Inspections of hydraulic and slope stability structures with UAV-based high definition thermal camera

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Abstract

Due to the global climate change in recent years, Taiwan often suffered from short-delayed and heavy participation. It may lead to the occurrence of regional disasters or expansion of already-existed disaster areas. Inspections to hydraulic and slope stabilization structures have been carried out. However, those inspections were often restricted by on-site environmental factors which make it difficult to reach. Furthermore, some of the structural damages cannot be observed with visible light images. Therefore, this project aims to apply UAV with high-resolution visible light and thermal-sensing camera to inspect the structural deterioration and overcoming the environmental limitations.

This project mainly studies the hydraulic structures located at Nantou mountainous area. Thermal images were used as the fundamental evidence and proven by the visible light orthophotos and digital surface model (DSM). The key objectives are to establish the Standard Operation Procedures (SOP) of UAV inspections, evaluate the reliability of UAV for inspections of hydraulic structures and prove the hydraulic structural damages by the UAV-based high-definition visible light and thermal-sensing camera.

Keywords: UAV, Thermal-sensing camera, hydraulic structure, crack inspection

1 Introduction

Nowadays, with the fast development of UAV technologies; aerial observation, can access places hard to be reached or be approached by personnel, which greatly reduces the concern of personnel safety and improve operational efficiency. Except carrying general high-resolution visible light (RGB) cameras to take photos and videos, the UAV can be equipped with other sensors, such as the thermography cameras, IR sensors and thermometers and humidity indicators to detect spectrum other than visible light and help interpret the phenomena that cannot be observed by human eyes. Hydraulic structures or slope stabilization works are often located in the riverbed or the roadside slopes where people cannot easily reach thereof, yet the peel-off and cracks on the surface of reinforced concrete structures rely on close-up photography or high-resolution cameras to find them out. Perhaps the structure itself isn't damaged on the surface, yet the damage on the internal steel bars cannot be directly observed by direct eye-watch through the spectrum of visible light. In this study, discussion and description was addressed about the advantages of applying a UAV equipped with a high-resolution thermography camera on the inspections of hydraulic structures and slope stabilization, while utilizing non-destructive detection method to achieve the effect of personnel safety, rapid detection, and accurate result interpretation. If new science and new technology can achieve the goal of sensing structural damages, it will greatly improve the feasibility of UAV application and shorten the time of UAV inspection and shorten the time of manual inspection. For the business units, it can improve the management capacity and operational efficiency.

2 Feasibility of UAV applied in the inspection of structures

The application of an Infrared thermography camera has the advantages of rapid surface inspection; it has the advantages of simply digitizing temperatures and easily interpreting thermography. This technology has quickly attracted people's attention and is widely used in non-destructive inspections.

2.1 Methods of observing cracks on the hydraulic structure surface

Thermal infrared images were used to photograph several protection facilities and side slopes in the section from Jiaxian to Meishan on the Southern Cross-Island Highway. The results show that the thermography camera can detect the concentration of groundwater behind the concrete retaining wall and the cracks on the retaining wall. (Der-Her Lee, 2000).,

The Infrared thermography camera was used to photograph the buildings on the campus at different hours of the day and compared and analyzed the images. The results show that the Infrared thermography camera has the features of non-contact, comprehensive, and large-area detection, rapid acquisition of thermography, and consecutive images were taken. It first excludes the abnormal temperature distribution locations in the building caused by the environmental characteristics, then, analyzed and judged the thermography map at different time intervals in the evening, noon, and early morning. The result shows that cracks, material difference portions, holes, moisture-concentrating points, empty wall back or the jointing place of the wall back and the beam can show different temperature pictures from the surroundings.. (K.G. Tien, 2002).

The phase-locked thermography was used to conduct experiments on various types of specimens and associate the numerical analysis method to find the best time in observing any deep defects. The result shows that if using the infrared thermography method to detect, the best detecting time is within the hours under sunlight beam or a few hours after the exposure of sunlight beam. It appears that while the test object is under heat absorption or discharge status, deflective zones show up due to the difference in thermophysical properties; and it also points out that no matter the test object contains water or not, the infrared thermography can detect the cracks under the surface of concrete structures, shown in Figure 1 (Tzu-yang Cheng, 2005).

