Accurate detection method of pig's temperature based on non-point source thermal infrared image

Zaiqin Zhang¹² | Hao Wang¹ | Tonghai Liu² | Yueqiang Wang³ | Hang Zhang² | Feiyuan Yuan² | Xue Yang² | Shunlai Xu¹ | Yuhuan Meng³

¹Chongqing Academy of Animal Sciences, Scientific Observation and Experiment Station of Livestock Equipment Engineering in Southwest for Ministry of Agriculture and Rural Affairs, Chongqing, 400246, China
²College of Computer and Information Engineering, Tianjin Agricultural University, Tianjin, 300384, China
³Department of Scientific Research, Tianjin Agricultural University, Tianjin, 300384, China

Abstract

Body temperature measurement is a very important task in the sow breeding process. The authors used an infrared camera to detect the temperature of the body surface of the sows, relying on calculating the average of the infrared image temperature in the ear root region. Based on the grayscale value of the target image of the infrared image and the corresponding temperature value of 180 infrared images, a G-T (Gray-Temperature) model was established by linear least squares method, which achieved temperature inversion of each pixel of the target pig. For the different growth stages and different breeds of sows, the R-square of the all established models is greater than 0.95. The average relative error of the model inversion of the body temperature was only 0.076977%. This means that the body temperature of the sows could be detected without relying on the software. Based on the G-T model, the authors design a kind of sow’s ear root recognition and body surface temperature detection algorithm for different sow population scenarios.

1 | INTRODUCTION

Body temperature is a physiological indicator that is very important assessing the pig’s health. The temperature of the deep part of the pig’s body is an objective reflection of the activities occurring in the animal body [1]. A huge change in the body temperature of pigs may be caused by disruption in the normal physiology of pigs. Abnormal body temperature indicates the occurrence of certain diseases, especially infectious diseases in the latent period [2]. Body temperature is a major piece of information that is used in the diagnosis and treatment of animal diseases [3-5]. It could help detect animal diseases early, as well as explore the extent and severity of the disease. Therefore, if the physiological indicators of pig body temperature change are correctly recognised and rationally used, some pig diseases can be detected, diagnosed, and treated early. The change in sow body temperature is an important condition for judging estrus [6]. The identification of sow estrus is crucial for pig production. Measuring body temperature helps identify estrus sows accurately, establish appropriate time for breeding and improve the conception rate of breeding pigs [7]. Accurate and real-time control of temperature changes in pregnant sows also facilitates in assessing the health of sows, improving the sow rate and enhancing economic benefits. With the development of the agricultural internet of things (IOT) technology, timely and real-time access to sow body temperature data has become a reality. Real-time access to sow body temperature information has become a very important part of the breeding process.

Compared with the traditional mercury thermometer to measure the rectal temperature [8], the handheld infrared
thermometer has been rapidly developed with its advantages of convenient carrying and simple operation [9], and is popularised in the actual pig farm. In the actual breeding process, the ear root, eyes, underarms, etc., are generally measured to detect whether the body temperature of the pig is abnormal [10]. However, the infrared thermometer is mainly used to measure several points on the surface of the pig. Even if the body temperature is measured on the same part of the pig, the random selection of the measurement points is easy to cause a great measurement error. The infrared camera is an infrared temperature measuring device based on field analysis, which can realise temperature detection in the whole region and overcome the limitation of randomly selecting thermometer measuring points [11]. The infrared camera is used to obtain the infrared thermal field data of pigs, and the body temperature of pigs can be obtained, which could be applied for health assessment, breeding pigs monitoring, disease detection and prevention and guidance breeding [12,13].

Soerensen et al. [14] evaluated the application of infrared temperature measurement technology in the measurement of pig body temperature and explored the relationship between skin, environment and body temperature. The optimal skin position that was highly correlated between the skin temperature and rectal temperature was likely to be a hot window such as that of the ears, eyes and breasts.

Knizkova et al. [15] discussed the use of infrared camera in the field of veterinary medicine as a diagnostic test for orthopaedic diseases in livestock and poultry, and analysed the significance of infrared thermal imaging as a breeding tool, which could participate in the thermoregulation of the breeding process to increase animal welfare.

Kammersgaard et al. [16] evaluated the thermal status of new-born piglets by infrared thermal imaging, and found that the maximum temperature (IRmax) of the infrared image was highly correlated with rectal temperature. In addition, the IRmax of the infrared camera was mainly located in the ear (27/50), and the head region (12/50). The IRmax of infrared image could be used as the basis for evaluating the thermal status of new-born piglets.

