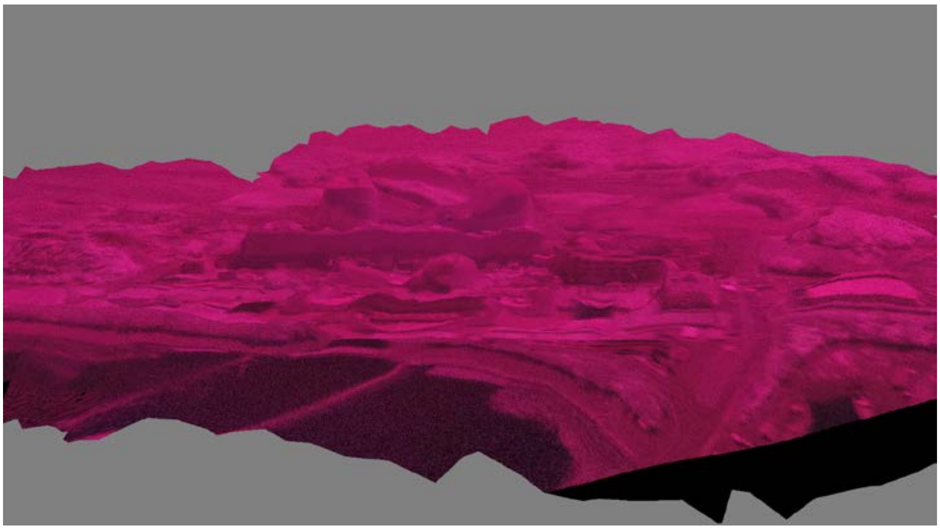

Figure 8. Near-infrared 3D model of Sendai nuclear power plant.

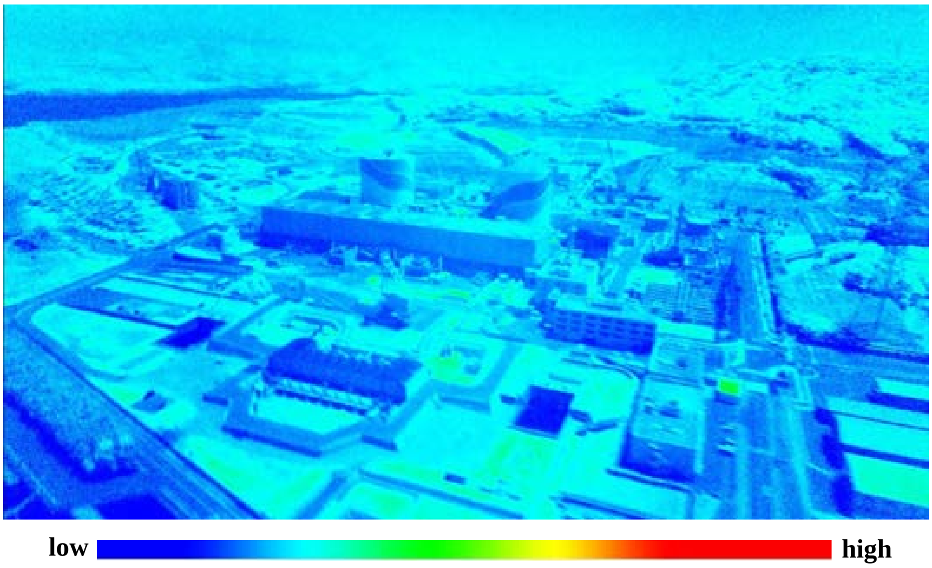

Figure 9. IR-gradation images of Sendai nuclear power plant.

