

Non-contact evaluation of pigs' body temperature under various infrared sources

Hoc Thai Nguyen¹, Tien Xuan Dao², Duong Tri Ngo¹

¹Department of Automation, Vietnam National University of Agriculture, Hanoi, Vietnam

²Faculty of Engineering, Vietnam National University of Agriculture, Hanoi, Vietnam

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ABSTRACT

The purpose of this study is to verify the feasibility of using an infrared camera to measure the surface temperature and then estimate the core body temperature of pigs under various infrared sources. We first conducted experiments with pig-body temperature measurement by an infrared camera. Then we have tried to increase the accuracy rate in estimating the core body temperature of pigs by measuring the temperature of moving pixels. We concluded that the relation between the core body temperature and the estimated pig-body temperature was $y = 1.0392x - 0.6621$ with no static infrared source in the field view of infrared camera. With the existence of heat lamps in the field of view of the infrared camera, the relation was $y = 1.0248x - 0.0921$. With both the root mean square error and the mean absolute error lower than $1.12\text{ }^{\circ}\text{C}$, the experimental simulation results show that the proposed method is feasible and effective in fast and non-contact evaluation of pigbody temperature under various infrared sources.

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Corresponding Author:

Hoc Thai Nguyen

Department of Automation, Vietnam National University of Agriculture

Gialam, Hanoi, Vietnam

Email: nguyenthaihoc@vnu.edu.vn

1. INTRODUCTION

It is known that body temperature is one of the most important physiological indicators that provides useful information in early assessment of the pig's health status [1]–[4]. The core body temperature reflects many activities, which occur simultaneously and continuously inside the body [5]. Normally, the rectal temperature is used to present the body temperature of the pig, and the body temperature range of a growth healthy pig is from 38 to $40.8\text{ }^{\circ}\text{C}$ [6], [7]. Unfortunately, it is quite hard, costly, time-consuming and a variety of techniques are used for rectal temperature measurement in pigs [8]. Furthermore, the physical contact in the process of the rectal temperature measurement could cause stress for pigs [8], [9], which most farmers try to avoid. Therefore, non-contact measurement method is one of the primary concerns of the present body temperature measurement methods in pigs [5], [8]–[10]. In this method, there is no direct physical contact between temperature sensors and the pig bodies. The body temperature is measured based on the optical analysis of the infrared radiation emitted by the pig bodies. Using this measuring principle, the infrared camera is widely used in pig body temperature measurement [6], [7], [9], [10].

Although a number of studies has been developed to measure temperature from different parts on pig body based on the infrared image processing, such as ear [10]–[12], feet [12], [13], body surface [10], [12], [14], eye [10], [13], much of the research works is based on idealized assumption without considering the

surrounding infrared sources. In reality, it is known that the existence of the surrounding infrared sources in the infrared image such as heat lamps, incandescent light bulbs, and the sun, is one major factor affecting the accuracy of body temperature measurement in pigs based on infrared image processing [15], [16]. It is observed that most of these surrounding infrared sources are static, while the target object is dynamic. Therefore, against this background, using object motion detection method, this paper is able to detect all moving objects in the field of view of the infrared camera. Consequently, all the pixels, which are used for temperature detection based on infrared image processing, belong to the target object. The result is the temperature detected in the infrared image is the surface temperature of pigs. This result improves significantly the performance of our proposed pig-body temperature detection method.

The remainder of this paper is organized as follows. First, related work is discussed in section 2. Following this, the materials and method of our proposed model is introduced in section 3. Then section 4 evaluates the proposed model by simulation results. Finally, section 5 concludes.