Skykes et al. [7] used digital infrared thermal imaging equipment to obtain the temperature of the sow vulva, and analysed the minimum, maximum, mean, standard deviation of temperature gradients, ambient and rectal temperature.

The application of the above infrared camera in pig breeding was mainly used to analyse the temperature characteristics of the whole or part of the infrared image data [17]. The application and detection of the specific body temperature data of the target in the infrared image were generally based on several special temperature points (the highest temperature and the lowest temperature) in the image or the average value of all the temperature data of the target pig body in the image. The maximum and minimum temperatures could only to characterise the temperature characteristics of a few pixels of the infrared image, and the limitations were too large. The average temperature of the pig body was the average temperature corresponding to the effective pixel point of the whole pig body, so that the temperature data of the hot window region (small image region) of the pig body was averaged together with the temperature data of the whole pig body image (large image region). Significant changes of body temperature in the region that best characterises the thermal state were reduced or even eliminated, and the characteristics of the temperature in the hot window region could not be analysed. How to use the data processing algorithm to quickly obtain the specific hot window region (ear roots, etc.) and obtain the specific body temperature value of sows in the region of interest through infrared camera are the research objectives of the authors.

For pig, the temperature at the anus, eyes, ear roots and armpits is significantly higher than the body surface temperature of other parts [7,14-16]. Some researcher found that the temperature at the junction of the ears and the back of the pigs was significantly higher than that of other parts of the head, and there was a significant correlation between the temperature of the ear roots and the body temperature of the pigs. The body temperature status of the pig could be characterised by measuring the temperature of the pig's ear roots [18].

Here, a gray-temperature conversion model (G-T model) was established by linear least squares method based on the infrared image of the sows which could enable infrared camera to get rid of dependence on analysis software. The ear region of the sow body was taken as the region of interest. The designed algorithm automatically extracted the root region of the sow ear. After obtaining the grayscale value of the ear root, the temperature value of the ear root region was calculated by the G-T model. The mean body surface temperature in the root region of the ear represents the body temperature of the sow, which achieved the purpose of body temperature detection. On this basis, the accuracy of the handheld infrared thermometer and the designed algorithm to measure the temperature of ear root region were compared. The stability of the two temperature measurement methods was compared by analysing the relative error changes.

2 | MATERIALS AND METHODS

2.1 | Experimental equipment

The authors use a handheld Fotric-225 infrared camera in their experiment to take infrared images of pigs, whose pixel is 320×240. Since the acquisition distance and acquisition angle have a certain influence on the quality of the acquired image [19], we made sure that the collection distance and angle were consistent when capturing images of different kinds of pigs with a handheld infrared camera. The collection distance is maintained between 0.8 and 1.0 m to ensure that the entire head of the sow is photographed and the shooting angle is within the range of 45–90°.

Sow body temperature is greatly affected by ambient temperature [20]. According to the seasonal characteristics of the experiment time, the infrared image of the sow was taken using an infrared camera at an ambient temperature of 28–33°C, and ambient temperature was collected every 5 min using an Eltek-Squirrel 1000 thermocouple temperature collector. In
order to verify the correlation between the measured temperature of the infrared camera and the rectal temperature, a mercury thermometer was used to measure the rectal temperature of sows. In order to compare the accuracy of the designed algorithm and the handheld infrared thermometer temperature measurement method, the Raytek ST20 handheld infrared thermometer was used to obtain the temperature of certain points in the ear root of sows.

2.2 Data collection

The experiment was conducted from June to August 2018. Two groups of control experiments were set up according to different ages (24 months, 4 months old) and different varieties (Rongchang sow, Landrace sow), and each group consisted of 50 sows. The image of the sow was obtained at an ambient temperature of 28–33°C.

2.3 Data processing platform and methods

The tool used for data preprocessing is the infrared image preprocessing software AnalyzIR 4.1.1 that comes with the Fotric-225 camera. The original size of the image taken by the infrared camera is 960 × 720 pixels. AnalyzIR 4.1.1 can realise infrared image normalisation conversion and export 320 × 240 pixels infrared image, and export 320 × 240 size temperature table data. The temperature corresponding to the pixel in the temperature table data is the measured temperature of the whole infrared image. This software does not automatically obtain pig body region data and analyse the specific temperature of the pig body. To ensure consistency in the temperature and gray resolution, the infrared image was preprocessed using AnalyzIR 4.1.1 before data processing. The pig ear root temperature data manually obtained by the handheld infrared thermometer was written to Microsoft Excel 2013 (Microsoft Corporation, USA), and the pig body temperature data measured by the handheld infrared thermometer was obtained by the averaging method.

