Research and Application of Temperature Monitoring and Error Correction System for High-Strength Steel Hot Stamping Parts

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Abstract. In order to eliminate the error caused by the spatial angle between the camera and the target, it is necessary to correct the image resolution or spatial resolution error caused by the distance change in the same field of view for the monitoring of the mold loading and unloading temperature of the hot forming production line. The thermal image resolution or spatial resolution is an important parameter. The thermal image resolution of infrared lens from standard type to telephoto type can also be changed with the change of IFOV and FOV. Under the viewing angle of less than 45°, the constant emissivity bit, the most important parameter to determine the temperature, is used as a reference to automatically correct the viewing angle and thermal image resolution error of applications beyond this range, which has sufficient engineering accuracy and response when used to monitor the mold loading and unloading temperature of the hot forming production line.

Keywords: Hot stamping · Temperature monitoring · Infrared thermal imaging · Industry 4.0

1 Introduction

The hot stamping technology of high-strength steel plate is one of the main methods to realize the lightweight of automobiles [1]. With the development and maturity of the hot stamping process, new requirements are also put forward for the hot stamping production line. Based on the intelligent and digitalized production system, in addition to realizing the production process of the hot stamping process, it is also necessary to improve the safety of the production system.

The process control of the high-strength steel plate hot stamping production line mainly depends on the high-efficiency and high-reliability operation of the production line, and its forming quality and efficiency depend on the reliability of the mold. However, in continuous production, the stability of the production equipment, especially the automated conveying system for hot and cold blanks, the reliability of multi-manipulator

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cooperation, and the reliability of mold movement may affect the stability of the production line [2]. Product production defects and downtime on production lines can result from uncertainty in control and management systems.

Among them, the monitoring of working state of the mold on the press is particularly important. The automatic conveying mechanism sends the blank at about 900 °C to the mold and puts it on the mold, which has high technical requirements. Inaccurate positioning, or mold failure, can cause serious accidents. In addition to monitoring the operation of automatic machinery and presses [3], the monitoring of hot blanks involves the temperature and uniformity of the blanks. When the hot blank is transported in the air, uneven cooling will occur. When the temperature unevenness exceeds a certain error range, it also affects the quality and safety. This requires real-time monitoring of the temperature field. Second, the thermoformed parts also have a temperature of 90–180 °C, which also needs to be monitored. Due to the difference between high and low temperature, the corresponding feed temperature and ejection temperature require two sets of independent thermal imagers to monitor the temperature field in real time.

This system is developed to meet this demand. Its algorithm designs the limitations of the installation position of the thermal imager and the field of view of the equipment, as well as the resulting errors, as well as the automatic correction of the errors.

2 Influencing Factors and Error Correction Methods

2.1 Measurement Accuracy and Influencing Factors of Infrared Thermal Imager

When the infrared thermal imager measures temperature, the target distance and field of view change, which will greatly reduce the temperature measurement accuracy. According to the geometrical optics and infrared target radiation theory, the relationship between the temperature measurement error and the target distance and field of view can be deduced, and the temperature measurement error is calculated in combination with the system parameters of the infrared thermal imager. The field angle correction method is used to measure the temperature of objects under the same conditions, and the measurement error can be greatly reduced, which greatly reduces the influence of the target distance and field angle changes on the temperature measurement accuracy of the infrared thermal imager.

2.2 Error and Correction Principle of Optical System

Taking the calculated temperature relative error value as the correction value, and correcting the temperature value obtained by the calibration equation can reduce the influence of the target distance and field angle changes on the temperature measurement accuracy [4]. Using the above method to compensate the temperature measurement value, due to the certain reading error of the image plane position and the position of the imaging point, the temperature measurement error caused by the change of the target distance and the field of view cannot be completely eliminated.

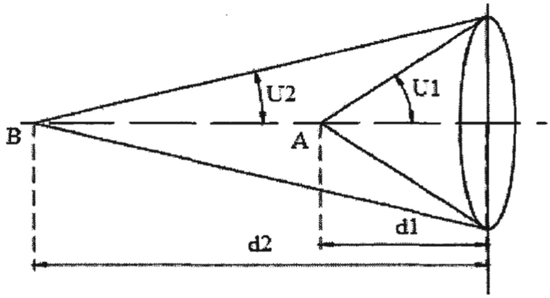

Fig. 1. Influence of distance on the measurement accuracy of points on the axis when fixed.

