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The impact of the dairy cow's position on eye and udder temperatures obtained with infra-red thermography within a walk-trough system

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ABSTRACT

Infra-red thermography (**IRT**) has the potential to detect disease, injury, and stress in dairy cows. Using IRT as a routine early warning system for such issues on-farm requires highly frequent imaging, which typically needs automation. To this end, automated systems collecting data every time an individual passes through a specified area have been developed (walk-through systems). Within these, the animal's speed, exact path and posture affect its distance and angle from the camera. While such variation in positioning is known to impact recorded temperatures, the extent of this impact is rarely quantified. If the error due to suboptimal positioning is sufficient to obscure temperature changes associated with the condition to be detected, the reliability of an early warning system is greatly impaired. This study aimed to quantify the impact of positioning on IRT-derived temperatures. Multiple IRT images were obtained from 197 lactating Holstein-Frisians using a walk-trough system. We assessed specific body parts chosen for their practical relevance: the eye centre (used to detect stress or general ill-health) and udder and teat area (used to detect mastitis or teat stress). The location of the body part within the IRT image ("position category") was used as a measure for combined changes in distance and angle of incidence. Minimisation of each of these two factors results in a maximisation of recorded temperature but was expected to occur at different position categories. Position category affected the recorded temperature of all three body parts on both sides of the cow ($P < 0.0001$). Temperatures peaked in position categories where distance was not yet fully minimised, underlining the importance of the angle of incidence. In images taken from the left side, recorded eye temperature showed a 2.2 °C (± 0.17 SEM) difference between the position where it peaked and the position where it bottomed out. This difference was 2.0 (± 0.07) and 1.5 (± 0.08) °C for maximum udder temperature and maximum teat area temperature, respectively. On the right side, these differences were 2.2 (± 0.28), 1.1 (± 0.11) and 0.6 (± 0.14) °C. The differences in temperature due to dairy cow positioning could mask the onset of a health problem, as these result in an approximately equal temperature rise. This suggests that even though walk-through systems standardise positioning to some extent, further standardisation is required. Our findings are not only of direct importance for the further development of walk-trough systems but also provide an insight into the optimisation of positioning when imaging freely moving animals.

Implications

Automated walk-through systems collect data every time a cow passes through a specified area. Although the cow's position impacts recorded temperatures, the extent of this needs quantified. This study aimed to quantify the impact of the cows' position on infrared thermography–derived temperatures. As dairy cows moved through an automated infrared-thermography setup, the distance and angle between the measured surface and the camera changed, which resulted in differences in recorded temperatures large enough to mask, or be misinterpreted as a physiological response to stress or disease. Automated systems would benefit from stricter standardisation of positioning when imaging freely moving animals.

Introduction

Disease, injury, and stress have detrimental impacts on farm animal welfare and productivity. This has been shown for bovine respiratory disease (Statham, 2018) mastitis (Puerto et al., 2021), lameness (Alvergnas et al., 2019), and stressful events such as transport (Hong et al., 2019). As prompt treatment improves welfare (Whay and Shearer, 2017), cure rates (Alvergnas et al., 2019;

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Pedersen and Wilson, 2021), and decreases production losses, (Michie et al., 2020; Garvey, 2022), early detection of such issues are key.

Traditionally, this early detection has relied on good stockmanship however, increasing herd sizes and a reduction in the agricultural workforce make the frequent and thorough inspection of animals challenging. For example, it has been reported that these larger cattle herds are at increased risk of reduced welfare, compared to those of a more traditional size (Robbins et al., 2016; Beggs et al., 2019). At the same time, there have been advancements in the development of sensor technologies that identify individual animals requiring closer attention from stockpersons. There are commercially available accelerometers, collar systems, subcutaneous thermometers and actometers, and intraruminal boluses, that continuously monitor behavioural activity, feed and water intake, total locomotor activity, subcutaneous temperature and health of agricultural animals (Stygar et al., 2021; Giannetto et al., 2022). However, as the reliability and accuracy of such systems are currently not optimal (Poulopoulou et al., 2019; Stygar et al., 2021; Charlton et al., 2022), there is a need for the continuing development of these technologies to individually and accurately monitor cow welfare.

Monitoring individual cows' temperature is one solution as increases in body temperature are a normal response to disease (Radostits et al., 2007), lameness (Wood et al., 2015), and stressful stimuli (Lees et al., 2020) such as thermal stress during transport (Aragona et al., 2024a). To monitor temperature, infrared thermography (**IRT**) is an effective and non-invasive way to detect non-visible mid to long-wave infrared radiation emitted by the surface of an object, which is directly related to its surface temperature (Lahiri et al., 2012). As well as being non-invasive, IRT can be automated, thereby making it a valuable tool for frequent or continuous monitoring of multiple areas of the body, as multiple images can be collected from individual animals (Berckmans, 2002). Furthermore, IRT cameras can be fitted to existing on-farm infrastructure such as shedding gates or cattle handling facilities, allowing for the assessment of all cows that pass through those areas. This is in contrast to many other sensors that need to be mounted on each individual cow, increasing the cost of their implementation.

Infrared thermography has been shown to be useful in the early detection of conditions that either cause an increase in core body temperature or localised inflammation. For example, eye temperature (which is correlated to deep body temperature (Wang et al., 2021) can be used in the early identification of cattle infected with Bovine Viral Disease (Schaefer, 2004), and an increased udder surface temperature can be used for the early detection of mastitis (Berry et al., 2003; Hovinen et al., 2008). Infrared thermography has been shown to be useful for monitoring disease-affected areas because cows with foot disease showed higher temperatures than healthy cows (Gianesella et al., 2018). Infrared thermography of the teat area has been used to monitor teat stress (Tangorra et al., 2019) and teat end hyperkeratosis (Juozaıtıene et al., 2018). Although Tangorra et al., 2019 states a low sensitivity and specificity of teat area temperature when compared to another indicator of teat stress (i.e., colour changes), Juozaıtıene et al., 2018 concludes an association between both teat temperature and the level of teat end keratosis, with a greater risk of mastitis.