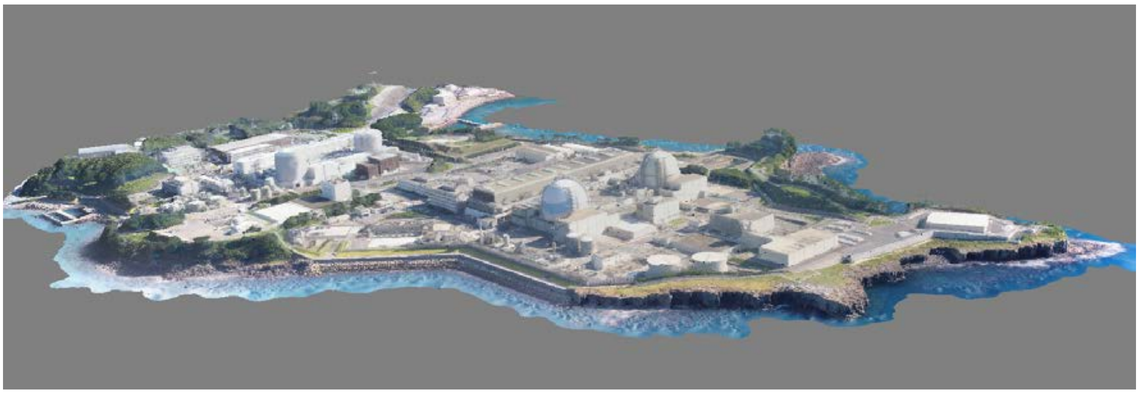

Figure 10. RGB 3D model of Genkai nuclear power plant.

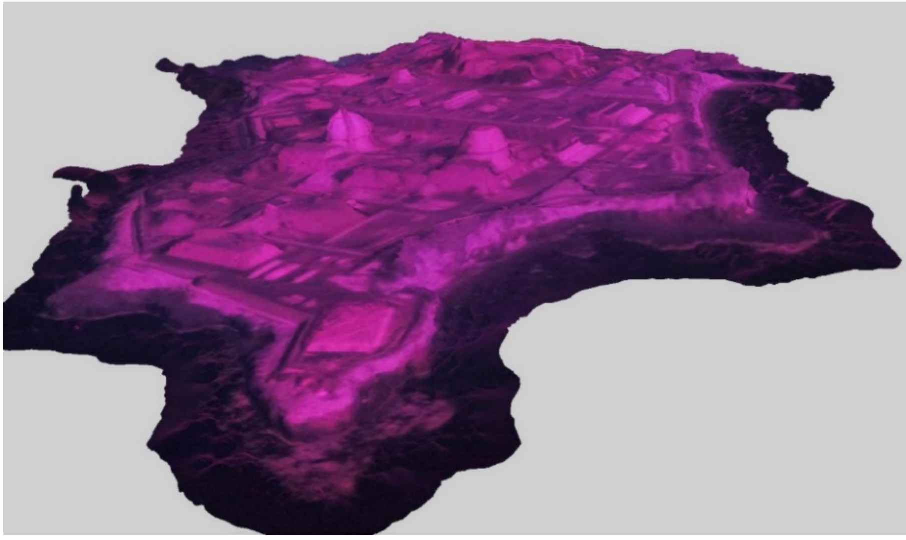

Figure 11. Near-infrared 3D model of Genkai nuclear power plant.

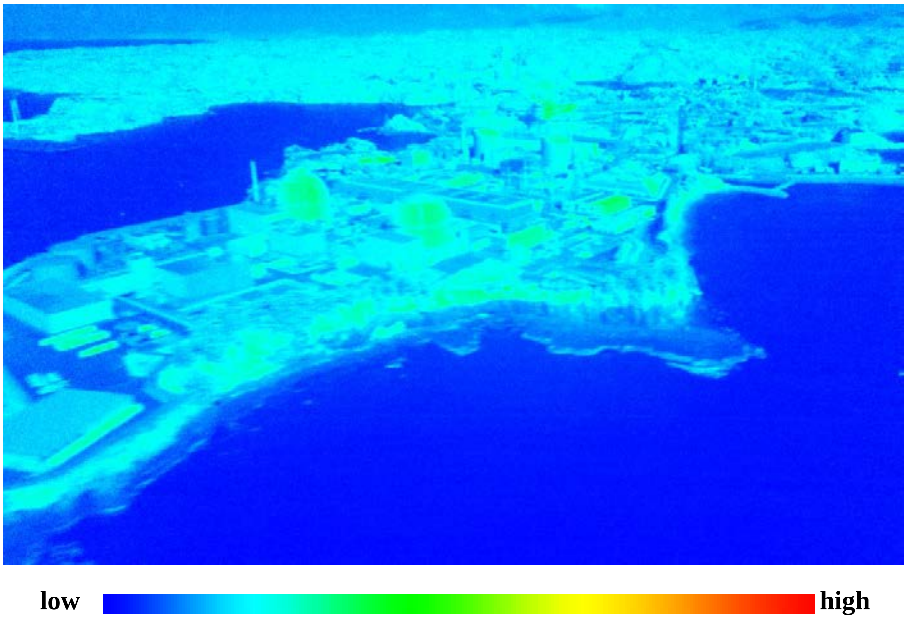

Figure 12. IR-gradation images of Genkai nuclear power plant.

