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Infrared temperature patterns of cow's body as an indicator for health control at precision cattle farming

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Abstract. Cows' infrared radiation temperature study was carried out at experimental cowshed (120 cows) of Estonian University of Life Sciences. Thermal image scanner Fluke TiS was used for obtaining 640×480 pixels thermal images with resolution of 0.1°C. The temperature distribution pattern of different parts of cow's body was estimated and analysed with SmartView software. Special attention was paid to udder, feet and areas with skin injuries. It was estimated that the temperature varies considerably at different parts of the body. Radiation temperature of healthy udder did not change considerably after milking. It means that automatic monitoring of udder temperature is possible not only in milking parlour or milking robot but also in other places where cows are identified. The udder thermograms enable to assess the milking hygiene, as the cleanliness of udder surface influences the measurement results, especially average temperature. The temperature of legs was lowest at the hoofs and highest at coronary band. Differences from this distribution may be used for estimation of leg disorders. Thermal images can be also successfully used for detection of skin injuries. Radiation temperature of injured and depilous locations was higher by several degrees than their surroundings. The study showed that thermal images analysis is promising method to be implemented at precision cattle farming.

Key words: infrared temperature, dairy cow, health, precision livestock farming.

Introduction

Temperature is an important indicator at the diagnosis of cows' illnesses and for estimation of their physiological status. That is the reason also, why the temperature estimation should be quick and exact. In practice different methods are used for the cow's body temperature estimation with special emphasis on the measurement speed and reliability of the results. In addition to common thermodynamic temperature measurements the radiation temperature estimation, based on the energy radiated by the body to the surrounding environment is becoming more popular. At the specific wavelength the total emissive power of the body is:

$$P = \boldsymbol{\varepsilon} \cdot \boldsymbol{\sigma} \cdot A \cdot T^4,$$

where $\boldsymbol{\varepsilon}$ is monochromatic emissivity of the material, which is defined as the ratio between the emissive power of an actual surface at any wavelength and emissive power of a blackbody at the same temperature, $\boldsymbol{\sigma}$ – Stefan-Boltzmann constant, A – the area of the actual surface from which the radiation is registered, T – the absolute temperature of body surface.

The total radiation energy emitted or absorbed by the animal body depends on the emissivity of the skin. In order to determine the temperature by measuring the emissive power, the emissivity of the skin must be known. It is necessary to remember that the bodies with the surface temperatures higher than absolute zero emit energy at all wavelengths of the electromagnetic spectre. The largest part of radiation energy is emitted with wavelength of 7–14 μm, and is referred to as infrared (IR) radiation. In case of animals 40–60% of heat loss is within this range (Kleiber, 1975, quoted by Stewart et al., 2005).

The radiation temperature estimation is usually performed through the infrared radiation intensity measurements. The source of this radiation is the body surface, so the measured values describe first of all the skin temperature of the animal. The radiation temperatures of the inner layers of the body are definable by registering the intensity of super high radio frequencies (3–30 GHz), but unfortunately this method is still under development and is too expensive for practical purposes.

Most often the devices used for the surface radiation temperature estimation are comparatively cheap but they measure the average IR-radiation intensity of some spot on the surface with the area that depends on the measurement distance. Functionally much more possibilities suggest the devices measuring and registering the distribution of the thermal radiation on some larger surface. That purpose is achieved by thermal imaging systems using the emitted IR-radiation to generate a pseudo-colour picture of the object and its surroundings on the special screen or computer monitor. The temperature distribution is shown by the regions of different colour. Such temperature distribution image can be produced using mostly two different methods: scanning the surface point by point, or focusing the thermal radiation of the surface on cooled or uncooled sensor arrays with number of pixels sufficient for getting sharp enough images. Selection of the specific method and equipment is usually determined by cost. Nowadays most affordable devices with sufficient measurement accuracy are imagers with uncooled integral arrays of thermal sensing elements. Most developed of these have the thermal sensitivity less than 30 mK, accuracy up to ±1°C and possibility to save both thermal and visual (reference) images.

Thermographic equipment has found increasing applicability also in veterinary medicine, as infrared thermography is a non-invasive safe method and only minimal restraint may be necessary in some cases of producing thermal images (thermograms). The main limitations are:

- thermograms must be collected out of direct sunlight and wind drafts;
- hair coats of animals should be free of dirt, moisture or foreign material (Stewart et al., 2005).

In bovine medicine infrared thermography (IRT) is used primarily for diagnostic purposes, but also for assessment of animal welfare and even feed utilization efficiency. As early as in 1985 Hurnik et al. (1985) evaluated the effectiveness of thermal infrared scanning as a technique to detect oestrus and concluded that it may have potential as a research tool for the study of skin temperature patterns.