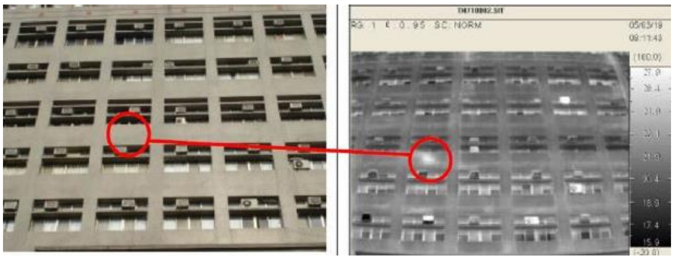


Figure1: Inspection result of building exterior wall

The infrared thermography thermometer was applied to replace the traditional manual visual inspection method in detection and made 24-hour continuous shooting on the on-site cracks with different sizes by the infrared thermography camera, and finally analyzed the relationship between the temperature changes and the damage types under assessment. The result is shown by the thermography map. It can effectively identify the characteristics of thermography, able to effectively judge for the cracks with sizes within 2~5mm. Crack with the smaller area has larger thermal inertia and slower temperature rise. (Kun-Chu Ho, 2006).

2.2 The appearance of thermography in different materials

The infrared thermography camera was used to detect the location and size of the cavity underneath the ground surface by injecting heat source and explore the available changes of temperature difference that the infrared thermography camera can detect thereof under the conditions of different concrete strength, plate thickness, cavity depth, soil layer, and with or without rebar. To match the graph with the position of the cavity for easy observation and comparison, we set the temperature difference in minus, and build a 3D temperature difference distribution map, as shown in Figure 2 and Figure 3 (Chun-hui Lee, 2008).

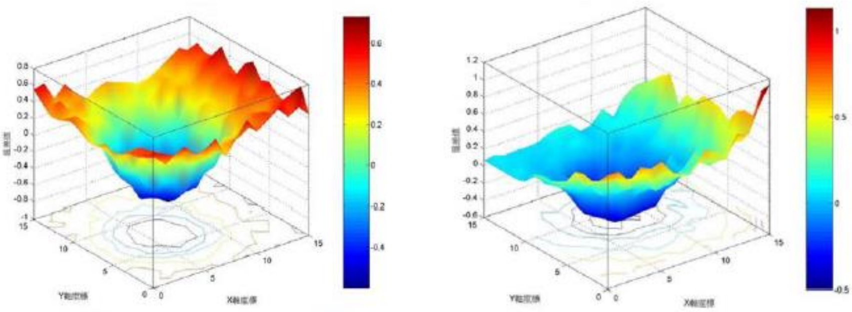


Figure 3: Fully display 3D temperature difference distribution map for 5cm-deep cavity and 10cm-deep cavity

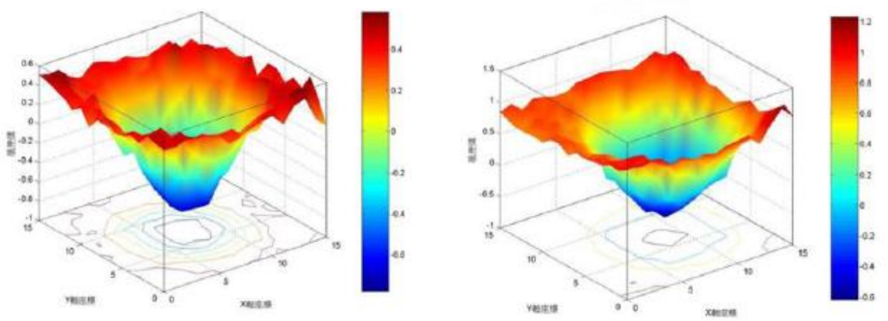


Figure 2: Fully display 3D temperature difference distribution map for 8cm-thick plate and 10cm-thick plate

The results show that using the detection of infrared thermography camera, there is no significant difference in the accuracy of the cavity under different soils, concrete with rebar reinforcement, and different concrete plate strengths, while there is an obvious and significant difference in concrete plate thickness and cavity depth. This experiment shows that the cavity location can be determined by calculating the temperature difference.

