Application of Dual-photothermal Imaging Technology in Leakage Detection of a Large-Scale Pool Structure

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Abstract. The leakage of reinforced concrete has been a key factor to affect the quality of waterproof structures, and the leakage detection has been the focus and difficulty to be considered in waterproof structures. Aim at this situation, based on a practical project as a case, an infrared thermal imaging nondestructive detection (ITID) technology was applied to the leakage detection of a reinforced concrete pool structure (RCPS) in this study. The dual-light infrared thermal imager (ITI), based on unmanned aerial vehicle (UAV) platform, was used to detect the leakage of external wall of the structure. The effectiveness and reliability of leakage detection were analyzed and verified for ITID technology applied into RCPS. Results show a good detection effect is obtained, and a new choice for detecting the leakage of RCPS is proposed.

Keywords: waterproof structure; leakage detection; Unmanned Aerial Vehicle (UAV); infrared thermal imaging detection (ITID)

1. Introduction
In recent years, water plants, sewage disposal plants, and other environmental engineering constructions have been increasing gradually in China, for the increasing public attention paid to the protection of water resources and the advanced disposal-reuse of sewage. And thus large reinforced concrete pool structures (RCPS) have been widely used [1]. Purifying and storing water is the main function of RCPS. During working, in addition to meeting the requirements of structure strength, RCPS also needs to meet the waterproof requirements such as high watertightness and impermeability. However, some quality problems (cracks, honeycomb, holes, construction joints, deformation joints, the failure of waterproof measures) occurring easily during construction, are easy to form leakage path and cause the leakage of RCPS [2,3]. The leakage not only affects the normal utilization of RCPS, but also causes the peeling of concrete protective layer and the corrosion of steel reinforcement, and even affects the durability and service life of the whole structure [4].

Traditional methods of detecting the leakage of RCPS mostly rely on observation and check by eyes or telescopes, with lower detection efficiency and bigger limitation. Moreover, it is difficult to find the potential leaks and to effectively identify the leakage degree of RCPS whose surface is normally covered with masonry mortar and decorative ceramics. Infrared thermal imaging detection (ITID) technology is a relatively mature nondestructive detection technology developed in recent decades [5-7]. In civil engineering, ITID technology is mainly used in the leakage detection of conventional building structures, but there are few reports on the leakage detection of the large RCPS.
Therefore, for the large scale leakage occurred during the construction of a large RCPS, a dual-light infrared thermal imager (ITI) based on unmanned aerial vehicle (UAV) platform was used to detect the leakage of the structure and according to the testing data the disease degree was evaluated, so as to provide guidance for similar engineering.

2. Infrared Thermal Imaging Detection (ITID) Technology

2.1. Basic Principle of ITID

Thermal radiation is a common way to transfer thermal energy through electromagnetic waves in nature. Any object has the ability to radiate, absorb, and emit electromagnetic waves continuously [8]. According to Stefan-Boltzmann Law, the infrared intensity of a general object is related to its temperature, material, and surface state, and the corresponding equation is [9,10]:

\[ E = \varepsilon \sigma T^4 \]

Where \( E \) is infrared intensity (W·m\(^{-2}\)), \( \varepsilon \) is gray-body emission coefficient (0<\( \varepsilon \)<1), \( \sigma \) is the Stefan-Boltzmann constant (\( \sigma = 5.67 \times 10^{-8} \text{W}\cdot\text{m}^{-2}\cdot\text{K}^{-4} \)), and \( T \) is the absolute temperature of the object (Unit: K).

Based on the phenomena of thermal radiation and the theory of Stefan-Boltzmann Law, ITID technology can analyze and evaluate the surface characteristics of the measured object. Figure 1 shows the basic principle of ITID technology. The temperature-field distribution on the object surface can be detected by this technology, so as to realize the analysis and evaluation of the surface characteristics of the object [11,12].

![Figure 1. Basic schematic diagram of ITID technology.](image)

2.2. Method for Leakage Detection of Large Pool Structure

Different objects, with different temperatures and gray-body emission coefficients, has different infrared radiant intensity. And thus the temperature-field distribution shown in the infrared thermal images detected will be different, by which to analyze and identify the surface characteristics of the object [13]. When the leakage occurs to the pool wall, the heat capacity of the pool wall (with water leakage) increases and the temperature increases less under the sunlight, because the specific heat capacity of water is greater than that of reinforced concrete. Under this case, the lower temperature of the wall with water leakage than that of other parts causes the temperature-field to be the "cold spot" distribution in the infrared thermal images [14]. Therefore, by analyzing the "cold spot" distribution, the water leakage on the surface of RCPS wall can be observed intuitively and detected effectively.