IRT has been used to predict changes in udder temperature and to elucidate possibilities for early diagnosis of mastitis in dairy cows (Berry et al., 2003). Scott et al. (2000) and Colak et al. (2008) found also that test for mastitis relying on IRT-measured udder temperature may be feasible. Results were promising for both tie-stall and free-stall housed cows. By Polat et al. (2010) IRT can be employed for screening dairy cows for mastitis similar to California Mastitis Test. Hovinen et al. (2008, 2009) affirmed that increase in body temperature of cows with experimentally induced clinical mastitis was successfully detected by thermal camera.

Nikkhah et al. (2005) evaluated the capability of IRT to detect effects on hoof (coronary band) temperature in dairy cows and relationship to visual abnormalities of the hoofs that are indicative of laminitis. They found that IRT may prove to be useful for early diagnosis of laminitis, in particular in earlier stage of lactation. Alsaaod & Büscher (2012) confirmed a significant difference in temperature of the coronary band between cows with lesions and cows without lesions.

IRT have been tested for early detection of foot-and-mouth disease virus infected cattle (Rainwater-Lovett et al. 2009). IRT technology may also be a tool for screening cattle for feed utilization efficiency (Montanholi et al, 2008; Montanholi et al, 2010).

Recent time advances have been achieved in the use of IRT in studies of animal welfare, namely for measuring stress. When an animal becomes stressed, the different physiological processes in the organism will change heat production and heat loss from the animal. This can be detected using infrared cameras (Stewart et al., 2005).

Investigations show also the useful potential of infrared measuring methods for the studying of the milking process and evaluating the effects of different milking technique on teats and udders (Kunc et al., 2007).

Stewart with colleagues (Stewart et al., 2005) have tested possibility to incorporate infrared thermal camera to a water trough, which animals visit regularly and where they are identified, to collect an infrared images of the eye region automatically. Eye IR-temperature is more consistent than temperature of any other anatomical region.

A Swedish company has developed an automatic monitoring system for dairy cows using two FLIR A310 thermal imaging cameras at automatic milking machine. From the thermal images a database was created for each individual cow. By comparing each new reading to the earlier recorded data the system can accurately detect the type of thermal anomalies that indicate mastitis ('Infrared …', 2012).

From the above review it becomes obvious that IRT as a method is based on non-invasive, simply handled tools with specific analysis software, and has been paid great attention and interest by the researchers in different areas of veterinary medicine and animal husbandry Great deal of these studies have been carried out by thermovision systems which are quite complicated and expensive to use.

The objective of this study was to test suitability of more handy and relatively cheap thermal camera with a sensor array to:

- determine the possibilities of cows' thermal profile registration at free-stall housing;
- investigate the possibilities of automatic cows' udder thermograms registration at milking parlour and milking robot and to compare the temperatures of the udder before and after the milking;
- investigate the possibilities of thermograms applicability for the assessment of milking hygiene;
- investigate the registration possibilities of leg injuries with the help of thermograms.

Materials and methods

In current study the Fluke TiS thermal imaging scanner with calibrated temperature interval from –25.0°C up to 105.0°C was used. This camera allows registering the objects radiation temperature from distances of 0.7–20 m with the sensitivity of 0.1°C. The digital thermal image is produced on a 640 x 480 display. The sensing system of the camera is based on 120 x 120 Focal Plane Array uncooled microbolometer. For image analysis the SmartView 3.1 software package was used. During calibration of the camera the emissivity of 0.95 was applied.

For achievement of broached objectives the measurements were carried out in Märja experimental cowshed of Estonian University of Life Sciences. The air mean temperature of the experimental area was +9°C. The number of lactating dairy cows engaged in the experiment of udder, *regio tarsi*, *regio calcanea* and *region metatarsi* thermal imaging was 56. The thermograms of the udders were registered before and after milking, the legs thermograms - during milking. Due to the constraints of the milking parlour construction, only the back surface of distal half of the udder was measurable. But as the majority of mastitis cases occur in two hind quarters (Berry and Meaney, 2006) this location was chosen as suitable for performing the measurements, especially with future automation possibilities in mind. Thermal images were taken with the handheld camera approximately from distance of 60 cm off the back surface of the udder rear quarters.