Data processing and analysis were performed using Matlab R2010b (The Mathworks Inc., USA) software and Excel 2013. As shown in Figure 1 60 images of the 24-month-old Rongchang sows, 60 images of the 4-month-old Rongchang sows, and 60 images of the 24-month-old white sows were selected. The software AnalyzIR 4.1.1 was employed to preprocess the image to obtain a standard infrared image of 320 × 240 pixels and export the original temperature data. The three groups of images were preprocessed separately. For a set of experiments, the temperature data and gray scale data of each target pig of the infrared images were extracted, and the gray-temperature conversion model was established by the linear least squares method to obtain 60 sets of model parameters. Thus, a total of 180 groups of model parameters were obtained from the three groups of experiments. We observed that the values of each group of parameters were generally similar. In order to obtain a universal model, the $G$-$T$ model of uniform parameters is obtained by averaging the parameters.

![Diagram of data processing](image)

**FIGURE 1** Data processing

Based on the $G$-$T$ model, an algorithm was designed to process images to detect sow body temperature. The standardised infrared image and original temperature data processed using AnalyzIR 4.1.1 were imported into Matlab R2010b. First, the algorithm was designed to identify the number of breeding sows in various scenes and extract the grayscale data of each sow. Second, the designed algorithm was used to identify the ear region of each sow and extract the grayscale data of the ear root region. And finally, the $G$-$T$ model was used to calculate the average temperature of the ear root region. The average temperature of the ear root region was the predicted body temperature of the target pig. According to the measurement values of the software, the software measured values and the algorithm detection values were counted in Excel 2013 and the average relative error of the mean temperature of the ear roots was analysed.

3 G-T MODEL ESTABLISHMENT

3.1 Image preprocessing

Most of the Rongchang sows were covered with hair, and the hair has been a great influence on the grayscale value of the infrared image. Denoising the grayscale image was performed...
to reduce the noise caused by the pig hair. The function ‘wthcoef2’ was used with appropriate scale vector and threshold vector twice to obtain the denoised image. The original image, grayscale image and the denoised image are shown in Figure 2. The original image comes with an icon and a temperature bar, and the icon and temperature bar regions were automatically cropped after the image was denoised. Figure 3 shows an effective grayscale image. The temperature data were automatically cropped according to the effective grayscale image size. The grayscale and temperature data are uniformly unified, and the image size after cropping was $268 \times 240$ pixels.

Threshold segmentation of effective grayscale images was performed using the Otsu algorithm to obtain binary images of the target sow (Figure 4a). Due to the large amount of hair in the face region of the Rongchang pig, the temperature in the dense region of the pig hair is low, and these regions may be removed when the target pig is extracted by threshold. After the threshold segmentation was completed, the holes in the region of the target pig were filled by the closed operation, and the corrected target pig binary map is shown in Figure 4b. The binary image is the cropping template.

The grayscale data of the pig body region were obtained by multiplying the cropping template by the effective grayscale image point. The body temperature data of the pig body were obtained by multiplying the cropping template by the effective temperature data point. Then the block separating operation on acquired pig body temperature data and grayscale data were performed, which needed a $4 \times 4$ separation block to average the pig grayscale and temperature data. A gray matrix $g$ and a temperature matrix $t$ were obtained.

### 3.2 Model establishment

After obtaining the gray level $g$ and temperature $t$ of the target, we found that they have a close relationship between these variables. However, there was a non-deterministic relationship between them. It was consistent with the definition of correlation, and the relationship between the two variables could be statistically analyzed by regression analysis [21].

Assume the fitted straight line: $t = ag + b$;

For any sample point $(g_i, t_i)$;

Error: $e = t_i - (ag_i + b)$;

When $S = \sum_{i=1}^{n} e_i^2$ is the smallest, the fitting degree is the highest, that is when $\sum_{i=1}^{n} (t_i - ag_i - b)^2$ is the smallest;

First-order partial derivative:

$$\frac{\partial S}{\partial b} = -2 (\sum_{i=1}^{n} t_i - nb - a \sum_{i=1}^{n} g_i) \quad (1)$$

$$\frac{\partial S}{\partial a} = -2 (\sum_{i=2}^{n} g_i t_i - b \sum_{i=1}^{n} g_i - a \sum_{i=1}^{n} g_i^2) \quad (2)$$