Studies have also demonstrated changes in eye temperature in response to stressful stimuli in several species including cattle, such as during painful procedures in bull calves (Stewart et al., 2010). However, this may be less straightforward than the detection of infection as temperature changes are inconsistent between studies. Whereas some authors reported a stress-induced increase in temperature (Aragona et al., 2024b), others reported a decrease likely due to sympathetic nervous system–regulated vasoconstriction (Stubsjøen et al., 2009). Furthermore, any effect would need to persist until the animal passes by the automated detection system, whereas eye temperatures may return to baseline levels rapidly. For example, (Stewart et al., 2008a) showed that when cattle were exposed to stimuli assumed to cause pain, fear, or both (electric prodding, striking with a plastic tube, or waving of a plastic bag) eye temperature was initially reduced, but rapidly returned to baseline. Nonetheless, as other technologies are incapable of monitoring stressful events, further exploration of IRT in this way is desirable.

Due to the many potential applications of IRT, it is important to understand the factors that cause variation in IRT-derived temperatures as these could impede accurate monitoring. The main three sources of such variation are the environment, the animal and the camera setup (Rekant et al., 2016). Environmental factors such as wind (McManus et al., 2016), humidity (Kastberger and Stachl, 2003) and ambient temperature (Gloster et al., 2011) affect conductive heat loss from the measured surface. It is vital to account for these environmental conditions (Berckmans, 2002), as they can create changes in IRT-derived temperature greater than the temperature changes typically associated with health conditions (Berckmans, 2002; Wirthgen et al., 2011). Relevant animal factors such as skin and hair colour (Hellebrand et al., 2003 and the presence of dirt, can reduce the convective heat loss from the skin (McManus et al., 2016). As environmental and animal factors were not of direct interest for the current study, they were standardised by selecting areas that were unlikely to vary in colour or be dirty. Instead, our study focused on camera setup factors as a source of variation.

Key camera setup factors include the distance and angle between the infrared camera and the surface to be measured (Playà-Montmany and Tattersall, 2021). Increasing the distance from 0.5 to 3 m resulted in a 2 °C decrease in cattle eye temperature (Church et al., 2014), while Ijichi et al. (2020) found that imaging horses' eyes perpendicular rather than from 45° resulted in 0.5 °C higher temperatures. This drop-off in temperatures for angles of incidence over 50° is well known (Jiao et al., 2016; Playà-Montmany and Tattersall, 2021); however, small differences in distance or angle may not lead to such extreme variation in the recorded temperature. For instance, a study assessing horse legs showed only minimal effects (mean difference of 0.21 °C) of increasing the distance from 1 to 1.5 m (Westermann et al., 2013). Similarly, this study found only minimal effects (mean difference of 0.18 °C) of changing the camera angle by 20° from perpendicular. It should be noted that when measuring a round object like a leg, a change in the camera angle does not necessarily lead to a change in the angle, which may explain why these authors found no major effects. However, as the variation in IRT temperature due to distance and angle can be different depending on the type of surface being imaged (Playà-Montmany and Tattersall, 2021), it is essential to assess these effects as per the specific conditions under which the data are collected.

Although the need for standardising distance and angle of incidence is known, and procedures to do so are taught during IRT certification courses, standardisation is very difficult to achieve with freely moving animals that largely consist of irregular, non-flat surfaces leading to unpredictable angles of incidence (Playà-Montmany and Tattersall, 2021). Nonetheless, the technology is commonly used on such freely moving animals. In cows, greater standardisation can be achieved by capturing images from restrained individuals, although some variation remains due to differences in cows' size, shape, and posture. It is important that such restraint does not negate the non-invasive character of thermography, leading to stress-induced changes in measured temperature. Crucially, using complete restraint makes the technique difficult to automate fully. This is problematic as automation is an essential aspect of on-farm early warning systems, which require a monitoring frequency that is too high to achieve with non-automated assessments. Therefore, a walk-through system, which minimises the lateral variability in a cow's path, may be an ideal compromise allowing automation whilst minimising variability in distance and angle. Although in a walk-through system standardises the cow's direction of travel, images obtained at different stages of the cow's progression through the system will be taken at a different distance and angle between the camera and the body part of interest. It is currently unknown if such variation impacts the recorded temperatures to such an extent that this hinders diagnostic capacity.

The aim of this study was to investigate the impact of the cow's position within a walk-trough system on temperatures recorded with IRT. Temperatures were obtained using IRT cameras mounted on a weighbridge, which captured images of the cow from both sides as she passed through the weighbridge freely after milking. We focused on three different body parts currently used in the thermographic detection of disease and stress: the cows' eyes, udders and teat areas. It was hypothesised that for all measured areas, the recorded temperatures would increase with decreasing distance between the imaged surface and the camera. Especially for the eye, the angle of incidence was expected to be minimised when the cow was imaged anterolaterally (aligning with eye placement), resulting in higher recorded temperatures before the eye reached its closest distance to the camera. For the udder, it was more difficult to predict when the angle of incidence would be minimised due to the udder's mostly round and irregular surface. Thus, no clear hypothesis could be formulated a priori regarding how the angle of incidence would influence the distance at which the highest temperature would be recorded.

Material and methods

Study design

This study was conducted at Agri-Food and Biosciences Institute (**AFBI**) farm in Hillsborough, County Down, Northern Ireland. A total of 197 lactating Holstein-Friesian cows (the entire herd) were imaged on a single day in March 2023. The herd was considered representative of a commercial herd as there was a range of parities and lactational stages and were fed a partial mixed ration containing grass silage and concentrates. On the day, there were no health incidences recorded. All images were obtained after the morning milking, between 0600 and 0800 h. During this time, ambient temperature and relative humidity fluctuated between 6.1 °C and 7.1 °C, and 93.5 and 100%, respectively, as measured using Tinytag TGP-4500 data loggers (Gemini Data Loggers Ltd., Chichester, UK). As is the normal daily procedure in the milking herd, upon exiting the 50-point rotary parlour after milking, each cow walked through a weighbridge before joining the rest of the herd. The parlour, weighbridge, and collecting yard were all in a single large partially open building.

A FLIR A310 thermal camera (FLIR Systems UK, Kent, UK) was mounted on each side of the weighbridge (Fig. 1). Cows entered the weighbridge, paused briefly whilst being weighed automatically, and exited when the front gates opened. Between entry and exit, a sequence of images was obtained from both sides of the cow. Within a sequence, consecutive images were taken at 0.3–second intervals with the number of images per cow depending on how quickly she moved along the weighbridge. As the cameras' original 90° field of view was slightly curtailed on the left side due to the camera mounts, the angles of the left and right cameras were slightly different to enable imaging of the same areas.