Auxiliary detection equipment such as UAV and visible light camera, can be used to improve the detection efficiency and accuracy, while ITID technology is applied to RCPS: Visible light camera and
infrared thermal imager are combined to be a dual-light (visible light and infrared ray) infrared thermal imager, which can form clearer thermal images to enrich the water leakage information shown in the images; The combination of UAV and infrared thermal imager can realize high-efficiency leakage detection and real-time comparison of data on RCPS, so as to provide basis for the manual disease evaluation. The schematic diagram of the leakage detection by UAV equipped with the dual-light ITI [15] is shown in figure 2.

![Figure 2. Schematic diagram of the pool leakage detection by UAV equipped with dual-light ITI.](image)

XT2 dual-light thermal imaging camera with high resolution, having FLIR high-precision thermal imaging sensor and 4K visible light sensor, was used in the field detection. The temperature range of objects measured is 25 °C–135 °C. The equipment can transmit infrared thermal images and visible light images at the same time. Moreover, it is very convenient to compare the characteristics of defect anomalies images, which greatly improves the efficiency of field detection.

3. Implementation of Detection Scheme
A combination utilization pool for preserving sand, grid flocculation, and air-floating sedimentation, is constructed in a water pool. The pool has a design capacity of 60000 m$^3$/day, with 6 m in height and 40 m in length and width. The wall of the pool is made of reinforced concrete and covered with masonry mortar and decorative ceramics. Due to the loopholes during controlling construction quality, although the concrete strength meets the design requirements, the external walls of the pool still leak to different degrees after water storage, especially the construction joints (figure 3). As an important water-disposal structure in the water plant, the floating-sinking pool’s leakage degree is directly related to its normal operation. Due to the large detection scope of the external wall, in addition to visible leakage, there are also hidden leakage areas which are hard to discover and need to be detected by means of nondestructive testing. Therefore, to timely understand and find out the leakage scope and status, and to avoid structural utilization function and durability problems caused by the long-term water leakage, and to provide a reliable reference for reinforcing and disposing the water leakage, the infrared thermal imager is used to completely detect the leakage of the external wall of the floating-sinking pool during the water load test. Traditional hand-held infrared thermal imager has the disadvantages of lower work efficiency and inconvenient operation to detect the leakage of the floating-sinking pool, since a wide space scope of outer wall.
In this project, the dual-light ITI was mounted on the UAV platform to comprehensively detect the leakage of the pool. The detection scope includes all the external walls of the floating-sinking pool, and the detection path sequence is the west side, south side, east side, and north side walls, as shown in Figure 4. The operation steps are: firstly, the water level of the floating-sinking pool rises to the design height (5.7m), kept this design height for 24h to make the leakage areas of the external wall fully infiltrated, as shown in figure 5; Secondly, the UAV equipped with the dual-light ITI is used to detect the external walls of the floating-sinking pool according to the detection path set, as shown in figure 6; Then, the images collected and data gained are processed and analyzed after the detection; Finally, according to the leakage status of floating-sinking pool, the leakage results are classified and evaluated, and reasonable reinforcement suggestions are proposed.
Figure 4. Regional division of the detection areas of external wall.

(a) State of empty pool.  
(b) State of water storage.

Figure 5. Process of water storage of the pool to the design water level.

Figure 6. Diagram of water leakage detection for the UAV equipped with dual-light ITI.

The field detection was implemented in August in summer when the pool was full of water. The
daytime temperature was relatively high (the maximum temperature exceeds 35°C) with a sunny weather. The detection time was chosen at noon with higher temperature, because the high temperature is conducive to the infrared leakage detection in floating-sinking pool. During the field detection, the UAV equipped with the dual-light ITI photographed the external walls of the floating-sinking pool. The photographic distance should be as close to the external wall of the pool as possible, no more than 11m (the maximum focal length of visible light lens of the dual-light ITI is 11m). And the photographic direction of the dual-light ITI was always perpendicular to the external wall.

4. Analysis of Detection Data
The evaluation methods for the leakage degree of concrete structures are come from the detection specifications by the method of infrared thermography (GB/T 29183-2012 [16] and GB 50141-2008 [17]) and the construction and acceptance specification for water structures (GB 50141-2008 [18]).

The leakage degree of the floating-sinking pool was evaluated, including the visible leakage and hidden leakage (see figure 7 and table 1). Results shows that the external wall of the floating-sinking pool has a large area of leakage.