Let (1) and (2) be 0, and there were $n \bar{g} = \sum_{i=1}^{n} g_i$ ,

$$n \bar{t} = \sum_{i=1}^{n} t_i$$

Get the final solution:

$$a = \frac{\sum_{i=1}^{n} (g_i - \bar{g})(t_i - \bar{t})}{\sum_{i=1}^{n} (g_i - \bar{g})^2}$$

$$b = \bar{t} - a \bar{g}$$
Sixty infrared images of 24-month-old Rongchang sows, 60 infrared images of 24-month-old Changbai sows, and 60 infrared images of 4-month-old Rongchang sows were selected, and each image was modelled using linear least squares. Sixty sets of model parameters \( A \) and \( B \) were obtained for each set of experiments. Furthermore, a set of experimental unified \( G-T \) models was obtained by calculating the mean values of \( A \) and \( B \), respectively.

Figure 5 shown one of the 24-month-old Rongchang sow's gray-temperature fitting model and the R-square was 0.9479. By analysing parameters \( A \) and \( B \) of the 60 groups of models, we observed that the size of each group was very close, and the R square was always greater than 0.9. The average value of the parameters was obtained, and the unified \( G-T \) model of 60 24-month-old Rongchang sows was obtained: \( A = 0.0404, B = 30.026 \). The model sought was as follows:

\[
T = 0.0404 \times G + 30.0260 \quad (3)
\]

The same method was used to process 60 infrared images of the 4-month-old Rongchang sows, all the resulting R square values were greater than 0.9. The \( G-T \) model of 4-month-old Rongchang sows was as follows:

\[
T = 0.0404 \times G + 30.0052 \quad (4)
\]

The same method was used to process 60 infrared images of 24-month-old Landrace sows, and all the resulting R square values were greater than 0.9. The \( G-T \) model of the 24-month-old Landrace sows was as follows:

\[
T = 0.0405 \times G + 30.0152 \quad (5)
\]

Table 1 shows the average parameter model of 60 infrared images of 3 groups of sows. It was found that the grayscale model parameters of infrared images of different breeds and different ages were very similar, and the model was obtained by means of averaging. The parameters were unified and the gray-temperature model was obtained as follows:

\[
T = 0.0404 \times G + 30.0155 \quad (6)
\]

### 3.3 Model verification

Accuracy verification was needed after model establishment. The grayscale data \( g \) of the pig region were obtained by multiplying the effective grayscale image by the cropping

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**TABLE 1** Models with average parameter of infrared images of three groups of sows

| Experimental objects       | \( G-T \) model               |
|----------------------------|--------------------------------|
| 24-month-old Rongchang     | \( T = 0.0404 \times G + 30.0260 \) |
| 4-month-old Rongchang      | \( T = 0.0404 \times G + 30.0052 \) |
| 24-month-old Landrace      | \( T = 0.0405 \times G + 30.0152 \) |
| Unified model              | \( T = 0.0404 \times G + 30.0155 \) |

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**FIGURE 5** \( G-T \) model parameters

**FIGURE 4** Otsu threshold segmentation and closed operation
template, and the temperature data $t_d$ of the pig body region were obtained by multiplying the effective temperature data point by the cropping template, and $t_1$ was the true temperature data of each pixel of the pig body. Substituting $g$ into the $G-T$ model to calculate the body temperature $t_2$, and $t_2$ was the detected temperature of the model at each point of the pig body. In the same two-dimensional coordinate system, the relationship between the detected temperature $t_2$ and the gray level $g$ was represented by a red “o”, and the relationship between the true temperatures $t_1$ and $g$ was represented by a blue ‘+’. Figure 6 shows that the detected temperature value of the target pig body was very close to the actual value, and several detected values were equal to the true value. The actual temperature grayscale relationship trend was based on the model relationship trend as a standard line floating up and down.

The average relative error of the highest temperature detected values of 60 infrared images was 0.233%. Except for the second image which was greater than 1%, the relative error of the highest temperature reading of the other images was less than 1%. The average relative error of the lowest temperature detected value was 0.456%, the 2nd, 13th and 55th images were greater than 1%, and the relative errors of the lowest temperature of the other images were less than 1%. The detected value of the lowest temperature was accurate, but the average relative error was larger than the average relative error of the highest temperature. The average temperature relative error was 0.077% except the 2nd and 56th images that were greater than 0.2%, and the relative error of the average detected temperature of the other images was less than 0.2%. Compared to the highest and lowest temperature, the average temperature of the detected sows was the most accurate. From the above data, it could be seen that the accuracy of the pig body temperature detected by the $G-T$ model was higher generally, and the pig body temperature could be better detected.