3. Method and procedure

The purpose of this study is to inspect hydraulic structures and slope stabilization, trying to identify structural problems with a thermography camera. The research starts by studying the older hydraulic structures within the jurisdiction of the Bureau of Soil and Water Conservation, expecting to find more obvious defects to learn the characteristics of thermal perception and transfer the learning process to the general structures.

3.1 Applying UAV in the standard operating procedures of inspection

The main key points of the investigation include: (1) the plant coverage of the structure, (2) the obstacles around the structure, and (3) the terrain and signal conditions of the field. By considering that the camera photography cannot penetrate the plants in front of the lens, if the structure is covered by many plants, the measured temperature would be the temperature of the plant surface rather than the structure temperature itself, which will cause misjudgment of the inspection result. In the early stage, the research conducted two aerial photo-taking missions on February 22, 2021, and March 31, 2021, and selected seven regions in Nantou County for preliminary verification. Due to the influence of weather, many days unfavorable for flight and image analysis were excluded; the mid-term verification was carried out on July 6, 2021.

3.1.1 Filed environment check

After arriving at the verification site, the research first judged whether the structure is covered by plants, the coverage rate is lower than the acceptable one, the surrounding obstacles would affect flight safety, and the terrain affect the wireless signal status. The observation was locked to whether there are water flow marks and white tracks at the concrete dam and surface cracks on of the dam and observed the growing status of weeds in the joints of the concrete structure. We tended to observe the situation presented in the thermography at different locations and study the connection between water flow marks and the white tracks.

3.1.2 Pre-work for an aerial photography task

When planning the aerial photography task, the research checked the weather conditions in the working area within a week, including rainfall, average wind speed and gust speed, etc. Starting from the rainy season in June of this year, the mountain area had heavy rain and it lasted for a long time; it is difficult for the surface of hydraulic structures to maintain a dry state. The detection theory of the thermography camera is to receive the heat radiation from the object's surface. If the surface is covered with moisture, the temperatures at different surfaces will be averaged, making the temperatures of the entire hydraulic structure to be close, making it impossible to study the structure by temperature difference.

3.1.3 Application of airspace permit

According to the airspace specification for drones issued by the Civil Aeronautics Administration, MOTC, Taiwan's airspace is divided into the restricted zone (red zone), limited zone (yellow zone), and general zone (green zone). The selected flight verification zones are all green zones and there is no need for airspace application.

3.1.4 Flying route plan

After a detailed study, the space of these two flight verifications was narrow that needed low-altitude precise flight. Due to the serious mountainous downhill wind problem, the automatic flight was risky. Therefore, the research manually flew according to the planned route and altitude, performing aerial photography at multiple angles and close distances.

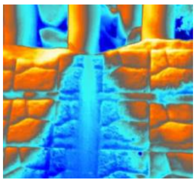
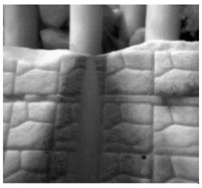
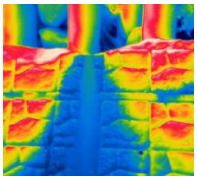
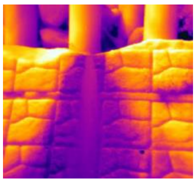
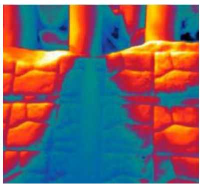
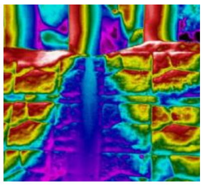
3.1.5 Aerial photography

Since the flight area of aerial photography is in the green zone, there is no need to "register" in the remote-controlled drone management information system of the Civil Aeronautics Administration. The site personnel worked as the UAV controller, observer, and site administrator. The aircraft controller is responsible for flight routes and camera operation; the observer is responsible for paying attention to the surrounding obstacles and UAV status for the controller; and the site administrator is responsible for on-site equipment management, vehicle management, and other site affairs.