4. DISCUSSION

4.1. RGB 3D models

In this study, the UAV route map of Sendai nuclear power plant was created for one turn of Sendai nuclear power plant. However, obstacles such as forests and electric wires existing on the east side were not considered when the route map was created. Then, UAV was returned home after only half of the west side was taken. Therefore, one round of the nuclear power plant was not taken because distortion occurred in RGB nuclear reactors. The photographing positions of the images used for creating a 3D model are shown by blue figures in upper Figure 13.

Black parts in Figure 13 are areas where images were not acquired. On the other hand, at Genkai nuclear power plant, a 3D model of the entire power plant was created because one turn shooting was successful. Even when the altitude is 150 m and more than 300 m away from the site boundary to comply with Civil Aeronautics Act, if one round shooting of the nuclear power plant is taken, a higher-quality 3D model would be created.

4.2. IR 3D models

The accuracy for IR 3D models was lower than RGB 3D models in both Sendai and Genkai nuclear power plants. This main reason was vibration affected by covering lens filters. IR 3D models were difficult to construct since the images vibration was large than RGB images. Furthermore, in case of Sendai nuclear power plant, brightness of IR images differs one by one because of the automatic exposure. The examples are shown in Figure 14. This reason is because exposure correction was not applied to the UAV camera setting. When IR images are taken, if one round of the nuclear power plant is taken with the exposure correction to the camera, a higher quality 3D model would be created.

4.3. IR gradation images

In the IR gradation image of Figure 12, it was recognized that the temperatures of two nuclear reactors at the center were higher than the surrounding. Currently, inspection for the re-operation started in these nuclear reactors (Units 3 and 4). Meanwhile, in Sendai nuclear power plant, Units 1 and 2 nuclear reactors which are currently in operation in Figure 9, the temperature was low. The authors considered that the infrared temperatures of the nuclear reactors were low in the difference image because the vegetation existing in the siting and the backward indicated more strongly in infrared than the nuclear reactors.

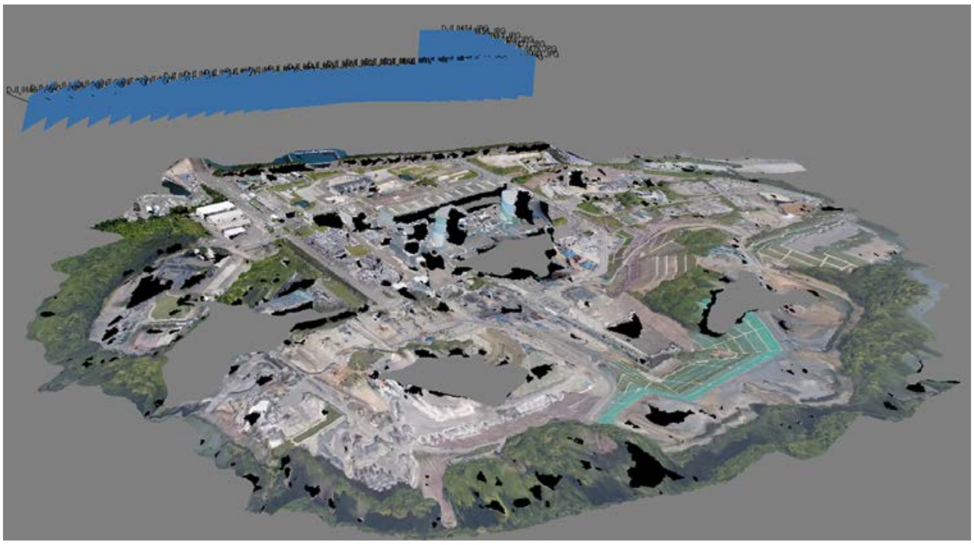

Figure 13. UAV images for Sendai nuclear power plant.

Figure 14. Two types of IR images of Sendai nuclear power plant in the auto exposure mode.

5. CONCLUSIONS

By automatic navigation of UAV, a 3D models and infrared distribution images of Sendai and Genkai nuclear power plants were created. If the images of one round for the nuclear power plant were acquired in consideration of forests and electric wires, a three-dimensional model of the whole nuclear power plant would be created easily, even if shooting points were located more than 300 m away from the site boundary. In a 3D model for IR, a more accurate 3D model would be constructed by applying the exposure correction. Furthermore, there is a function for automatically shoot at fixed intervals in UAV. Therefore, anyone can create a high-resolution 3D model by automatic navigation and automatic shooting easily. These technologies would be applied for a pollution simulation at nuclear power plant accidents.

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