4 | PIG IDENTIFICATION AND BODY TEMPERATURE DETECTION ALGORITHM DESIGN

4.1 | Pig identification

In the lower-month-old reserve breeding pigs, seven or eight pigs are usually raised in a pig pen, and the breeding density is higher. The timely identification of pigs with abnormal body temperature in group pigs is also important for epidemic control [22]. When an infrared camera was used to capture images, the infrared image may contain multiple breeding pigs. So, the authors designed an algorithm that could accurately identify the number of sows in infrared images of different scenes and extract the grayscale data of each pig to determine the thermal state of each pig.

Under different scenarios, the following steps are carried out: Step 1: Preprocessing the infrared image, including wavelet denoising, effective region cropping, and Otsu threshold segmentation. Step 2: Identifying the connected region of the value map. Step 3: Counting the number of connected regions. This method enables the number of non-adhesive pigs to be counted due to the bright and connected nature of the pig region. In the statistical process, it is necessary to identify whether the highlighted region is a pig region. By analysing the marked connected region, we determined that the number of pixels in the pig region is much larger than the connected region generated by noise, and their difference is more than an order of magnitude. The pig statistical variable was set by traversing each connected region and specifying a connected region of 5,000 pixels or more as a pig region. The region of a pig was obtained through each traversal and the region was automatically extracted, and then the statistical variable of the pig was increased by one. Step 4: Rectangular calibration was performed on the connected region...
to verify whether the number of pigs was statistically correct. This algorithm could accurately identify the number of breeding pigs in different scenes.

The pig identification process in the non-adhesive multi-pig scenario was shown in Figure 7: Figure 7a is a grayscale image; Figure 7b is a binary image, and the algorithm identified the pigs in the image from left to right. Each time one pig in Figure 7a is recognised, its grayscale data were extracted and stored; Figure 7c shows the binary map of the first recognised pig; Figure 7d shows the binary map of the second recognised pig. The minimum rectangle calibration (shown in Figure 8) of the connected region was used to check whether the number of rectangular calibrations was consistent with the number of breeding pigs. This method was used to process 20 images, 10 of which contained 2 sows, and the pig identification rate was 100%. The other 10 images in adhesive multi-pig scenario could not be identified correctly.

4.2 | Ear root region recognition

The ear region is one of the hot window parts of the pig. In the infrared image, one distinct characteristic of the ear region of the pig is that the brightness is high, and the grayscale of the ear of the gray image is higher than that of other parts of the head. The flow of ear extraction algorithm designing was shown in Figure 9. After the pig identification was completed, the ear region was selected by the grayscale range marker. Then, the gray level of selected ear region was zeroed. Then, the image with ear region was zeroed and XOR was performed to obtain an ear binary image. The ear binary image may be the case of a single ear region or two ears regions. By selecting the maximum connected region, the largest ear region was obtained, and at the same time, it could eliminate the interference of bright pixels in small regions. The target region was cropped with the binary image of the largest ear region, and the grey image of the pig ear was obtained by dot-multiplying the original gray image of the pig, and then the ear was extracted.

The extraction process of pig ear is shown in Figure 10, where Figure 10a: a pig grayscale image; Figure 10b: the target pig binary image obtained after the Otsu threshold segmentation; Figure 10c: grayscale value was set to zero; and Figure 11a: the image of the ear region obtained by the exclusive OR of Figure 10b and c. After being extracted into the binaural region, the maximum connected region could be selected to eliminate the influence of highlights in other small regions, and the maximum ear region in Figure 11b was obtained. The ear binary region was used as the next target cropping region. The grayscale data of the pig corresponding to Figure 10a were cropped, the grayscale data of the target ear region were obtained, and the ear recognition was completed.
4.3 Design of sow body temperature detection algorithm

After obtaining the grayscale data of the ear region, the G-T model was used to calculate the temperature value corresponding to the grayscale value of each pixel in the ear root region. The designed process of the pig body temperature detection algorithm was shown in Figure 12. In the single pig scene, the grayscale data of the pig ear were directly obtained, and then the average temperature of the ear was calculated using the G-T model. In the multi-pig scenario, the number of pigs need to be identified first, the grayscale data of the ear root region of each pig also required to be obtained, and then the body temperature of each sow was calculated using the G-T model.