Based on the data from field detection, the infrared thermal images and visible light images were analyzed. Part of the infrared thermal images and visible light images derived from the external walls of the pool are shown in figure 8. The contours of different structures for the external walls can be clearly observed in the infrared thermal images, mainly due to the different temperature generated on the surface of materials with different structure forms under sunlight. The temperatures in the regions with a same structure form are close to each other, indicating that the temperature field of the floating-sinking pool with a same structure form changes little. The effect of infrared thermal imaging for the external walls is good, which provides favorable conditions for the subsequent analysis of the leakage characteristics. Under the further analysis, when leakage occurs to the external wall of the pool, there are obvious low temperature areas in the infrared thermal images, that is, there are "cold spot" temperature field distributions. Combined with the visible light images, the leakage location can be accurately determined and the hidden leakage area can be found. In conclusion, combined with the detection principle of ITI and the engineering characteristics of the floating-sinking pool, the leakage occurs in the low temperature anomaly area (shown in the infrared thermal images), and the leakage area and location can be basically distinguished and defined.
In order to further analyze the influence area of the leakage location of the pool detected by the dual-light ITI, the temperature data shown in the infrared thermal images were extracted, then were

**Figure 8.** Leakage detection results of part of external walls of the pool.
projected by 3-D color mapping by professional data analysis software, as shown in figure 9. The temperature at the top of the west wall of the floating-sinking pool is generally higher and closer under direct sunlight. Under direct sunlight, the temperature at the top of the external wall decreases, being overall relatively low and proximate. The presence of water leads to the "cold spot" temperature field distribution in the infrared thermal images, when leakage area occurs. In the 3-D temperature distribution diagram (figure 9), the overall mutation and sag state of the leakage area are shown, and the overall temperature is relatively low. Under the further analysis, the 3-D diagram of the temperature distribution for the infrared thermal image shows the temperature mutation in the leakage area of the floating-sinking pool intuitively. Meanwhile, it also shows that the temperature in the non-leakage area of the floating-sinking pool is relatively proximate as a whole and there is no obvious mutation. Therefore, the 3-D temperature distribution diagram of infrared thermal images can be used as the basis to judge the leakage of the floating-sinking pool.

Figure 9. Diagram of 3-D color mapping projection of the west external wall under infrared thermal images.

The temperature gray section curves were draw, as shown in figure 10. The horizontal test of temperature section for the infrared thermal image was implemented. When there is no leakage area in the external wall of the pool, the overall temperature section curve has little variation with the temperature approaching 36°C, as shown in Curve 2 in figure 10. Compared with the Curve 2, the temperature section curve of the infrared thermal image (Curve 1) fluctuates significantly at the leakage location, and the lowest temperature tends to 34°C, when there is a leakage area near the top of the external wall of the pool. Known from Fig. 10, there are obvious intersection points of Curve 1 and Curve 2, by which the position and scope of leakage on horizontal direction finding can be determined. Similarly, the vertical test of temperature section for the infrared thermal image was implemented. When there is no leakage area in the external wall of the pool, except for the area at the top of the external wall, the overall temperature section curve changes gently, and the temperature tends to 36°C, as shown in Curve 3. The temperature section curve of the infrared thermal image (Curve 4) changes significantly in the leakage area, and the lowest temperature tends to 34°C. Similarly, there are also obvious intersection points of curves 3 and 4, by which the position and scope of leakage on vertical direction finding can be identified. Therefore, the temperature section curve of the infrared thermal image can be used as the basis to determine the location and scope of leakage in the floating-sinking pool.
Figure 10. Comparison of the temperature gray section curves of the west external wall under infrared thermal images.

Table 1. Summary of leakage diseases.

| Position       | Leakage condition | Quantity | Ratio(%) |
|----------------|-------------------|----------|----------|
| West external wall | wet stain         | 3        | 16.7     |
|                 | water seepage     | 8        | 44.4     |
|                 | drip              | 1        | 5.6      |
|                 | line flow         | 6        | 33.3     |
|                 | wet stain         | 4        | 10.8     |
| South external wall | water seepage   | 25       | 67.6     |
|                 | drip              | 3        | 8.1      |
|                 | line flow         | 5        | 13.5     |
|                 | wet stain         | 3        | 6.5      |
| East external wall | water seepage   | 33       | 71.7     |
|                 | drip              | 0        | 0.0      |
|                 | line flow         | 10       | 21.7     |
|                 | wet stain         | 2        | 10.0     |
| North external wall | water seepage | 18       | 90.0     |
|                 | drip              | 0        | 0.0      |
|                 | line flow         | 0        | 0.0      |

In conclusion, the dual-light ITI mounted by UAV can be used to effectively detect the leakage of the exterior wall of the floating-sinking pool. By comparing and analyzing the infrared thermal images and visible light images, the leakage area and scope of the external wall can be determined, so as to propose a method to detect the leakage of large floating-sinking pool rapidly and accurately and to resolve the problems that difficult to determine the defect degree and location of leakage.