2. RELATED WORKS

In recent years, a large number of researches have been conducted to detect the temperature of the pig-body, which is an important physiological indicator in many applications such as the early diagnosis and treatment diseases [7], [11], [14], [17]. To date, pig body temperature measurement techniques can be classified into two group, namely: i) contact; and ii) non-contact [5]. In the former, the temperature instruments must directly touch the target object during the measurement process. Although this technique achieves a high accuracy rate, is very economical and works very effectively to get the core temperature of target objects, it still reveals limitations and weaknesses such as requiring a large amount of labor, slow response time and could cause unnecessary stress for pigs [8]. On the other hand, the body temperature of a pig is detected based on the optical analysis of the infrared radiation emitted by itself, so that there is no physical contact between the temperature instruments and pig body. Therein, infrared thermography (IRT), which detects radiation from an object, translates it into a temperature reading, and displays image of temperature distribution, is one of the most important non-contact temperature measurement methods. Therefore, the latter technique is widely used in many application fields such as pig disease diagnosis [13], pig behavior detection [18] and health monitoring of pigs [8], [19]. However, this technique still has some limitations, such as high initial investment cost, does not tend to work well underwater, can not detect radiation through glass, and especially the accurate temperature measurements are hindered by surrounding infrared sources. In order to improve the performance of the IRT method and to eliminate the influence of ambient temperature on temperature detection, some studies have focused on using infrared image processing techniques to detect target objects [17], [20]–[22]. In the context of various illumination conditions, Sa *et al.* by their work [20] represented a pig monitoring strategy, in which the complementary information from depth and infrared images is exploited for pig detection. The noises caused by sunlight is removed by applying spatiotemporal interpolation. In this way, an image processing-based method is proposed for pig detection, which guaranteed a fast execution time. Zhong *et al.* in [21] introduced a novel infrared and visible image fusion method for pig-body detection. The strategy of the pigbody shape and temperature detection under different situations was proposed in non-subsampled contourlet transform domain. In their technique, an automatic threshold segmentation method and optimized by morphological processing were utilized for pig-body shape detection. While the highest temperature of the pig-body was extracted based on body shape segmentation results. They proved that their proposed method achieved a high average detection rate of 94.452%, while the time consumption was significantly reduced.

It is observed that in the mentioned articles, there are two fundamental issues associated with a high accuracy rate in body temperature measurement of the IRT method: i) the segmentation of pig-body shape based on infrared images, which helps to recognize the features of the pig-body exactly, is quite consistent with the IRT method; and ii) by comparing pixel by pixel technique, the temperature of each pixel in infrared images is extracted effectively and in short time consuming. In extracting the pig-body temperature from infrared images, Zhang *et al.* in [17] proposed a gray-temperature (G-T) model, which was established by linear least squares method. They found that the correlation between the gray (G) and the temperature (T) values based on their Fotric-225 infrared camera image is: $T = 0.040428G + 30.01546$. They proved that all R-square values of their established models are greater than 0.95. As a result, in this paper, we present a novel model for pig-body temperature measurement based on infrared image processing technique.

3. METHOD

3.1. Overall process of pig body temperature detection

The goal of this work was to improve the accuracy rate of pig-body temperature estimation under various infrared sources by non-contact measurement method. For this purpose, A scheme for pigs' motion detection was proposed based on frame difference and interactive threshold (FDIT) method. The overall process for estimating the surface temperature of pigs based on thermal image processing technology is shown in Figure 1.