5 RESULTS AND ANALYSIS

5.1 Body temperature detection algorithm accuracy

Many studies had shown a correlation between body surface temperature and rectal temperature. The rectal temperature of 20 4-month-old Rongchang sows was first measured by the mercury thermometer as shown in Figure 13a and then the rectal and body surface temperatures were compared using the designed algorithm (Table 2).

According to the analysis of 20 groups of data in Table 2, the rectal temperature shown a certain correlation with the temperature algorithm, and the correlation coefficient was 0.847825%. This indicated that the temperature of the pig body could be detected according to the body surface temperature measurement of the ear root of the pig, and the heat state of the pig could be analyzed based on changes in body surface temperature of the ear root of the pig.
The algorithm predicted the average relative error of body temperature was 0.132889%, and the average relative error of handheld infrared thermometer was 2.712676%. This indicated that the method of measuring body temperature based on infrared images is more accurate. This is because the body temperature detection method of the designed algorithm involves measuring the most of all root of sow’s ear. Compared to temperature measurements of several points of the pig ear using an infrared thermometer, the temperature data are more precisely measured. Therefore, the body temperature measurement method designed by the authors has higher detection accuracy. As can be seen from Figure 14, the fluctuation of the error measured by this algorithm is smaller than that of the handheld infrared thermometer.

### 5.2 Detection of body temperature in sows under multi-pig scenario

In the multi-pig scenario, there was adhesion and non-adhesion between sows. 10 infrared images of two non-adhesive sow scenes were selected, and the designed algorithm was used to measure the body temperature of the target pigs. At the same time, 10 infrared images of two pig scenes in the state of adhesion were selected and processed. The data show that the accuracy of the algorithm for identifying multiple target pigs in the non-adhesive state were 100%. The algorithm could accurately calculate the body temperature of each pig. The mean relative error of body temperature measurement was 0.129755%.

However, the algorithm could not accurately identify the target sows in the adhesion state because the glued pigs would be recognised as one sow. The effectiveness of this algorithm in identifying adherent sows required further investigation.

### 5.3 Sow body temperature detection in a single pig scene

#### 5.3.1 Comparison of sow body temperature of different ages

Now, 10 images of 24-month-old Rongchang sows in the single-pig scene at ambient temperature of 28–29°C, 29–30°C, 30–31°C, 31–32°C and 32–33°C were selected. The ambient

| Pig NO. | Rectal temperature (°C) | Ear root surface temperature (°C) |
|---------|-------------------------|----------------------------------|
| 1       | 39.6                    | 37.4231                          |
| 2       | 39.8                    | 37.6481                          |
| 3       | 39.4                    | 37.4995                          |
| 4       | 39.5                    | 37.7079                          |
| 5       | 39.7                    | 37.9198                          |
| 6       | 39.8                    | 38.0276                          |
| 7       | 39.8                    | 38.1734                          |
| 8       | 39.7                    | 38.1483                          |
| 9       | 39.5                    | 37.904                           |
| 10      | 39.8                    | 38.2209                          |
| 11      | 39.8                    | 38.1842                          |
| 12      | 39.9                    | 38.2734                          |
| 13      | 40                      | 38.5237                          |
| 14      | 39.9                    | 38.2965                          |
| 15      | 40                      | 38.279                           |
| 16      | 39.7                    | 38.2606                          |
| 17      | 39.7                    | 38.1691                          |
| 18      | 40.5                    | 38.8119                          |
| 19      | 39.9                    | 38.4852                          |
| 20      | 40.3                    | 38.753                           |

Note: Temperature is expressed as °C.

T able 2 Rectal temperature and ear root temperature of 20 Rongchang sows

| Pig NO. | Rectal temperature (°C) | Ear root surface temperature (°C) |
|---------|-------------------------|----------------------------------|
| 1       | 37.678                  | 37.655                           |
| 2       | 37.098                  | 37.074                           |
| 3       | 37.664                  | 37.662                           |
| 4       | 38.108                  | 38.141                           |
| 5       | 37.721                  | 37.726                           |
| 6       | 37.772                  | 37.738                           |
| 7       | 38.228                  | 38.245                           |
| 8       | 38.174                  | 38.202                           |
| 9       | 38.275                  | 38.314                           |
| 10      | 38.148                  | 38.187                           |
| 11      | 38.752                  | 38.829                           |
| 12      | 38.985                  | 39.065                           |
| 13      | 38.728                  | 38.813                           |
| 14      | 39.075                  | 39.146                           |
| 15      | 38.859                  | 38.911                           |
| 16      | 38.762                  | 38.845                           |
| 17      | 38.701                  | 38.779                           |
| 18      | 39.216                  | 39.305                           |
| 19      | 39.147                  | 39.228                           |
| 20      | 39.411                  | 39.503                           |

Note: Temperature is expressed as °C.