The cameras had previously been fully calibrated in accordance with procedures laid down in BS EN ISO/IEC 17025. The software development kit used was Thermovision SDK Runtime, and an emissivity value of 0.95 was used. The images were recorded to a hard drive for analysis. Temperatures were recorded separately for each camera and not adjusted for any camera differences. From these images, eye temperature was manually extracted by locating the centre of the eye (not including the lacrimal gland or surrounding skin) in custom–built software (Agricam AFBI Tool, AgriCam, Uppsala, Sweden) with time stamps the measure of time equivalency. Temperatures were obtained for every image in a sequence in which the entire eye was visible and not blurred. The horizontal distance between the eye centre and the side of the image was used as a proxy for the cow's progression through the weighbridge

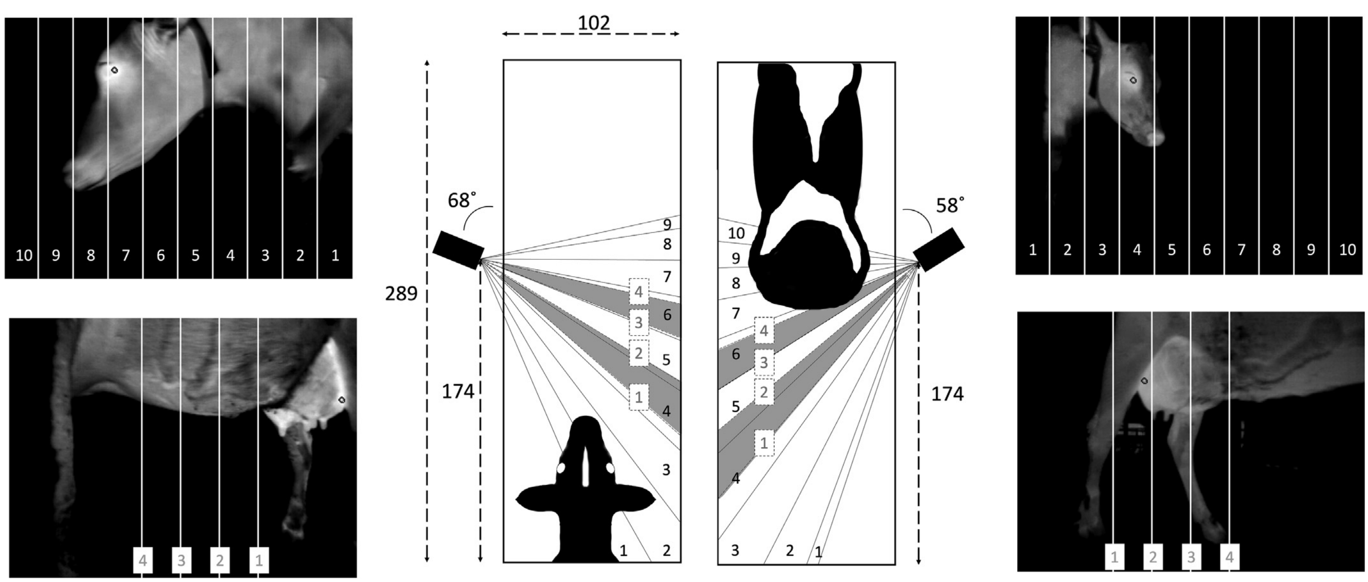

Fig. 1. Thermography setup and examples of resulting images. Left and right columns: Thermographic images of the cow's eye and udder taken from the left and right side, respectively. Numbers refer to the position categories that images were divided into (see text). In the udder image taken from the left, the cow is just in position category 1, whereas in the udder image taken from the right the cow is in position 3. Middle column: Top view of the weighbridge (open rectangle) equipped with thermal cameras (black rectangles). The left and right cameras are depicted separately here, but in reality, both were attached to the same weighbridge. Position categories for the eye are delineated by solid lines, those for the udder by dotted lines and grey fill. Eye position categories shown are adapted to reflect the curtailing of the cameras' field of view due to the camera mounts. Measurements are in cm. Cows of average size for the breed are shown entering and exiting the weighbridge to aid in the visual interpretation of the scale (and thus the limited potential for lateral movement).

and thus its position in relation to the camera. The horizontal distance was divided into 10 categories, each containing 10% of the width of the image. These position categories were termed 1–10, with category 1 being the first category that the cow passed through.

The maximum udder temperature and maximum teat area temperature were extracted using the same software, from four images per sequence. The first selected image within the sequence was the first image in which the front of the udder had reached (or passed beyond) a 50 mm distance from the side of the image, without having reached a distance of 70 mm from the side of the image (Fig. 1). Further images were selected as the udder reached or moved beyond markers set at 70, 90 and 110 mm from the side of the image from which the cow initially entered. If a cow moved past two markers between consecutive images, no data was collected for the short–distance marker. Selected images were discarded if the hind left leg covered over 50% of the udder surface area or bisected the udder (i.e., if parts of the udder were visible both in front of and behind the leg). Maximum udder temperature was extracted automatically by the software based on the hottest pixel in the image. If this pixel was outside the udder area (Fig. 2A), the image was discarded. Maximum teat area temperature was obtained by drawing a 20-pixel high rectangle whose width spanned all teats and the space between them (Fig. 2B, C). The vertical centre of the rectangle was at the point where the teat met the main udder, which was determined separately for the first and last teat (thus, the rectangle was not necessarily placed horizontally). In addition to images with mostly covered or bisected udders, images were discarded for maximum teat area temperature analysis if fewer than two teats were visible.

Statistical analysis of data

All analyses were performed using a linear mixed effects models in R (version 4.1.3). Temperature was analysed separately for the left and right eye, left and right side of the udder, and the left and right teat area. Position category (i.e., our proxy for the cow's progression through the setup) was the only fixed factor included in the models. Cow was included in all models as a random factor. Approximate normality of the residuals was confirmed visually. Tukey adjustment was used when making pairwise comparisons between estimated marginal means.