2.2.1 The Influence of the Installation Position of the Camera

When the camera is aimed at a high-temperature object with a real surface, a clear image of the high-temperature object can be obtained on the photosensitive surface by adjusting its focal length. Take a surface element from the surface of the high-temperature object facing the extension line of the main optical axis of the camera lens, assuming that the temperature of this surface element is, and its radiance is. In order to calculate the illuminance of the image, a one-sided element is taken on the entrance pupil plane of the lens, see Fig. 1. Under the condition of a certain wavelength, there is a one-to-one correspondence between the luminous flux and the temperature. Integrating the area of the entire object to be measured can be obtained (Eq. 1):

$$\Phi' = \int_s \Phi = \pi L(T) \int_s \sin^2 U dS \tag{1}$$

When the target is very close to the lens, a pixel can only present the image of a very small object, so the small surface source on the optical axis can be approximated as a point, which is a fixed value, see (Eq. 2):

$$\Phi' = \pi L(T) \sin^2 U \cdot S \tag{2}$$

Assume that the luminous flux Φ is the energy entering the entrance pupil during calibration, and the luminous flux Φ is the energy entering the entrance pupil in the actual measurement under the same temperature conditions as the calibration. Then there is (Eq. 3):

$$\frac{\Phi_1}{\Phi_2} = \frac{\pi L(T) \sin^2 U_1 \cdot S_1}{\pi L(T) \sin^2 U_2 \cdot S_2} = \frac{S_1 \cdot (r^2 + d_2^2)}{S_2 \cdot (r^2 + d_1^2)} \tag{3}$$

It can be seen from the above proof that if the assumed position is fixed, when the distance between the target and the lens changes, the same pixel receives the radiation energy emitted by targets of different sizes, that is, the instantaneous field of view of the thermometer, see Fig. 2. The area of the field of view of the angle will change, and it will be different from the size when we calibrate it, which will cause errors and need to be corrected.

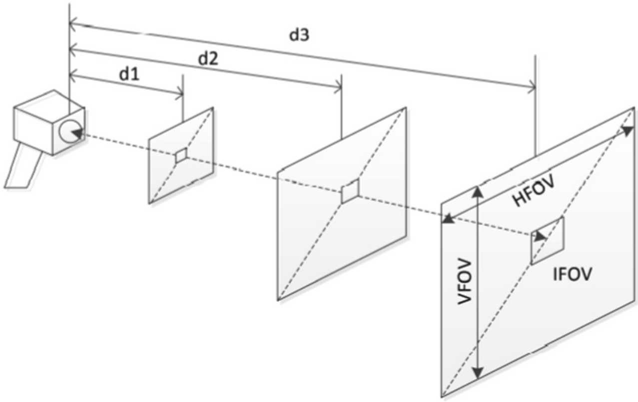

Fig. 2. The relationship between the measurement distance and the field of view of the infrared thermal imager.

2.2.2 Thermal Image Resolution or Spatial Resolution

Thermal image resolution or spatial resolution is an important parameter such as field of view (FOV), instantaneous field of view (IFOV), detector array. Infrared lenses from standard to telephoto can also change thermal image resolution with changes in IFOV and FOV.

Influencing factors, it mainly depends on the distance from the measured object to the camera, the lens system and the size of the detector. As shown in Fig. 2, thermal image resolution decreases as the distance from the object to the camera increases (objects of the same size have different resolutions at distances d1, d2, and d3). Only small, small field lens systems have high spatial resolution. Only detectors with more image elements will produce thermal images with better spatial resolution.

2.2.3 Pseudo-color Image Information and Temperature

The infrared image stores temperature information, and its most basic purpose is to detect and analyze the temperature of the target object on the image. There is no color-related information in the infrared image, so it cannot be displayed directly and needs to be converted. Therefore, the display process of the infrared image requires three mappings: 1) The temperature measurement process realizes the grayscale-to-temperature mapping; 2) The histogram equalization process realizes the image; 3) The artificial coloring process achieves false color enhancement from temperature to true color.