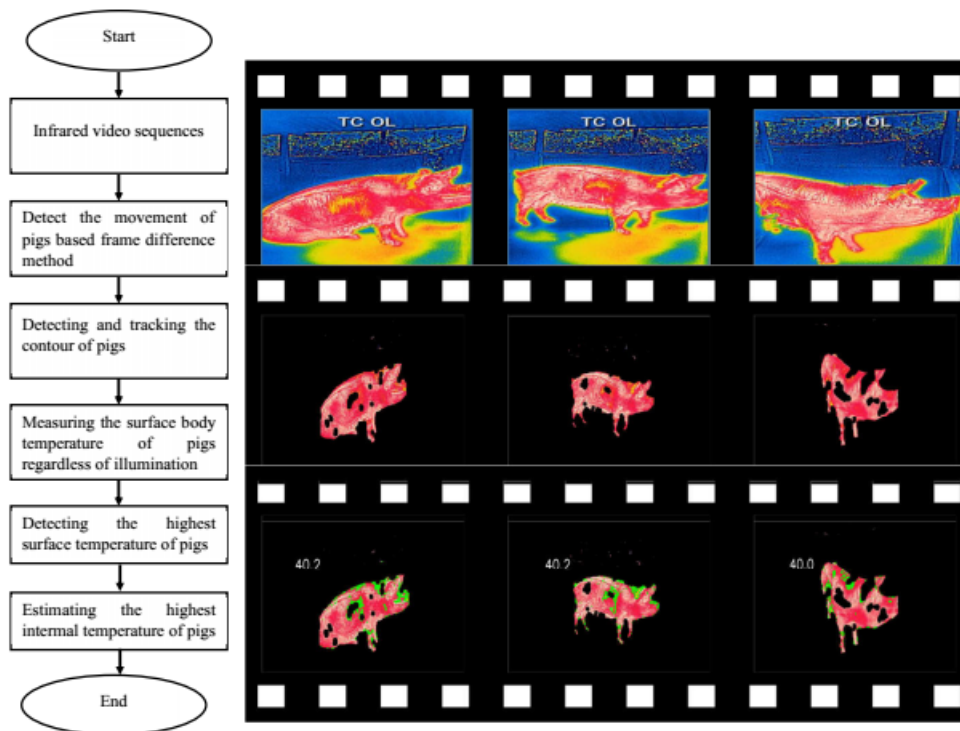


Figure 1. The overall procedure of the proposed pig body temperature detection

First, infrared video sequences were used to detect the movement of pigs. Second, the contour of pig was detected and tracked by framed difference method. Then, these contour images of pigs were used to measure the surface temperature based on thermal image processing technology. Finally, the highest surface temperature of pigs were detected, which was used to estimate the internal body temperature of pigs. The rectal temperature and skin temperature, which were measured manually, were used to evaluate the effectiveness of the proposed method. Generally, the prominent advantages of our proposed method are summarized as follows:

- By comparing with some existing results in the literature, our proposed scheme for pigs' motion detection based on the combination between frame-difference method and the iterative threshold method achieves a higher accuracy rate under different illumination conditions.
- Achieving a high accuracy rate in movement detection of pigs, our proposed method obtained a high accuracy rate in estimating the inner temperature of pigs.

3.2. Experimental materials and treatments

3.2.1. Experimental pigs

This study was conducted on fifteen male Landrace and Yorkshire pigs at age of 3 months. They were grouped in three adjacent pens (3.6 x 3.0 m per pen). The pigs were tested twice a day at 10.00 am and 15.00 pm, respectively. The temperature of pigs was measured in this paper by three methods. Firstly, the estimated body temperature of pigs was obtained via an infrared camera (INC), and it is named the tstimated value of

pig-body temperature (ET). Then, we used an infrared thermometer (INT) to measure the temperature of pig-body surface (manually measured temperature). Finally, a rectal thermometer (RET) is used for measuring the core body temperature of the pigs, and it is called the ground-truth temperature of the pigs (GT). However, the infrared images were taken 5 minutes before using IRT and RET in order to avoid the increase in pigs body temperature response to stressful situations.

3.2.2. Experimental monitoring system

FLIR E8-XT thermal camera (FLIR systems UK, Kent, UK), which had specific parameters given in Table 1, was used to capture pigs as a sequence of images. To do it, an external triggered image taking was used for capturing images automatically at an interval of 4 seconds per image. The proposed algorithm was implemented in Matlab R2016a on a PC computer with processor: Intel(R) Core(TM) i7-7500U CPU @ 2.70 GHz and 16 GB of RAM. The setup of the whole monitoring system in a semi-closed pig farm is depicted in the Figure 2.

Table 1. Parameters of the thermal infrared camera

Parameters	IR resolution (pixels)	Spectral range (μm)	Temperature range ($^{\circ}C$)	Thermal sensitivity ($^{\circ}C$)	Accuracy ($^{\circ}C$)	Image frequency (Hz)
Parameter range	320 x 240	7.5 ÷ 13.0	-20 ÷ 550	0.05	±2	9



Figure 2. The experimental design for pig-body temperature measurement

3.3. The movement of pigs detection based on frame difference and interactive threshold method

It is known that the surface temperatures of pigs were significantly affected by ambient temperature [23] and pigs in motion would decrease the reflection of these thermal conditions [24]. Therefore, in this section, the movement of pigs was extracted by analyzing the infrared image motion. These infrared images of pigs in motion will be used for core body temperature estimation. Generally, the moving target can be detected based on the changes of pixels intensity between the adjacent frames, while the background points are fixed all the time. In the traditional three-frame difference (TTD) method, the contour of a moving target is obtained by detecting the changes of the gray value in the images of three adjacent frames. According this method, all the following steps are mentioned in extracting the movement of pigs.

Algorithm 1 The iterative threshold algorithm (ITA)**Input:**

- Original image in N frames: $f_t(x, y), t = 1, \dots, N$;
- Original image is split into M equal regions $f_t^m(x, y), \{m = 1, \dots, M\}$;
- L_m denote the number of grey scales of region m^{th} .