3.1.6 Post-processing of images

The original file taken by the thermography camera is grayscale. Each bit in the image contains temperature data. To make the grayscale file turn into a color image easy to identify therewith, the research fed the original thermography file into the professional FLIR TOOL analysis software to perform the rendering process according to the temperature grade. The rendering spectrum in the software is divided into six types: Arctic, Gray, Iron, Lava, Rainbow, and Rainbow HC. The rendering spectrum images are shown in Table 1.

Table 1 Rendering spectrum

Arctic	Gray	Rainbow
		
Iron	Lava	Rainbow HC
		

3.1.7 Verification of structural damage detection

In this study, the hydraulic structures (including bank revetment, comb dam and bed fixing, etc.) in seven areas of the Nantou mountain region were photographed by UAV equipped with a visible light camera and a thermography camera. The result of preliminary comparison in one of these areas is shown utilizing analyzing and verifying the difference and comparability of the imaging result of the hydraulic structure through the two cameras in different times and situations. In this area (Tannan Village, Xinyi Township), there are a lot of suspected cracks found in 4 locations (A~D) for detailed analysis. The distribution locations are shown in Figure 4.

Figure4 : Location distribution of Area A~D

By observing the thermography, A of this area (as shown in Figure 5, the (1) and (2) in the figure show irregular lines, and (3) and (4) on the comb dam column show darker color blocks and line types. After compared the visible light images (such as Figure 6), it is found that there are suspected cracks in (1) and (2), and possible defects of concrete reinforcement as shown in (3) and (4). Observing the thermography cases of B~D in this area (shown in Figure 7), there are several dark circles at B, and irregular lines at C and D. After compared the visible light images (Figure 8),

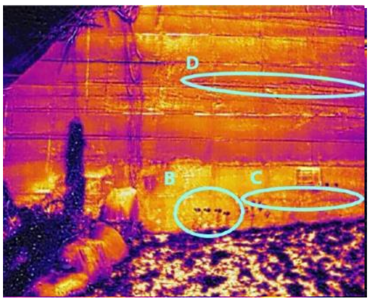


Figure7: Infared thermography at dam wing in area B

Figure 8: Visible light image at dam wing in area B~D

it is found that B is drainage holes, whereas C and D are suspected cracks.

The research conducted the second flight shooting and comparison at the same location on July 6, 2021. At this time, the shooting method mainly focused on the area spot shooting. The part of the suspected structural problems obtained from the initial flight shooting is carefully recorded, and the following factors were discussed in the impact of the image presentation. After the flight shooting was completed, using the software FLIR TOOL to make an analysis (as shown in Figure 9) and compare the maximum and minimum temperature differences in different weather conditions at the same location. The result shows that the difference between high and low temperatures was 11.2°C in a sunny environment; during the second flight, the difference between high and low temperatures was 5.3°C in cloudy weather.

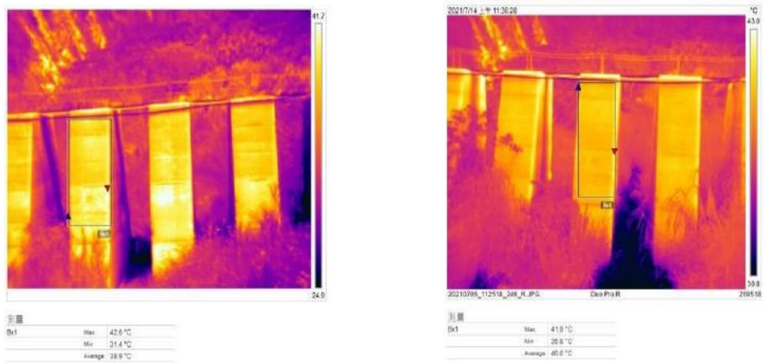


Figure 9: Use FLIR TOOL to analyze the thigh-low emperature difference in Area A

(left one was taken at the initial flight shooting, right one was taken at mid-term flight shooting)

The difference in thermography images taken between the two flights: in the mid-term flight verification (on July 6), the suspected cracks in area 4A and the reinforced concrete condition were compared with the one taken in the initial flight (on February 22). It became less apparent in the thermography images, as shown in Figure 10 and Figure 11.

