Diagnostic of Calf’s Body Temperature by Using Thermal Imaging Camera and Correction of Camera Errors

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Abstract In this paper, we present a method of using a thermal imaging camera to measure the external temperature of a calf. We select the eye as the best spot that can be used to assess an animal’s internal temperature. We also show a method of dealing with the nonstationarity of a low-cost thermal imaging camera.

Keywords Veterinary · Image processing · Thermal imaging · Contact-less temperature measurement

1 Introduction

Body temperature of animals is a very important indicator of their health, physiological status and welfare. Theoretically, measurement of internal temperature is a basic tool in clinical treatment. In practice, especially in farm animals, it doesn’t work as expected because of physical effort and time on the one hand, the requirement to immobilize the animal on the other. Additionally, the stress of handling can result in an increase of temperature which interferes with the correct interpretation of the correct results [5, 8]. Looking for other non-invasive, precise, reliable and efficient methods of temperature measurement in animals is a challenge. Infrared technology looks very promising in this area and an infrared camera alongside scintigraphy, x-ray and ultrasound is recommended as a diagnostic tool in livestock animals [1, 10, 13]. Accurate measurement of bovine body temperature in a non-contact way is difficult due to its thick body hair. But it is widely reported that the eye, nose, vulvar and udder surface temperature are good substitutions for rectal temperature.
It looks very promising in routine husbandry animal health monitoring [3, 4, 11, 13, 14]. The aim of the study was to evaluate the correlations between rectal (traditional thermometer) and eye/ear (infrared camera) temperature in calves. The study was carried out on 81 calves between 9 days and 3 months old from three herds (A,B,C).

The outline of the paper is as follows: firstly we will present the basics of thermal imaging. Then our problem will be stated. An image processing solution will be shown. Finally, a problem of correcting error due to nonstationarity of measurements will be presented and solved.

2 IR Cameras

In recent years thermal imaging cameras have shifted from being expensive and rare into small affordable devices with multiple uses. Not only have prices dropped, but, thermal cameras (commonly called IR cameras for short) are much easier to use and do not require separate cooling. Medical imaging is one of many uses, but we should not forget about other uses, including electrical maintenance, assessing a building’s thermal properties and many others. Especially the requirement for energy efficiency certification is the main reason for the proliferation of IR cameras.

Most image analysis is carried out by the human eye with just simple software tools. Most of them allow us only to change colors attributed to different temperatures, changing the temperature range and see the temperature profile along a specified line. Usually, an even more limited number of functions are available in the camera firmware.

General interpretation of a thermal image requires some experience. Additionally, any form of automatic processing would be tailored only to a specific problem. In this paper, we want to present one such solution in the area of veterinary diagnostics. We will also present how to solve some drawbacks of popular, low-cost thermal imaging cameras.

3 Basics of Thermal Imaging

Every object in a temperature above absolute zero (0K) spontaneously emits some energy in the electromagnetic spectrum. This emission is continuous. Its distribution is given by Planck’s law for an ideal black body.

\[ B_\lambda(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{k_B T}} - 1}. \]  

(1)
Generally, only in high temperatures do objects emit light in the visual spectrum. Below (in the sense of frequency) this range lies within the infrared band where what is commonly called heat is being emitted in a typical temperature range.

This allows for many methods of contactless temperature measurements. The simplest one is useful in case when radiated energy is in the visible spectrum – as in the case of glowing metal. The method is called a disappearing-filament pyrometer.

By using special lenses (normal and optical glass is reflective to IR) emitted radiation is focused on some kind of detective device. Generally, these detectors are of the bolometric type where every pixel is heated by thermal radiation, its temperature measured and then the temperature of the object is being calculated. This process causes an increase in temperature of the sensor itself and can, in turn, falsify the reading.

The amount of emitted energy depends not only on temperature but also on the emissivity. Generally it is taken into account as a coefficient valued 1 for ideal black body (full theoretical emission) and 0 for ideal white body (which reflects everything but does not emit).