Output: list of optimal threshold T_t^{*m} for image binarization of each region $\{m = 1, \dots, M\}$ in frame $t^{th}, \{t = 1, \dots, N\}$;

Initial: List of initial threshold $T_t^{km} = T_t^{0m}$; Predefined value δ_0 .

Procedure *ITA_ALGORITHM*($N, M, f_t^m(x, y), L_m$);

while do ($1 \leq m \leq M$)

Dividing region m^{th} into two areas $\{A_1^m, A_2^m\}$ through threshold region T_t^{km} .

Calculating the shade of grey average of area A_1^m and A_2^m as μ_1^m and μ_2^m , respectively.

$$\mu_1^m = \frac{\sum_{i=0}^{L_i} i n_i^m}{\sum_{i=0}^{L_i} n_i^m} \quad (1)$$

$$\mu_2^m = \frac{\sum_{i=L_i+1}^{L_m-1} i n_i^m}{\sum_{i=0}^{L_i} n_i^m} \quad (2)$$

where n_i^m is number of pixels at gray scale $i^{th}, \{t = 1, \dots, L_m\}$ in region $m^{th}, \{m = 1, \dots, M\}$
Calculating the new threshold of region m^{th} in frame t^{th} :

$$T_t^{(k+1)m} = \frac{\mu_1^m + \mu_2^m}{2} \quad (3)$$

if ($|T_t^{km} - T_t^{(k+1)m}| > \delta_0$) **then**

$$T_t^{km} = T_t^{(k+1)m};$$

Go back Step 3.

else

$$T_t^{*m} = T_t^{(k+1)m};$$

$$m = m + 1;$$

Go back Step 2.

end if

end while

Basic assumption: we consider an image sequence with N frames. Let $f_t(x, y), t = 1, \dots, N$ denote the intensity value of pixel point (x, y) at time c . Calculating the difference between two adjacent frames: Let $D_{(i,j)}(x, y)$ denote the difference between the intensity values of pixel point (x, y) at time $t = i$ and $t = j$, respectively.

$$\begin{cases} D_1(x, y) = |f_t(x, y) - f_{t-1}(x, y)| \\ D_2(x, y) = |f_{t+1}(x, y) - f_t(x, y)| \end{cases} \quad (4)$$

Image binarization based on the iterative threshold method: let $R(x, y)$ denote the binarization image, and it is determined in (5).

$$\begin{cases} R_1(x, y) = \begin{cases} 1, D_1(x, y) \geq T_0 \\ 0, D_1(x, y) < T_0 \end{cases} \\ R_2(x, y) = \begin{cases} 1, D_2(x, y) \geq T_0 \\ 0, D_2(x, y) < T_0 \end{cases} \end{cases} \quad (5)$$

The difference between three frames is determined by an AND operation and given in (6).

$$R'(x, y) = \begin{cases} 1, & D_1(x, y) \cap D_2(x, y) = 1 \\ 0, & D_1(x, y) \cap D_2(x, y) = 0 \end{cases} \quad (6)$$

Where T_0 indicates the threshold segmentation. The problem here is that how do we choose an appropriate threshold T_0 for each image? If T_0 is too low, many pixels in the background (pixels are not in pig body contour) are detected mistakenly as foreground (pixels of pig body). Contrastingly, if T_0 is too high, many pixels in the foreground are lost. Additionally, it is also proved that using only a threshold T_0 for whole image segmentation (it is known as the global threshold method) may be failed when the illumination is not sufficiently uniform [25]. Therefore, in this paper, we develop an interactive threshold method for image binarization. The main idea of this method is dividing an original image into M equal regions. Each region has L_m gray scales. Firstly, we chose an initial threshold for each region, and then find the new threshold based on the shade of gray average. The values of new threshold is calculated recursively until the difference between two threshold is smaller than a predefined value. The details of proposed interactive threshold method is given in the Algorithm 1. Then the (5) is written as follows.

$$f_t^m(x, y) = \begin{cases} 1, & D_{i,j}(x, y) \geq T_t^{*m} \\ 0, & D_{i,j}(x, y) < T_t^{*m} \end{cases} \quad (7)$$

Figure 3 explains the principle of our proposed method to detect and track the movement of pigs in the pen. Figures 3(a)-3(c) are three adjacent frames of pigs in a red green blue (RGB) image. While the thermal images of these pigs are depicted in Figures 3(d)-3(f), respectively. The difference between adjacent frames is depicted in Figures 3(g)-3(l).