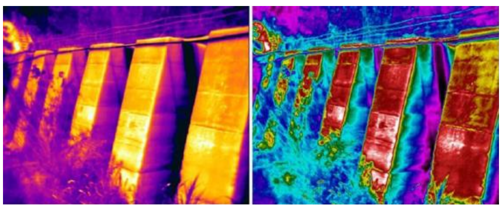


Figure10: Thermography taken in February

(iron rendering in the left picture, rainbow HC rendering in the right picture)

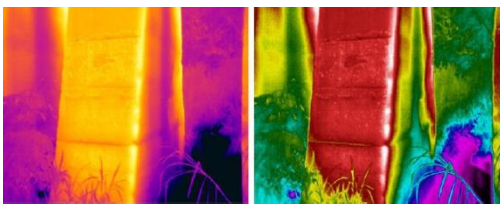


Figure11: Thermography taken in July

(iron rendering in the left picture, rainbow HC rendering in the right picture)

Other discoveries in the study: when manually reviewing the photos, the research found that the corners of one of the dam columns on the comb dam had uneven temperatures (as shown in Figure 12); the difference between high and low temperatures was about 4°C. Therefore, the visible light image was used for comparison (as shown in Figure 13). The research found that the point of low temperature was the concrete damage with the exposed steel bars. It is assumed that heat at the exposed steel bars dissipates faster than in concrete in cloudy weather, so it appears the dark color in the thermography, which is in contrast to the lighter color of higher temperature nearby.

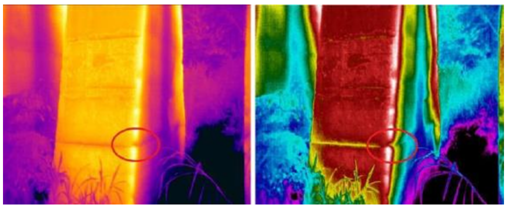


Figure12: The temperatures at the corner of dam column taken in July is uneven
(iron rendering in the left picture, rainbow HC rendering in the right picture)

Figure13: Visible light image of dam column and locally enlarged picture taken in July

3.2 Summary

Taking the result of photo shooting in this area as an example; after the initial flight shooting (on February 22), the thermography images captured by the high-resolution thermography camera can clearly show the concrete layering phenomenon of hydraulic structures, the location of drainage holes, and suspected cracks, and the effect of plant coverage, causing the image show different degrees of darkness. By comparing the thermography images with the visible light images, it can be preliminarily judged that when the thermography has irregular lines, there may be a crack in that location. When the thermography has darker color blocks in the brighter area, it may be the concrete reinforcement. In the mid-term flight shooting (on July 6), the thermal sensor successfully showed the temperature difference between the exposed steel bars and the surrounding concrete. By compared with the visible light image, it can be confirmed that the structure of hydraulic structure is damaged. According to the results of the mid-term shooting, the weather for the second flight shooting was a cloudy day. In the temperature analysis, it was found that the overall temperature difference (between different materials) for flight shooting on a cloudy day was less apparent than shooting on a sunny day, making it more difficult to analyze and compare about.

4. Conclusions and suggestions

Since there are many suspected cracks found in this area, a detailed image comparison analysis was made at this area in priority, and 4 points are identified for further image analysis results and actual situation discussion. Preliminary study has found that when the groundwater level at the upstream (back-fill side) of the structure is higher than the detection point, thermography images can be used to determine the leakages and drainages of concrete construction layered joints and drainage holes, etc., and it can be assumed that there may be through-type drainage paths in the structure. In addition, the suspected concrete delamination, drainage-hole locations, concrete reinforcement defects, and suspected cracks can be clearly distinguished on the thermography images. For the use of UAVs with thermography, the initial results of applying UAV for flaw inspection on hydraulic structures was promising. From the experience in this study, appropriate weather condition was suitable for using thermography camera and at least two flights on the same area were suggested.

5. Literature

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