The region of udder surface on the thermogram, corresponding to *sinus lactifer* was contoured with the help of the camera software, starting just above the teat and centred according to the teat. This area was chosen as it expresses the smallest variation in temperature of the healthy udder (Barth, 2000, quoted by Hovinen, 2009). The mean, maximum and minimum temperatures within the couture were measured and used for analysis. Before taking thermograms the cleanliness of udders was assessed using 5-grade scale: 1 – clean, 2 less than 10% of udder surface covered with litter or manure (unclean), 3 – 10–20% unclean, 4 – 20–50% unclean and 5 – more than 50% unclean.

Results and discussion

The thermal profile of cow's body left flank is shown on Fig.1. The histogram of the temperature distribution of the whole image can be used for the overall estimation of environmental impact. For the analysis of temperature distributions and other significant thermal parameters of cows' body or its parts these areas were separated from other regions by the contour line. The average contoured area temperature in the measurement series was 23.9°C, minimum and maximum temperatures 30.8°C and 10.8°C correspondingly with standard deviation 3.62.

It was found that the highest temperature regions are the udder and cow's eyes. The IR temperature of distal part of the legs was comparatively low and more influenced by surrounding environment temperature. Corresponding numerical values are presented in Table 1.

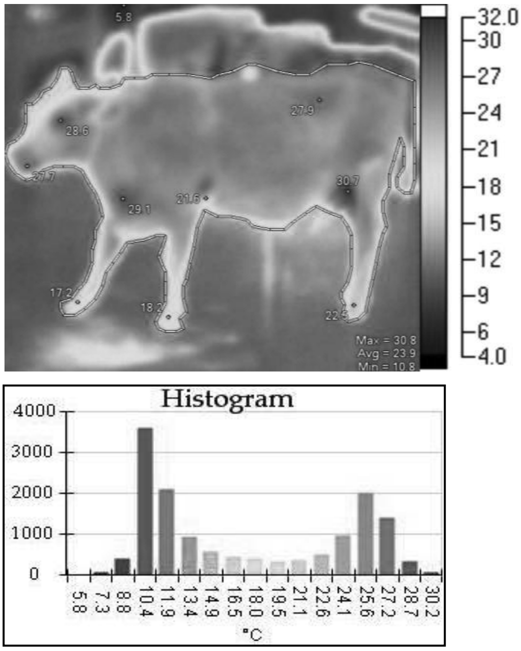

Fig. 1. Cow's contoured IR image and IR temperature histogram.

Table 1. Temperatures of selected thermogram points

Area	**Temperature, °C**
Uber	30.7
Oculus	28.6
Skin injury in *regio brachii*	29.1
Regio ungulae of left front leg	18.2
Regio ungulae of right front leg	22.5
Regio ungulaeof left hind leg	17.2
Fossa paralumbalis	27.9
Planum nasolabiale	27.7

Fig. 2 shows that skin injuries are clearly distinguishable with their remarkably higher temperature (injury region temperature is 32.8 ºC, the surrounding normal skin temperature is 27.4–28.2ºC). The healthy cows' body surface IR thermograms allow creation of temperature distributions for all anatomical regions and detection of different injuries. In our experimental cowshed the best place for registration of body flanks thermograms was the alley from milking parlour to feeding area.

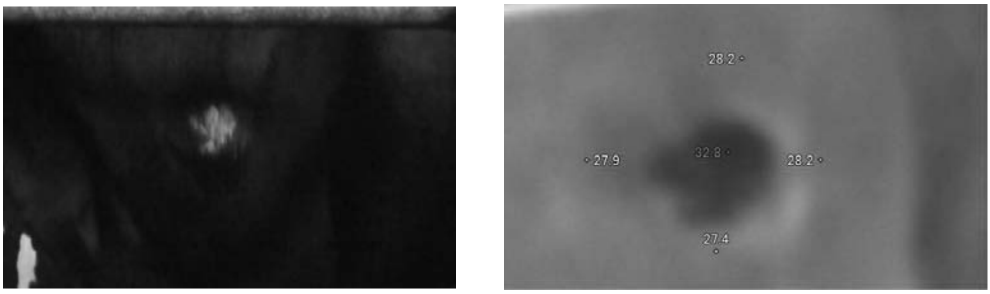

Fig. 2. Visual and IR image from the *regio articulationis humeri* with skin injury.

Visual and IR images of udder hind quarters are presented in Fig. 3, numerical values of udder IR temperatures in Table 2.