3 Algorithms and Implementations of Error Correction

The following methods are used to explain the principle of this system, and the correction and operation of actual parameters have been included in the software system. At viewing angles less than 45°, the emissivity, the most important parameter for obtaining accurate temperatures, is approximately constant. This software takes the standard value of the

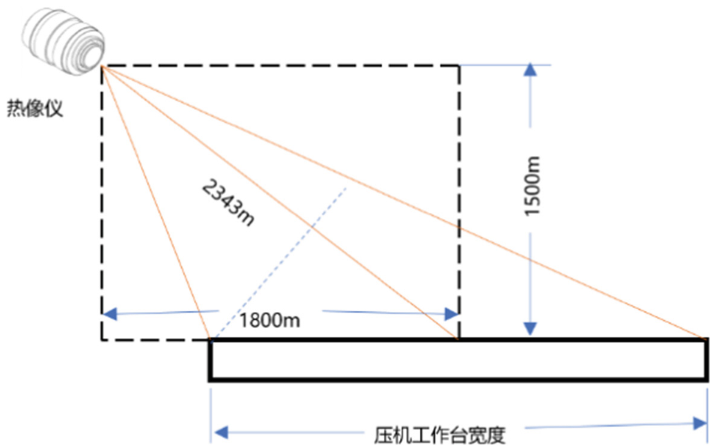

Fig. 3. Over-the-field installation that is limited by the installation location.

emissivity under the viewing angle of less than 45°, and obtains the correction data of different viewing angles and distances through experimental research, see Fig. 3.

Using advanced algorithms and high-efficiency software development platform, while ensuring stability and accuracy, the system has the characteristics of fast system response and high precision, which is convenient for monitoring the temperature of mold loading and unloading in thermoforming production lines, see Fig. 4.

The influence of the test distance on the accuracy of the near-infrared temperature field thermometer is theoretically analyzed, and the formula for temperature error compensation is given. In order to verify the correctness of the compensation formula, the compensation formula needs to be experimentally verified. To install the standard temperature heating block at a fixed length, the operation steps are as follows:

(1) Determine the calibration temperature of the integrating sphere and the calibration distance of the thermal imager in the linear working area of the thermal imager.
(2) Place the thermal imager at the calibration distance, facing the integrating sphere, and use the computer to read out the temperature value in the central area of the thermal imager.
(3) Move the thermal imager and use a tape measure to place it at 0.5 m, 1 m, 1.5 m, 2.0 m, and 2.5 m respectively.
(4) Align the thermal imager with the integrating sphere at different distances, and use the computer to read out the gray value of the central area of the thermal imager at different distances.

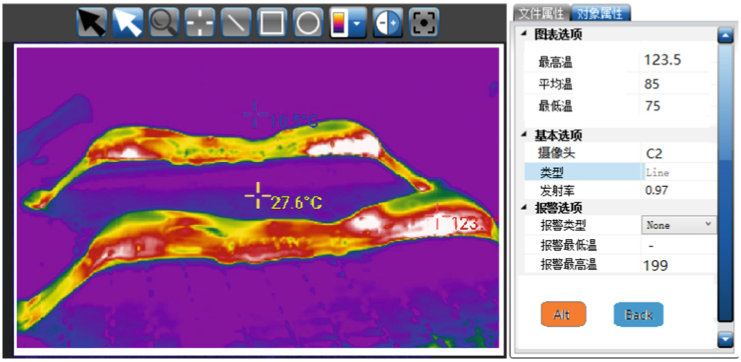

Fig. 4. Detection image of mold temperature field after correction by system software.

4 Conclusion

Using advanced algorithms and high-efficiency software development platform, while ensuring stability and accuracy, this system has the characteristics of fast system response and high precision, which is convenient for monitoring the temperature of mold loading and unloading in thermoforming production lines. When the camera is installed in a fixed position, the influence of distance on the measurement accuracy of the point on the axis must be eliminated.

The system has an emissivity under the viewing angle less than 45°, and for applications beyond this range, the viewing angle and thermal image resolution errors are automatically corrected, and it is used for the monitoring of the mold loading and unloading temperature of the thermoforming production line. It has sufficient engineering accuracy and response.

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