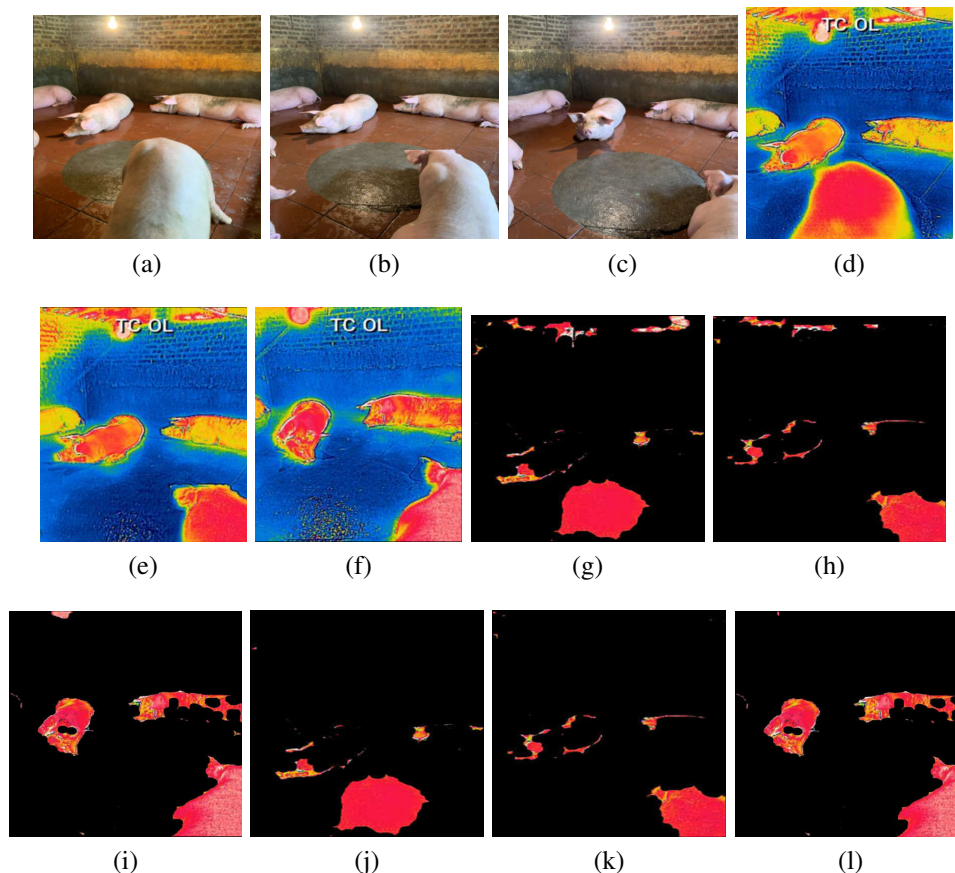


Figure 3. The experimental design for pig-body temperature measurement: in RGB frame (a) t_1 , (b) t , and (c) $t + 1$; in thermal frame (d) t_1 , (e) t , and (f) $t + 1$, (g) by traditional three-frame difference method the difference between frame t_1 and frame t , (h) frame $t + 1$ and frame t , (i) 3 frames; (j) by our proposed method the difference between frame t_1 and frame t , (k) frame $t + 1$ and frame t , and (l) 3 frames

3.4. Pig body temperature measurement methodology

In section 3.3, we have extracted the movement of pigs. All the pixels now in the images whose intensity value is 1, belong to pig-body. Therefore, the temperature values extracted from these pixels are pig-body temperature. The estimated pig-body temperature (EV) is determined as (8) [26].

$$EV = (260 - GV)\alpha_c + T_m \quad (8)$$

Where GV indicates the gray scale value of the pixel, α_c denotes the correction value, which is calculated by Monte Carlo simulation technique. T_m is the minimum temperature that the system can display.