4 Image Processing Problem

One common veterinary procedure is measuring an animal’s internal temperature. Using a traditional, contact thermometer has many disadvantages. Mainly it takes time and a live subject can not be expected to cooperate. Thermal imaging can prove to be the answer to that problem. Before this, certain problems should be solved. Most of them are traditional in image processing.

– Image acquisition—a thermographics image has to be created,
– Choosing the measurement spot—most of the animal is covered by its coat or fur, and whose main function is preventing heat loss by thermal isolation. Therefore, the animal’s eye was chosen,
– Image segmentation—an eye has to be detected,
– Temperature measurement,
– Temperature correction—eye temperature is not an internal animal temperature due to different emissivity, also errors of the camera should be corrected.

5 Proposed Image Processing

In this section image processing methods are described (see [12]). Such methods are widely used in veterinary and medicine like in [2, 6].
5.1 Image Acquisition

Currently, due to the high costs associated with their purchase, the permanent installation of an IR camera in places where animals are kept is impractical. The measurement had to be taken using a hand-held camera in conditions far from optimal conditions. In addition, the camera is running changes. Typically, it was left running from 200 to 500 s. Since heat accumulation in a bolometric matrix does not stop, the time at which the image is taken is important. Fortunately, most electronic devices are able to record this.

5.2 Choosing Measurement Spot

An eye was chosen as a trial spot for measurements due to being visible at all times. It can also be presumed to have a temperature less dependent on the environment and more on internal body temperature.

Another reason for choosing an eye is the fact that its temperature is the highest. It makes it easy to find in the image by image processing methods. The relatively high temperature also suggests that this point is the closest to the internal temperature of the animal (Figs. 1, 2 and 3).

Steps carried out during processing our thermal image follow traditional patterns in image processing:

– Image segmentation—thresholding,
– Detecting eye—the Hough transform.

Fig. 1 Thermal image of a calf—base for processing
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Fig. 2 Thermal image after thresholding

Fig. 3 Thermal image after thresholding and with detected circle
Thresholding is probably the most common segmentation method. In the simplest variant, known as binary thresholding, it works as a simple transformation applied to each point of the image (point transformation). If its value is larger than the specified threshold then the result is 1 and 0 otherwise.

$$\forall x, y \in I = \begin{cases} 1 & \text{if } I(x, y) \geq \text{threshold}, \\ 0 & \text{if } I(x, y) < \text{threshold}. \end{cases}$$

(2)

Other, more advanced methods of thresholding were devised but their use was not required in this problem.

The main problem in thresholding is a selection of the correct threshold level. Generally, the simplest method is to use the histogram of an image. The amount of each value (proportional to temperature) can be helpful to determine a good threshold. The histogram of the calf’s thermogram is shown in Fig. 4.

We can clearly see that selecting the highest temperature area is relatively easy. In Fig. 1 we can see that the eye is probably the hottest point in the image. We choose the threshold accordingly resulting in the image in Fig. 2.

### 5.4 Detecting Eye Position

In the thresholded image (see Fig. 2) we can clearly see the eye—which is our target and some residue pixels. How can we find where the eye is?
The answer is its nearly circular shape. A method called the Hough transform can detect a shape in the image. The basic method detects straight lines. The generalized method can detect nearly any shape and is especially suited to the detection of a circle with a multitude of existing implementation.

Let us start from a binary image with detected points. For the sake of simplicity, we will firstly present the method for lines and show how it works. Then we will show how to use the same method for detecting circles, which is the main point of this section.

The points along the line fulfill its equations, so for each point \((x_i, y_i)\), holds the following

\[
y_i = a \cdot x_i + b, \quad i = 1, 2, ..., n,
\]

from (3) we can calculate

\[
b = (-x_i) \cdot a + y_i, \quad i = 1, 2, ..., n.
\]

So, from a group of points on a single line in Fig. 5, we have a group of lines with a single common point. See Fig. 6. Of course, due to noise and other factors, in a typical image, there would be a group of crossings rather than a single point. A good example may be found in [7].

Generally, a type of matrix accumulator is used to calculate the crossing. Its cells span through limited parameter space with some division. Again a shape (line in a simple case) is recognized when the amount of crossings in a certain box is larger than the threshold. It is represented by the grid in Fig. 6.
The described method is simple for lines. It can be extended easily to any shape that can be parameterized. Additionally, more than two dimensions are possible – two dimensions are easy to visualize.