Results

Eye centre temperature

The position category had a significant effect on the measured eye centre temperature, for both the left and the right eye ($P < 0.0001$, Fig. 3A and Fig. 3B). For the left eye, there were no observations within category 10. The estimated marginal means increased from position category 1–4 (by 1.2 °C in total) and decreased from position category 5–9 (by 2.2 °C in total), although not each increment between position categories was statistically significant (see Fig. 4 for the exact pairwise significance). For the right eye, there were no observations in categories 1 and 10. The estimated marginal means increased from category 2 to category 4 (by 1.3 °C in total) and decreased from category 5 to category 9 (by 2.2 °C in total). Most position categories differed from all others ($P < 0.05$), the only non-significant contrasts were those between categories 2, 7 and 8, those between categories 3 and 6, and those between categories 4 and 5.

Maximum whole udder temperature

Position category had a significant effect on the whole udder temperature for both the left and right side camera ($P < 0.0001$, Fig. 5A and Fig. 5B). Temperature increased from position 1 to position 3 (by 1.1 °C for the left side and 2 °C for the right side) and then decreased from position 3 to position 4 (by 0.1 °C for both sides). For the left side, position 1 differed significantly from positions 2, 3 and 4 ($P < 0.05$), whereas for the right side, all positions differed significantly from each other ($P < 0.05$), except position 3 did not differ from position 4.

Maximum teat area temperature

The position category had a significant effect on the maximum teat area temperature on both the left and right sides ($P < 0.0001$, Fig. 6A and Fig. 6B respectively). For the left side, temperature increased from position 1 to position 2 (by 0.4 °C) and then decreased from position 3 to position 4 (by 0.6 °C). For the right side, temperature increased from position 1 to position 3 (by 1.5 °C) and decreased thereafter (by 0.3 °C). For the left side, positions 1 and 4 differed significantly from positions 2 and 3 ($P < 0.05$). For the right side, all positions differed significantly from all others ($P < 0.05$).

Discussion

The aim of this study was to assess the impact of cow position relative to the camera on IRT-derived temperatures obtained from the eye, udder, and teat area using an automated walk-through system. For all three body parts, position relative to the camera affected the recorded temperature and resulted in differences large enough to mask, or be misinterpreted as a physiological response to stress or disease.

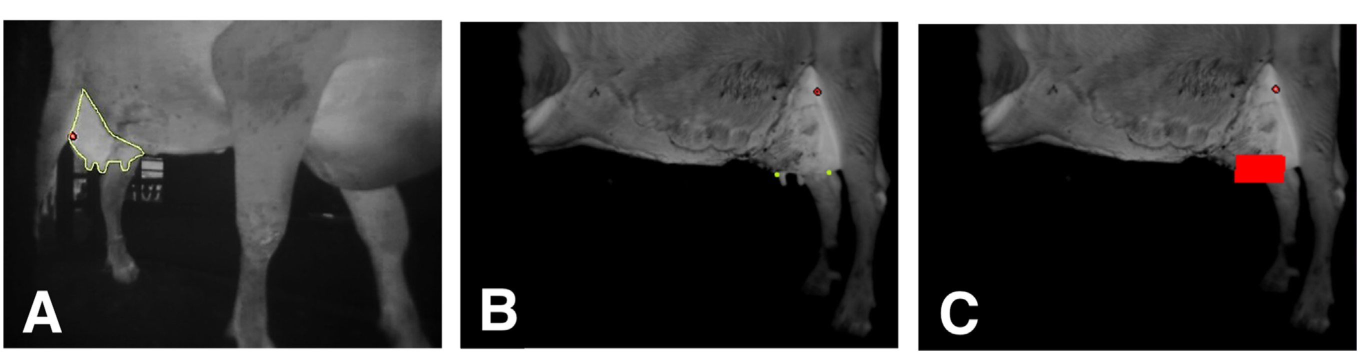

Fig. 2. Thermal images of the cow's udder as acquired during the experiment. A: The yellow outline indicates the area as used to obtain the maximum whole udder temperature. B: Yellow dots indicate the far left and right side and vertical centre of the rectangle within which the maximum teat area temperature was measured. C: Same image as in B, but now with the full shown (red).