4. EXPERIMENTAL RESULTS AND DISCUSSION

To evaluate the performance of our proposed scheme for pigs' motion detection, which used to detect all hightemperature objects moving in the field view of the infrared camera, we first used the initial pig-free condition images as background reference images. Then, the pixel-by-pixel comparison between these background reference images and the output images of motion detection method will be made automatically in order to perform our proposed method. Finally, we used Fscore, which is widely used metric to assess the output of a detection method [27], [28]. The Fscore metric is defined as the measure of balance between precision (P) and recall (R). The higher of the Fscore metric is, the better performance of the method is. The Fscore metric is calculated according to (9).

$$F_{score} = \frac{2RP}{R + P} \quad (9)$$

Where the recall R (defined in (10)) and the precision P (given in (11)) are calculated based on the number of true positives (TPs), false negatives (FNs), false positives (FPs), and true negatives (TNs), respectively.

$$R = \frac{TP_s}{TP_s + FN_s} \quad (10)$$

$$P = \frac{TP_s}{TP_s + FP_s} \quad (11)$$

Where TPs are the number of motion pixels of the pigs are detected correctly. FNs represents the number of motion pixels belong to a pig are detected incorrectly as nonmotion pixels. FPs stands for the number of non-motion pixels are detected incorrectly as motion pixels on the pig. As shown in Figure 3, for example, the number of TPs and TNs of our proposed method are always greater than that of the traditional method. It means that with higher number of TPs and TNs, our proposed method achieves a higher accuracy rate than the traditional method. Figure 3 illustrated the effect of some static infrared sources (e.g. heat lamps, incandescent light bulbs, and the sun) to the accuracy rate of the motion detection methods. It is shown that the missed detection rate (FPs) and the false detection rate (FNs) of the traditional method increase with the number of static infrared sources. In Figure 3(i), it is shown that pixels on the heat lamp were detected incorrectly as motion pixels on the pigs. While these pixels were detected correctly in Figure 3(l). All these experimental results are given in Table 2.

Table 2. The effect of some static infrared sources to the accuracy rate of the motion detection methods

Method	Static infrared sources	Accuracy recall	Precision	Fscore
TTD	No	0.88	0.85	0.87
FDIT	No	0.92	0.93	0.93
TTD	Incandescent light bulbs	0.85	0.82	0.84
FDIT	Incandescent light bulbs	0.90	0.87	0.89
TTD	Heat lamps	0.83	0.79	0.81
FDIT	Heat lamps	0.88	0.85	0.86

It is shown that the maximum Fscore of the proposed method is 0.93, while this value of the TTD method is only 0.87. The temperature of these motion pixels will be computed in order to estimate the core body temperature of the pigs. In this paper, to evaluate the accuracy of the pigs core body temperature estimation methods, the root mean square error (RMSE), mean absolute error (MAE), and the correlation coefficient

r between the estimation and ground-truth temperature of the pigs were computed. These metrics were determined according to (12)-(14), respectively.

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (GT_i - ET_i)^2} \tag{12}$$

$$MAE = \frac{1}{N} \sum_{i=1}^N |GT_i - ET_i| \tag{13}$$

$$r = \frac{\sum_{i=1}^N (GT_i - \overline{GT_i})(ET_i - \overline{ET_i})}{\sqrt{(\sum_{i=1}^N (GT_i - \overline{GT_i})^2)(\sum_{i=1}^N (ET_i - \overline{ET_i})^2)}} \tag{14}$$

Where ET_i denotes the estimated value, GT_i denotes the ground-truth value. $\overline{ET_i}, \overline{GT_i}$ stand for the mean values of the ET , and GT , respectively. N is the number of samples.

Table 3 shows the difference between temperatures of the pigs by different methods in $N = 250$ samples. It is shown that the temperature range (range = maximum value - minimum value) of the RET method is the widest with $2.25^\circ C$. While the largest range reaches $4.15^\circ C$ by the INC method. It means that the pig body temperature, which is extracted from infrared images, varies quite substantially among pigs. It may be caused by the noise sources appearing in the thermal images.

Table 3. The pig body temperatures were measured by RET, INT, and INC methods

Method	Temperature ($^\circ C$)			
	Minimum	Median	Maximum	Range
RET	38.00	38.60	40.25	2.25
INT	37.56	38.25	41.25	3.69
INC	37.21	37.28	41.36	4.15

As shown in Figure 4 and Table 4, there is a positive correlation between GT and ET values. As shown in the scatter plots obtained from our proposed method, the estimated pig-body temperature values are very similar to the measured temperature values. With Pearson correlation coefficient $r = 0.73$, $RMSE = 0.88^\circ C$, and $MAE = 0.86^\circ C$ with no static infrared source in the field view of the infrared camera (Figure 4(a)). In Figure 4(b), there are some static infrared sources (such as heat lamps, incandescent light bulbs, and the sun) in the field of the infrared camera, therefore, there is a difference between the GT and ET values. These values are increased significantly due to the existence of some static infrared sources. The correlation coefficient now is $r = 0.74$, while $RMSE = 1.12^\circ C$, and $MAE = 1.09^\circ C$.