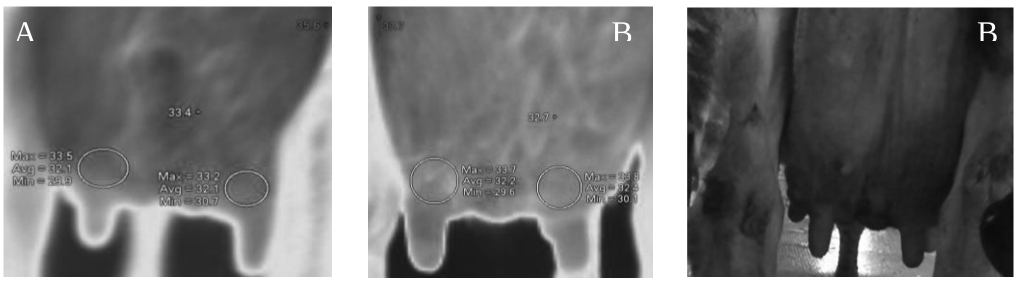

Fig. 3. IR and visual images of udder hind quarters (A – before milking, B – after milking).

Table 2. Cleanliness and IR temperature of udder hind quarters before and after milking

Measurement time	Quarter	Item	Average	Standard deviation	Min	Max
Before milking	Left	Max.	34.4	1.17	31.8	36.1
		Average	32.4	1.11	29.9	34.2
		Min.	28.7	2.40	23.8	31.8
		Cleanliness	2.4	1.11	1.0	4.0
	Right	Max.	33.9	1.23	30.3	35.6
		Average	32.4	1.01	29.2	33.7
		Min.	29.3	2.28	23.2	32.5
		Cleanliness	2.3	1.16	1.0	5.0
After milking	Left	Max	34.5	0.94	32.4	35.9
		Average	32.9	1.76	31.2	38.6
		Min	28.9	3.49	19.4	32.3
		Cleanliness	2.1	1.02	1.0	4.0
	Right	Max	34.6	0.78	33.4	36.3
		Average	33.2	0.98	31.4	35.1
		Min	30.2	2.37	25.3	33.4
		Cleanliness	2.3	1.19	1.0	5.0

Obtained data was analysed by Student *t*-test. There were no significant differences between temperature of left and right udder quarters before and after milking ($p>0.05$). It means that udder surface temperature does not depend on milking and it is possible to carry out the measurements not only in milking parlour or milking robot but also in other places where cows are identified. The cleanliness of udder surface influences the measurement results, especially the average temperature. The correlation coefficient between cleanliness/maximum temperature was –0.29, cleanliness/average temperature –0.42 and cleanliness/minimum temperature –0.22.

To get thermograms of *regio calcanea* and *regio tarsi*, where different injuries are quite usual, and from lower part of front legs (see Fig. 4), the milking parlour was also suitable.

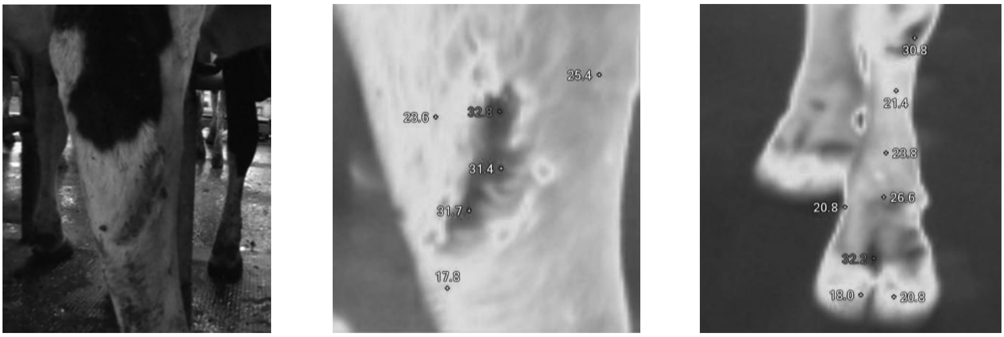

Fig. 4. Visual and IR images of *regio metatarsi* and distal part of the front leg.

The thermal images of the legs were registered at a distance of 0.6 m (hind legs) to 1.2 m (front legs). The temperature distribution was more closely studied for the lower part of a front leg. On Fig. 4 some specific area temperatures are shown. The *regio coronarlis* had the highest temperature (32.1ºC). *Regio ungulae* was found to have considerably lower temperature (18–21.4ºC). *Regio metacarpi* had temperatures of 21.4–26.6ºC. On the visual image and thermogram of the *regio metatarsi* the skin injury is clearly visible.

Conclusions

Our pilot investigation affirms that IRT as a method that is based on non-invasive, simply handled tools with specific analyzing software, has remarkable priorities in veterinary medicine (diagnostics of mastitis, leg injuries, body surface damages, milking hygiene etc.) as well as in precision cattle farming. The IR camera applied in our experiment is suitable for these purposes.

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