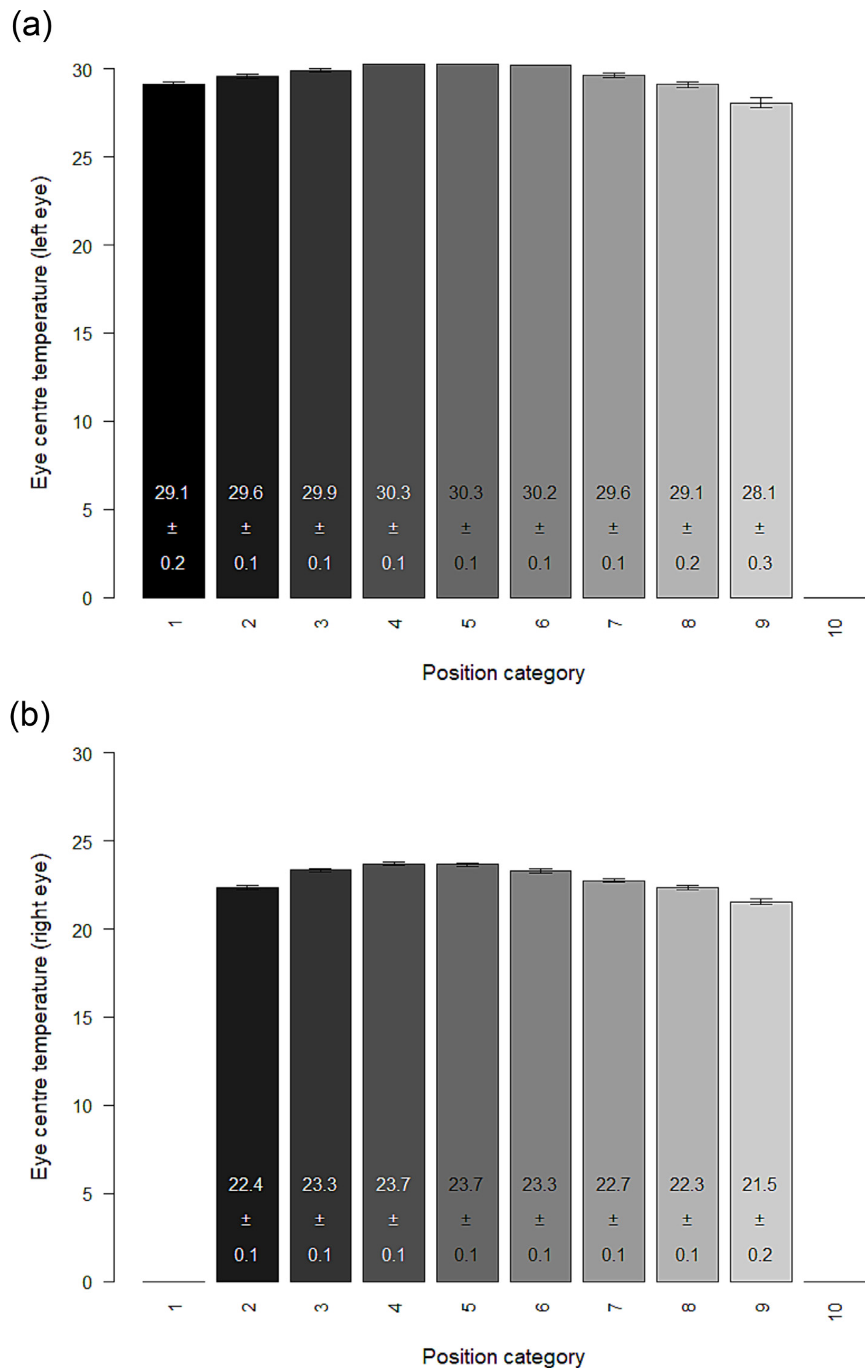

Fig. 3. Eye centre temperature (estimated marginal means in °C ± SEM) of the left (A) and right (B) eye as affected by eye position relative to the camera. Position category 1 was the first category that the cow passed through, with a higher position category indicating that the cow had progressed further towards or past the camera.

Recorded eye centre temperature increased significantly as the eye progressed from the edge of the camera's visual field (as captured at position category 1) towards the camera. Subsequently, it decreased again as the eye moved beyond the camera (towards position category 9). This was as expected, as subject-to-camera distance was greater for more extreme position categories, and is inversely related to IRT-derived temperature (Playà-Montmany and Tattersall, 2021). However, the maximum recorded temperature did not occur at the minimum eye–to–camera distance (which happened when the cow's eye was level with the camera, around position category 8 as shown in Fig. 1). Instead, recorded eye temperatures peaked at position category 4 and category 5, likely as a result of a more favourable angle of incidence due to the eye's anterolateral placement.

Recorded temperature increased by 1.2 °C whilst the eye moved towards position category 4 and category 5 and decreased by 2.2 °C whilst moving beyond those. Such differences in recorded temperature due to positioning are equal in size to reported physiologi-

	1	2	3	4	5	6	7	8	9
1		-	*	*	*	*	-	-	*
2			-	*	*	*	-	-	*
3				-	-	-	-	*	*
4					-	-	*	*	*
5						-	*	*	*
6							*	*	*
7								-	*
8									*
9									

Fig. 4. Significance of pairwise contrasts between the different position categories (centre temperature of the cow's left eye). * Significant pairwise contrast ($P < 0.05$), - no significant pairwise contrast ($P > 0.05$).

cally relevant changes in actual body temperature resulting from disease, stress or pain. For instance, the bovine respiratory disease increased eye temperature by 0.8 °C (Schaefer et al., 2012), whilst aversive handling procedures decreased it by 0.2–0.6 °C (Stewart et al., 2008a) and disbudding without local anaesthetic did so by 0.3 °C (Stewart et al., 2008b). The finding that positioning effects can equal or exceed the physiological response to conditions that one might want to monitor has important implications for the use of walk-through thermography systems. Because of the large variation between individual cows in many biologically relevant parameters, automated detection systems generally use within-individual changes over time to detect issues. If an individual's temperature would be recorded whilst it is slightly further away or at a greater angle of incidence on one day than on the next, this would result in a higher recorded temperature on the latter day, potentially triggering a false positive alert. Changes in recorded temperature that could be mistaken for or obscure physiologically relevant ones sometimes even occurred for minimal differences in positioning. For example, there was a 0.4 °C difference in temperature between eye position categories 3 and 4.

The use of a walk-through system standardises positioning to some extent (as the cow's lateral movement is restricted). However, our results show that stricter standardisation is required to further reduce non-physiological variation in recorded temperature. However, this may also reduce the amount of data that can be collected, as the cow may pass by the standardised position during the interval between the acquisition of two images. Whilst shortening this interval is possible, this requires greater data processing power for an automated detection system running in real-time (which would be optimal in the context of creating early warning systems, (McManus et al., 2022)). In practice, such systems may thus need to make a careful weighting of factors like the extent of standardisation of the relevant body part's position, the minimum interval between the acquisition of consecutive images and the expected increase in temperature associated with the condition that is to be detected. In our dataset, the exact positions that resulted in a significant and meaningful increase in temperature varied slightly for the left and the right eye. This suggests that small differences in the setup can lead to the need for an individual weighting between the factors mentioned above.

Given the high prevalence and economic importance of mastitis in cattle, it is not surprising that the udder has been one of the most frequently studied regions for IRT (McManus et al., 2022). Colak et al., 2008 have suggested IRT as a screening tool for mastitis because of the strong correlation between udder skin surface temperature and subclinical mastitis identified using a California Mastitis Test. Indeed, previous work with dairy cattle has demonstrated that an experimentally induced mastitis caused by endotoxin infusion caused an udder temperature rise observed on the other side of the udder (Scott et al., 2000). However, the variation we observed in recorded temperature due to positioning may hamper the use of automated walk-trough systems for mastitis screening. Positioning affected recorded udder temperature in a similar way as recorded eye temperature: temperatures increased as the