T able 3 Temperature measurement accuracy comparison table

| No. | Actual body temperature (°C) | The algorithm detected temperature (°C) | Infrared thermometer measured temperature (°C) | Relative error | Relative error |
|-----|------------------------------|----------------------------------------|-----------------------------------------------|----------------|----------------|
| 1   | 37.678                       | 37.655                                 | 37.6                                         | 0.062          | 37.6           |
| 2   | 37.098                       | 37.074                                 | 37.1                                         | 0.065          | 37.1           |
| 3   | 37.664                       | 37.662                                 | 37.3                                         | 0.003          | 37.3           |
| 4   | 38.108                       | 38.141                                 | 37.1                                         | 0.086          | 37.1           |
| 5   | 37.721                       | 37.726                                 | 37.1                                         | 0.013          | 37.1           |
| 6   | 37.772                       | 37.738                                 | 37.1                                         | 0.089          | 37.1           |
| 7   | 38.228                       | 38.245                                 | 37.1                                         | 0.046          | 37.1           |
| 8   | 38.174                       | 38.202                                 | 37.1                                         | 0.074          | 37.1           |
| 9   | 38.275                       | 38.314                                 | 37.1                                         | 0.103          | 37.1           |
| 10  | 38.148                       | 38.187                                 | 37.1                                         | 0.102          | 37.1           |
| 11  | 38.752                       | 38.829                                 | 37.1                                         | 0.198          | 37.1           |
| 12  | 38.985                       | 39.065                                 | 37.1                                         | 0.203          | 37.1           |
| 13  | 38.728                       | 38.813                                 | 37.1                                         | 0.22           | 37.1           |
| 14  | 39.075                       | 39.146                                 | 37.1                                         | 0.182          | 37.1           |
| 15  | 38.859                       | 38.911                                 | 37.1                                         | 0.132          | 37.1           |
| 16  | 38.762                       | 38.845                                 | 37.1                                         | 0.214          | 37.1           |
| 17  | 38.701                       | 38.779                                 | 37.1                                         | 0.202          | 37.1           |
| 18  | 39.216                       | 39.305                                 | 37.1                                         | 0.225          | 37.1           |
| 19  | 39.147                       | 39.228                                 | 37.1                                         | 0.205          | 37.1           |
| 20  | 39.411                       | 39.503                                 | 37.1                                         | 0.234          | 37.1           |

Mean 0.133 0.133 2.713

Note: Temperature is expressed as °C.
temperature was gradually increased according to the sequence of image numbers. The designed algorithm was used to detect the body temperature of the pigs. Blue line and red line of Figure 15 reflects the relationship between the measured values of the camera analysing software and the detected values of the algorithm for 50 24-month-old Rongchang sows at an ambient temperature of 28–33°C. Both fold lines were basically coincident, and the measurement error was very small. The average relative error of body temperature of fifty 24-month-old Rongchang sows was 0.094479%. The green line represents the value of traditional measurement method which measured ear root by infrared thermometer. The average relative error was 2.620491%. At the same ambient temperature, the sow’s body temperature measurement value gap was large.

Furthermore, 50 images of 4-month-old Rongchang sows under the same environmental temperature conditions were selected, and the body temperature of sows was detected using the designed algorithm. As shown in Figure 16, at an ambient temperature of 28–33°C, the line chart indicated the relationship between the actual value of the pig body and the predicted value of the algorithm, blue and red fold lines were substantially coincident, which indicated that the body temperature error of the algorithm was very small. Data analysis shows that the average relative error of body temperature of 50 4-month-old Rongchang sows was 0.115799%. The green line represented the temperature measurement result of the handheld infrared thermometer. Body temperature of sows in the same ambient temperature range fluctuated greatly. The average relative error was 3.053956%.

According to the two sets of data line graphs, from left to right, as the ambient temperature is increased, the body temperature of the sows also increased, and the ambient temperature imparted a significant effect on the body temperature of the sows. At the same time, it was found that the body surface temperature difference between different individuals of 24-month-old Rongchang pigs in the same environmental temperature range was large. As shown in the 13th and 15th images in Figure 15, the body temperature of the two pigs differed by about 1.4°C at 29–30°C. For the 41st and 42nd images, the temperature of the two pigs differs by about 1.5°C at an ambient temperature of 32–33°C. As shown in Figure 16, as the ambient temperature from low to high, the body temperature data of 4-month-old pigs changed significantly from low to high, while the fluctuation between individuals was small.