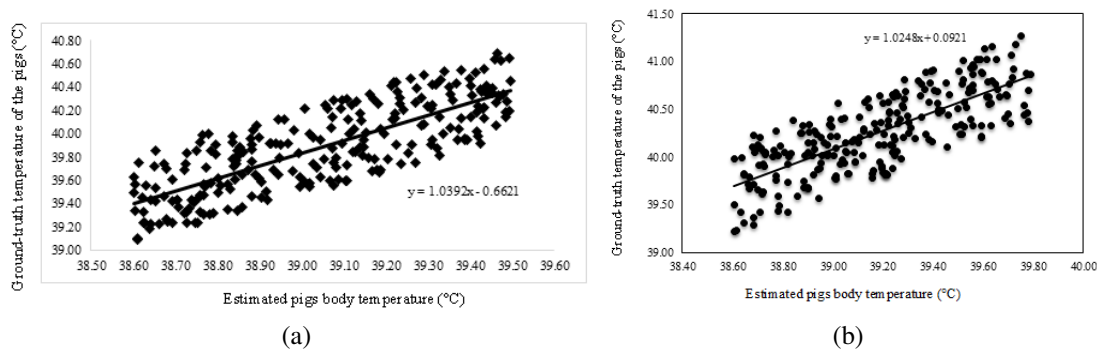


Figure 4. Scatter plot of measured and estimated pig’s body temperature (a) with no static infrared source in the field view of infrared camera and (b) with heat lamps in the field view of infrared camera

Table 4. The pig body temperatures were measured by RET, INT, and INC method

α_c	MAE	RMSE	r
0.0126	0.86	0.88	0.74
0.0158	1.05	1.08	0.78

5. CONCLUSIONS

The paper has presented an efficient method for infrared image processing to estimate remotely the core body temperature in pigs, where the pixel value of the infrared image is used for extracting the pig-body temperature. In the proposed technique, the motion of pigs is detected before using infrared images for temperature extraction. Though this motion detection problem is intrinsically NP-hard, solving it by an interactive threshold algorithm is proved to be practically feasible for pig movement detection. The obtained solutions are then proved to give high performance compared to other temperature measurement techniques. Limitation of the paper is the fact that the surface temperature of pig-body, which is captured by an infrared camera, does not depend on the internal temperature of the pig, it is also seriously affected by surrounding infrared sources. In the future research works, we are intending to enhance these issues by combining between the infrared thermography and infrared thermometry methods in pig-body temperature measurement.

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BIOGRAPHIES OF AUTHORS






Hoc Thai Nguyen    received his B.Sc. and M.Sc. degrees in electrical and electronic engineering from Vietnam National University of Agriculture, Vietnam in 2006 and 2010, respectively. He then received Ph.D. degree in infocommunication technologies and automation at the Budapest University of Technology and Economics (BME), Hungary in 2018. His research interests include wireless sensor networks, biosensors, intelligent networks, internet of robotic things, artificial intelligence (AI)-enabled robotic, infrared image processing and applications of artificial intelligence in precision agriculture. He can be contacted at: nguyenthaihoc@vnua.edu.vn; thaihocme@gmail.com.



Tien Xuan Dao    was born in 1982. He received the M.A. degree in electrical engineering and electrical system from the Vietnam National University of Agriculture, Vietnam, in 2010. He is currently a lecturer at the Faculty of Engineering of Vietnam National University of Agriculture. His research interests include control systems, smart grids, and AI applications for smart agriculture. He can be contacted at: dxtien@vnua.edu.vn.



Duong Tri Ngo    was born in 1974. He received the Ph.D. degree in control engineering and automation from Hanoi University of Science and Technology, Vietnam, in 2009. He is currently a senior lecturer at the Faculty of Engineering of Vietnam National University of Agriculture. His main research interests are control systems, IoT, and AI applications for smart agriculture. He can be contacted at: ntduongcd@vnua.edu.vn.