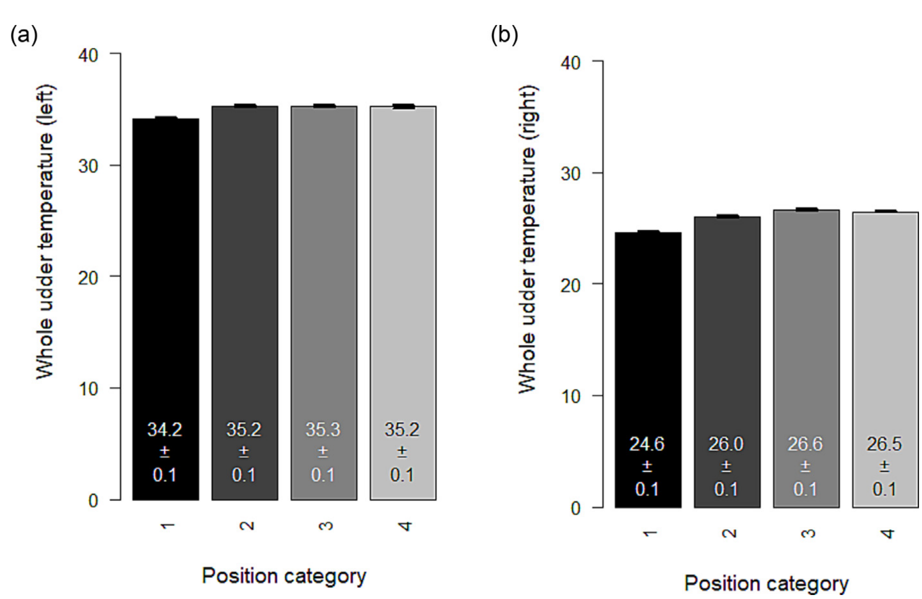

Fig. 5. Maximum whole udder temperature (estimated marginal means in °C ± SEM) on the left (A) and right (B) sides as affected by the udder's position relative to the camera. Position category 1 was the first category that the cow passed through, with a higher position category indicating that the cow had progressed further towards or past the camera.

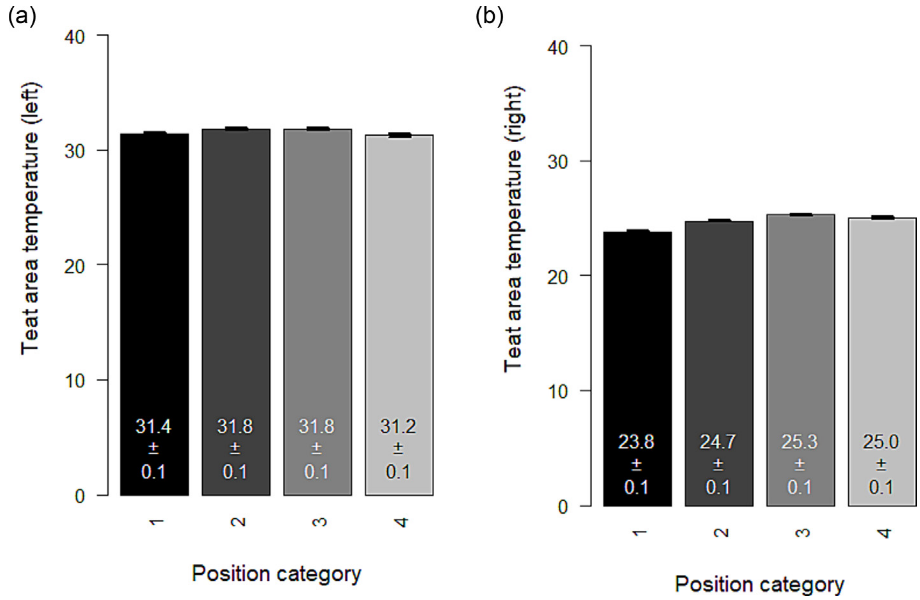

Fig. 6. Maximum teat area temperature (estimated marginal means in °C ± SEM) on the left (A) and right (B) sides as affected by udder's position within the thermographic image. Position category 1 was the first category that the cow passed through, with a higher position category indicating that the cow had progressed further towards or past the camera.

udder moved closer to the camera but peaked before udder-to-camera distances were minimised, likely as a result of a more favourable angle of incidence. This resulted in a substantial difference in recorded maximum whole udder temperatures (1.1 °C and 2.0 °C difference between position categories 1 and 3 for the left and right side, respectively). These values are comparable to cut-off points suggested for skin udder temperature rises used to detect subclinical mastitis (Polat et al., 2010; Ruegg, 2017; Gonçalves et al., 2018) and are thus likely to hinder the accuracy of detection. Similarly, positioning resulted in differences in maximum teat area temperature of 0.6 °C and 1.5 °C on the left and right cameras, respectively. Thus, teat area temperature increases associated with clinical mastitis (1.0 °C to 1.5 °C), hyperkeratosis (1.3 °C) and the combination of both (1.7 °C) (Hovinen et al., 2008; Juozaıtıene et al., 2018), could be effectively nullified or mimicked depending on the teat's position when the thermal image is captured.

In addition to differences associated with our positioning categories, recorded temperatures on the left side were markedly higher (by 6–9 °C) than those obtained on the right side. Cow behaviour during and prior to imaging may have contributed to the observed differences. For instance, during imaging cows may have walked closer to the left camera than the right camera, or may have oriented their head towards other cows waiting in the collection yard on the left side. Prior to imaging, lateralisation of behaviours like lying, stepping and stamping whilst housed or on their way to and from the thermography setup may have resulted in a greater chance of soiling or wetness on the right side of the udder, which are known to lower recorded temperature (Metzner et al., 2014). Furthermore, many environmental variables can affect IRT recorded temperature such as sunlight and drafts (Metzner et al., 2014; McManus et al., 2022). These could realistically have varied on both sides of the cow, as the walk-trough system was placed within a large and partially open building that further included a milking parlour and large collection yard. Additionally, the two cameras used in this study were set up at slightly different angles to enable the imaging of the same area (although on different sides of the cow), whilst working around the slight truncation of the original 90° field of view by the camera mounts. This may have contributed to the difference in temperature measurement by leading to a closer alignment of the position in which the distance and angle of emissivity were minimised, resulting in higher recorded temperatures (Jiao et al., 2016; Playà-Montmany and Tattersall, 2021). From our current data, it cannot be determined which (if any) of these factors contributed most to the difference between the sides. Although the effect of the position categories on recorded temperature was smaller on the left side than on the right, at 2.2, 1.1 and 0.6 °C (for the eye, whole udder and teat area, respectively), these differences would still have an impact on using IRT for the detection of stress or sub-optimal health in cattle.

Conclusion

This study aimed to quantify the impact of the dairy cows' position on infra-red thermography–derived temperatures. As cows progressed through our automated infra-red thermography setup, the changes in the distance and angle between the measured surface and the camera led to changes in recorded temperatures. These changes were large enough that they could be mistaken for indicators of the early onset of disease. Therefore, future systems would benefit from stricter standardisation of, or a correction for, positioning when imaging freely moving animals.

Ethics approval

Not applicable. The study was non-invasive, involving routine husbandry and behavioural observations, and was below the threshold of the Animals (Scientific Procedures) Act 1986. As such, it did not require ethical approval under current UK legislation.