By comparing the body temperature of the 4-month-old and the 24-month-old Rongchang sows at the same ambient temperature, we found several notable features. The data line graphs (Figure 17) indicated that the body temperature line of the 4-month-old Rongchang sows was higher than that of the 24-month-old Rongchang sows, and this maybe because the younger sows were more physically active and generated heat faster. This also satisfies the general rule of the difference in body temperature between different types of pigs [23].

5.3.2 | Comparison of body temperature of different sow breeds

Now, 50 images of 24-month-old Landrace sows under the same ambient temperature conditions were selected, and the
The designed algorithm was also used to detect their body temperature. Figure 18 shows the relationship between the measured values of the camera and the predicted values of the algorithm for the 24-month-old Landrace sows at 28–33°C. Both fold lines were basically coincident, and the measurement error was very small. The average relative error of body temperature of the fifty 24-month-old Landrace sows was 0.106143%. This algorithm could accurately measure the body surface temperature of 24-month-old Landrace sows. The average relative error of pig body temperature measured by a handheld infrared thermometer is 3.528042%. This method of temperature measurement commonly used in production had a large random error in measuring pig body temperature.

The body temperature of 24-month-old Rongchang sows and 24-month-old Landrace sows under the same ambient temperature was compared. Figure 19 indicated that the body temperature of the 24-month-old Rongchang sows is higher than that of the 24-month-old Landrace sows. This may be because the Rongchang sows had significantly more pig hair than the Landrace sows, and pig hair had a coarse texture that affected heat dissipation in the pig's body. Therefore, the overall body temperature of Rongchang sows was higher than that of the Landrace sows at the same ambient temperature.

6 | CONCLUSION

(1) A gray-temperature G-T model based on fotric-225 infrared camera image was established: $T = 0.040428 \times G + 30.01546$. Using this model, the temperature of each pixel of the target pig body can be calculated according to the grayscale data that correspond to the infrared image, and the average relative error of the temperature calculation was 0.076977%.

(2) Using the region recognition technology, an algorithm was designed to identify the number of non-adhesive sows under different scenarios and to extract grayscale data from each sow. The root region of each pig is automatically cropped by the grayscale value range calibration and image exclusive OR operation. The grayscale value of the ear root was observed, and the mean temperature of the ear root was calculated using the G-T algorithm. Using this approach, the surface temperature of the pig body was determined. Compared to the handheld infrared thermometer for measuring the body temperature of pigs, the accuracy of this algorithm is higher.

(3) Using a total of 160 infrared images of breeding sows with different environmental temperatures, ages, varieties and scenes, the temperature of the target body in the images was measured, the average relative error was less than 0.1%, and the measurement result was accurate. For data analysis, it is observed that the ambient temperature largely influences pig body temperature. Under normal circumstances, the higher the ambient temperature, the higher the body temperature of the pig. At the same ambient temperature, the average temperature of the Rongchang sows at different ages varied. The average body temperature of sows at 4 months is higher than that of 24-month-olds. The body temperature of sows of different breeds also varied. The average body temperature of Rongchang sows at 24 months is higher than that of Landrace sows at the same age.
The results of this study show that the proposed algorithm can accurately identify non-adherent target pigs and calculate body temperature. How to improve the algorithm to identify and count the pigs in the adhesion state and complete the body temperature measurement of each sow is the focus of future research. The accuracy of detecting sow body temperature is very high, but it uses the assumption that the camera software measures the true temperature error to zero. How to calibrate the infrared camera to ensure the accuracy of the infrared camera measurement needs further research and validation. With the continuous development of infrared cameras, measurement accuracy continues to increase, and pig body temperature measurement methods based on infrared images will be widely used.

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ORCID

Zaiqin Zhang https://orcid.org/0000-0001-6077-3847
Hao Wang https://orcid.org/0000-0002-2347-1492
Tonghai Liu https://orcid.org/0000-0002-7390-7098
Hang Zhang https://orcid.org/0000-0002-1108-5236
Feiyan Yuan https://orcid.org/0000-0002-1000-4502
Xue Yang https://orcid.org/0000-0001-9206-5159
Shunlai Xu https://orcid.org/0000-0001-8674-1341
Yuhuan Meng https://orcid.org/0000-0002-9896-3862

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