In case of the circle, we can use the simplest equation

\[(x - a)^2 + (y - b)^2 = r^2.\]  

(5)

In this scenario, we require a three-dimensional accumulator and this is a little more complicated.

6 Error Analysis

In Sect. 3 we described how a thermal imaging camera works. With any measurement we expect some errors. There are many sources. Some of them, like noise, are unavoidable. Others may arise from calibration. The last type of errors come from the non-stationary behavior of the device.

The main reason is usually thermal drift. Designers try to keep it in check. In the case of the camera used it was not successful.
7 Systematic Error Removal

It is obvious that the range of expected temperatures is limited by biological boundaries. No mammal should have an internal body temperature higher than 44°C. So a measurement of around 50°C must be considered a gross error or some kind of systematic degradation of the measuring device. Since the time of each measurement can be established from the file’s time stamp, then the measured eye’s temperature can be plotted as $T(t)$. This plot is shown in Fig. 7.

![Fig. 7 Eye’s measured temperature as a function of time](image)

Obviously, the temperature changes from one animal to another but the rise of temperature with time can be clearly seen. The shape of a possible curve looks similar to an inertial object.

The temperature of an object heated by a constant power heat source can be described by the following differential equation

$$\frac{dT}{dt} = -\alpha(T - T_q), \quad T(0) = T_0$$

(6)

the solution is

$$T(t) = T_0 e^{-\alpha t} + T_q (1 - e^{-\alpha t}).$$

(7)

The overall shape of this solution fits the data in Fig. 7, but increasing differences between the data suggests that the error is multiplicative rather than additive in its nature.
Let us consider the following correction where $T_m$ is a measured temperature and $T_c$ is after correction.

$$T_c = T_m \left(a - b \cdot e^{c \cdot t}\right)$$

(8)

$a$, $b$ and $c$ are parameters that should be fitted to the measurements. The situation is different than in typical data point fitting because deviations are useful information and the curve itself is a form of an error.

The simplest way of fitting a curve to the data are nonlinear least squares. As a result we obtain $a = 1.419$, $b = 0.477$, $c = -0.0009914$. The resulting curve can be seen in Fig. 8. We can clearly see that after the correction the range of temperatures was reduced and does not change in time. The corrected values are shown in Fig. 9.

8 Data Analysis

Measurements were taken in three different environments and in different ambient temperatures. Due to this fact, different corrections coefficients are required. The overall result can be seen in Fig. 10. One of the typical problems was the relatively small number of ill animals and the fact that temperature measurements have a tendency to cluster together, see Table 1.

We can state the hypothesis that some relationship exists between eye temperature and internal body temperature of the same animal. The biological functions of the body suggest that it would be true.
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Fig. 9 Corrected data in function of time

Fig. 10 After correction the pattern starts to be clearly visible

Table 1 General overview of data

| Herd | Healthy | Ill | Total |
|------|---------|-----|-------|
| A    | 13      | 3   | 16    |
| B    | 18      | 17  | 35    |
| C    | 26      | 4   | 30    |
The overall Pearson correlation factor is $r = 0.454$. Let us do a test for the correlation coefficient. The null hypothesis is that $r = 0$—no correlation. Then

$$t = r \sqrt{\frac{n - 2}{1 - r^2}}$$

has t-Student distribution with $n - 2$ degrees of freedom. There were $n = 78$ measurements taken. The critical test value for significance 0.999 is 3.195. The test statistics yield $t = 4.447 > 3.195$ so we reject the null hypothesis and we accept the alternative one—the existence of correlation.

## 9 Conclusion

In this paper, we have shown how to use a thermal imaging camera in simple veterinarian diagnostics. We have also corrected errors that made the results unusable at the first sight.

The statistical tests have shown that the correlation is relevant. The proposed method can be used in fast temperature screening of large groups of animals. It would be possible to use a similar methodology in testing humans for the increased temperature at large-scale during epidemic events like COVID-19.

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