Data and model availability statement

None of the data were deposited in an official repository. The data and models that support the study findings are available from the authors upon request.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

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CRediT authorship contribution statement

M.W. Little: Writing – review & editing, Writing – original draft. **J.E. Weller:** Writing – review & editing, Methodology, Investigation, Data curation. **S. Buijs:** Writing – review & editing, Visualisation, Supervision, Project administration, Funding acquisition, Formal analysis, Conceptualisation.

Declaration of interest

None.

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References

Alvergnas, M., Strabel, T., Rzewuska, K., Sell-Kubiak, E., 2019. Claw disorders in dairy cattle: effects on production, welfare and farm economics with possible prevention methods. Livestock Science 222, 54–64. https://doi.org/10.1016/j.livsci.2019.02.011.

Aragona, F., Arfuso, F., Rizzo, M., Fazio, F., Acri, G., Piccione, G., Giannetto, C., 2024a. Using infrared thermography for the evaluation of road transport thermal homeostasis in athletic horse. Journal of Equine Veterinary Science 138, 105102. https://doi.org/10.1016/j.jevs.2024.105102.

Aragona, F., Rizzo, M., Arfuso, F., Acri, G., Fazio, F., Piccione, G., Giannetto, C., 2024b. Eye temperature measured with infrared thermography to assess stress responses to road transport in horses. Animals 14, 1877. https://doi.org/10.3390/ani14131877.

Beggs, D.S., Jongman, E.C., Hemsworth, P.H., Fisher, A.D., 2019. The effects of herd size on the welfare of dairy cows in a pasture-based system using animal- and resource-based indicators. Journal of Dairy Science 102, 3406–3420. https://doi.org/10.3168/jds.2018-14850.

Berckmans, D., 2002. Advances in precision livestock farming (1st ed.). Burleigh Dodds Science Publishing, London, UK.

Berry, R., Kennedy, A., Scott, S., 2003. Daily variation in the udder surface temperature of dairy cows measured by infrared thermography: potential for mastitis detection. Canadian Veterinary Journal 83, 687–693.

Charlton, G., Gauld, C., Veronesi, F., Rutter, S.M., Bleach, E., 2022. Assessing the accuracy of leg mounted sensors for recording dairy cow behavioural activity at pasture, in cubicle housing and a straw yard. Animals 12, 638. https://doi.org/10.3390/ani12050638.

Church, J., Hegadoren, P., Paetkau, M., 2014. Influence of environmental factors on infrared eye temperature measurements in cattle. Research in Veterinary Science 96, 220–226. https://doi.org/10.1016/j.rvsc.2013.11.006.

Colak, A., Polat, B., Okumus, Z., 2008. Short communication: early detection of mastitis using infrared thermography in dairy cows. Journal of Dairy Science 91, 4244–4248. https://doi.org/10.3168/jds.2008-1258.

Garvey, M., 2022. Lameness in dairy cow herds: disease aetiology, prevention and management. Dairy 3, 199–210.

Gianesella, M., Arfuso, F., Fiore, E., Giambelluca, S., Giudice, E., Armato, L., Piccione, G., 2018. Infrared thermography as a rapid and non-invasive diagnostic tool to detect inflammatory foot diseases in dairy cows. Polish Journal of Veterinary Sciences 21, 299–305. https://doi.org/10.24425/122597.

Giannetto, C., Cerutti, R.D., Scaglione, M.C., Fazio, F., Aragona, F., Arfuso, F., Zumbo, A., Piccione, G., 2022. Simultaneous recording of subcutaneous temperature and total locomotor activity in Bos taurus and Bos indicus raised in a subtropical region of Argentina. Tropical Animal Health and Production 54, 371. https://doi.org/10.1007/s11250-022-03365-7.

Gloster, J., Ebert, K., Gubbins, S., Bashiruddin, J., Paton, D.J., 2011. Normal variation in thermal radiated temperature in cattle: implications for foot-and-mouth disease detection. BMC Veterinary Research 7, 73. https://doi.org/10.1186/1746-6148-7-73.

Gonçalves, J.L., Kamphuis, C., Martins, C.M.M.R., Barreiro, J.R., Tomazi, T., Gameiro, A. H., Hogeveen, H., dos Santos, M.V., 2018. Bovine subclinical mastitis reduces milk yield and economic return. Livestock Science 210, 25–32. https://doi.org/10.1016/j.livsci.2018.01.016.

Hellebrand, H., Brehme, U., Beuche, H., 2003. Application of thermal imaging for cattle management. Proceedings of the 1st European Conference on Precision Livestock Farming, 15–19 June 2003, Berlin, Germany, p. 761–763.

Hong, H., Lee, E., Lee, I.H., Lee, S.R., 2019. Effects of transport stress on physiological responses and milk production in lactating dairy cows. Asian-Australasian Journal of Animal Sciences 32, 442–451. https://doi.org/10.5713/ajas.18.0108.

Hovinen, M., Siivonen, J., Taponen, S., Hänninen, L., Pastell, M., Aisla, A.M., Pyörälä, S., 2008. Detection of clinical mastitis with the help of a thermal camera. Journal of Dairy Science 91, 4592–4598. https://doi.org/10.3168/jds.2008-1218.

Ijichi, C., Evans, L., Woods, H., Yarnell, K., 2020. The right angle: validating a standardised protocol for the use of infra-red thermography of eye temperature as a welfare indicator. Animal Welfare 29, 123–131. https://doi.org/10.7120/09627286.29.2.123.

Jiao, L., Dong, D., Zhao, X., Han, P., 2016. Compensation method for the influence of angle of view on animal temperature measurement using thermal imaging camera combined with depth image. Journal of Thermal Biology 62, 15–19. https://doi.org/10.1016/j.jtherbio.2016.07.021.

Juozaıtıene, V., Juozaıtıs, A., Zymantıene, J., Oberauskas, V., Anıulıenė, A., Kajokıenė, L., Sımokaıtıenė, A., Yılmaz, A., 2018. The effect of different levels of teat-end hyperkeratosis on mammary infrared thermograph and mastitis in dairy cows. Ankara Üniversitesi Veteriner Fakültesi Dergisi 66, 21–26.

Kastberger, G., Stachl, R., 2003. Infrared imaging technology and biological applications. Behavior Research Methods, Instruments, & Computers 35, 429–439. https://doi.org/10.3758/BF03195520.