5. Conclusion
(1) Aim at the floating-sinking pool structure with a large detection scope, based on the dual-light ITI mounted by UAV, the leakage location can be rapidly and universally detected, and the hidden leakage area can be basically and accurately determined by comparing the visible images and the infrared
thermal images.

(2) 3-D color mapping projection and temperature gray section algorithm are used to gain and analyze the data of the graphic characteristic from the infrared thermal images. It can quantitatively evaluate the leakage degree of the floating-sinking pool structure, and provide an effective criteria for the classification and reinforcement of the leakage for the floating-sinking pool structure.

(3) In this paper, the practical project verifies the feasibility of dual-light ITID technology based on UAV platform to detect the leakage of the floating-sinking pool structure, which provides a new approach for detecting the leakage of similar large-scale concrete structure. The temperature, material, surface condition, and other factors of the detected object will affect the test results, which should be considered in the actual detection.

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References
[1] Zhao X 2016 Optimal Design of Large Prestressed Concrete Tanks [D] Beijing: Beijing University of Civil Engineering and Architecture.(in Chinese)
[2] Xing Q H 2004 Causes and preventive measures for leakage of thin-walled reinforced concrete pools [J] New Building Materials (03): 34-35.(in Chinese)
[3] Wen X Y 2013 Leakage mechanism and anti-cracking and anti-seepage technical measures of large reinforced concrete pools [J] Special Structures 30(03): 60-63+104.(in Chinese)
[4] Su Ch Y 2017 Measures and application of seepage prevention measures of concrete tank body [J] Journal of Nanchang Institute of Technology 36(04): 18-20.(in Chinese)
[5] Stefan D, Laurent I, Yves C, et al. 2005 Improvement of building wall surface temperature measurements by infrared thermography [J] Infrared Physics and Technology 46(6): 451-467.
[6] Wang K, Yan B G, Zhang H Y, et al. 2015 Infrared thermograph nondestructive evaluation technique and Its application in construction engineering [J] Concrete 05(05): 154-157+160.(in Chinese)
[7] Liu Y L, Mei Ch, Tang Q J, et al. 2015 Research status and development trend of infrared thermal imaging detection technology [J] Machinery Design & Manufacture 06(06): 260-262+266. (in Chinese)
[8] Xu M J, Yang Zh J 2002 Application of infrared imaging in civil engineering [J] Guangzhou Architecture 06(06): 37-42. (in Chinese)
[9] Clark M R, McCann D M, Forde M C 2003 Application of infrared thermography to the non-destructive testing of concrete and masonry bridges [J] NDT and E International 36(04): 265-275.
[10] Yang L, Yang Zh 2012 Principle and Technology of Infrared Thermal Imaging Temperature Measurement [M] Beijing: Science Press.
[11] Jiang J T, Fan X Y 2011 Application and development of infrared thermal image technology on the concrete detection [J] Nondestructive Testing 33(02): 52-55.(in Chinese)
[12] Kyllili A, Fokaides P A, Christou Petros, et al. 2014 Infrared thermography (IRT) applications for building diagnostics: A review [J] Applied Energy 134: 531-549.
[13] Zeng B, Yang Y H, Ding H T 2018 Experimental study on detecting the defects of facing tiles by infrared thermal image technology [J] Guangzhou Architecture 46(02): 18-20. (in Chinese)
[14] Yang Ch, Yang Ch, Yan Zh G, et al. 2013 Preliminary study on infrared thermal imaging detection technology of highway tunnel lining structure quality Proceeding of China Civil Engineering Society.
[15] Zenmuse 2018 Zenmuse XT2 User Manual 1.0 [M] SZ DJI Technology Co., Ltd.(in Chinese)
[16] GB/T 29183-2012 *Infrared Thermographic Inspection-General Technical Requirements of In-Situ Inspection on Construction Engineering* [S]. (in Chinese)

[17] JG/T 269-2010 *Building Infrared Thermographic Inspection Requirement* [S]. (in Chinese)

[18] GB 50141-2008 *Code for Construction and Acceptance of Water and Sewerage Structures* [S]. (in Chinese)