Lahiri, B.B., Bagavathiappan, S., Jayakumar, T., Philip, J., 2012. Medical applications of infrared thermography: a review. Infrared Physics & Technology 55, 221–235. https://doi.org/10.1016/j.infrared.2012.03.007.

Lees, A.M., Salvin, H.E., Colditz, I.G., Lee, C., 2020. The influence of temperament on body temperature response to handling in angus cattle. Animals 10, 172.

McManus, R., Boden, L.A., Weir, W., Viora, L., Barker, R., Kim, Y., McBride, P., Yang, S., 2022. Thermography for disease detection in livestock: a scoping review. Frontiers in Veterinary Science 9, 965622. https://doi.org/10.3389/fvets.2022.965622.

McManus, C., Tanure, C.B., Peripolli, V., Seixas, L., Fischer, V., Gabbi, A.M., Menegassi, S.R., Stumpf, M.T., Kolling, G.J., Dias, E., 2016. Infrared thermography in animal production: an overview. Computers and Electronics in Agriculture 123, 10–16.

Metzner, M., Sauter-Louis, C., Seemueller, A., Petzl, W., Klee, W., 2014. Infrared thermography of the udder surface of dairy cattle: characteristics, methods, and correlation with rectal temperature. The Veterinary Journal 199, 57–62. https://doi.org/10.1016/j.tvjl.2013.10.030.

Michie, C., Andonovic, I., Davison, C., Hamilton, A., Tachtatzis, C., Jonsson, N., Duthie, C.-A., Bowen, J., Gilroy, M., 2020. The internet of things enhancing animal welfare and farm operational efficiency. Journal of Dairy Research 87, 20–27. https://doi.org/10.1017/S0022029920000680.

Pedersen, S., Wilson, J., 2021. Early detection and prompt effective treatment of lameness in dairy cattle. Livestock 26, 115–121. https://doi.org/10.12968/live.2021.26.3.115.

Playà-Montmany, N., Tattersall, G.J., 2021. Spot size, distance and emissivity errors in field applications of infrared thermography. Methods in Ecology and Evolution 12, 828–840. https://doi.org/10.1111/2041-210X.13563.

Polat, B., Colak, A., Cengiz, M., Yanmaz, L.E., Oral, H., Bastan, A., Kaya, S., Hayirli, A., 2010. Sensitivity and specificity of infrared thermography in detection of subclinical mastitis in dairy cows. Journal of Dairy Science 93, 3525–3532. https://doi.org/10.3168/jds.2009-2807.

Poulopoulou, I., Lambertz, C., Gauly, M., 2019. Are automated sensors a reliable tool to estimate behavioural activities in grazing beef cattle? Applied Animal Behaviour Science 216, 1–5. https://doi.org/10.1016/j.applanim.2019.04.009.

Puerto, M.A., Shepley, E., Cue, R.I., Warner, D., Dubuc, J., Vasseur, E., 2021. The hidden cost of disease: I. Impact of the first incidence of mastitis on production and economic indicators of primiparous dairy cows. Journal of Dairy Science 104, 7932–7943. https://doi.org/10.3168/jds.2020-19584.

Radostits, O.M., Gay, C.C., Hinchcliff, K.W., Constable, P.D., 2007. Veterinary medicine : a textbook of the diseases of cattle, sheep, pigs, goats and horses. Appendix 2, Reference laboratory values, 10th edition. Elsevier Saunders, Edinburgh, UK.

Rekant, S.I., Lyons, M.A., Pacheco, J.M., Arzt, J., Rodriguez, L.L., 2016. Veterinary applications of infrared thermography. American Journal of Veterinary Research 77, 98–107. https://doi.org/10.2460/ajvr.77.1.98.

Robbins, J.A., von Keyserlingk, M.A.G., Fraser, D., Weary, D.M., 2016. Invited Review: Farm size and animal welfare. Journal of Animal Science 94, 5439–5455. https://doi.org/10.2527/jas.2016-0805.

Ruegg, P.L., 2017. A 100-year review: mastitis detection, management, and prevention. Journal of Dairy Science 100, 10381–10397. https://doi.org/10.3168/jds.2017-13023.

Schaefer, A., 2004. Early detection and prediction of infection using infrared thermography. Canadian Journal of Animal Science 84, 73–80. https://doi.org/10.4141/a02-104.

Schaefer, A.L., Cook, N.J., Bench, C., Chabot, J.B., Colyn, J., Liu, T., Okine, E.K., Stewart, M., Webster, J.R., 2012. The non-invasive and automated detection of bovine respiratory disease onset in receiver calves using infrared thermography. Research in Veterinary Science 93, 928–935. https://doi.org/10.1016/j.rvsc.2011.09.021.

Scott, S.L., Schaefer, A.L., Tong, A.K.W., Lacasse, P., 2000. Use of infrared thermography for early detection of mastitis in dairy cows. Presented at the annual meeting of the Canadian Society of Animal Science, Winnipeg, MB, Canada.

Statham, J., 2018. Respiratory disease in cattle — a practical approach. Livestock 23, 206–213. https://doi.org/10.12968/live.2018.23.5.206.

Stewart, M., Schaefer, A.L., Haley, D., Colyn, J., Cook, N., Stafford, K., Webster, J., 2008a. Infrared thermography as a non-invasive method for detecting fear-related responses of cattle to handling procedures. Animal Welfare (south Mimms, England) 17, 387–393. https://doi.org/10.1017/S0962728600027895.

Stewart, M., Stafford, K.J., Dowling, S.K., Schaefer, A.L., Webster, J.R., 2008b. Eye temperature and heart rate variability of calves disbudded with or without local anaesthetic. Physiology & Behavior 93, 789–797. https://doi.org/10.1016/j.physbeh.2007.11.044.

Stewart, M., Verkerk, G.A., Stafford, K.J., Schaefer, A.L., Webster, J.R., 2010. Noninvasive assessment of autonomic activity for evaluation of pain in calves, using surgical castration as a model. Journal of Dairy Science 93, 3602–3609. https://doi.org/10.3168/jds.2010-3114.

Stubsjøen, S., Flø, A., Moe, R., 2009. Exploring non-invasive methods to assess pain in sheep. Physiology Behaviour 98, 640–648. https://doi.org/10.1016/j.physbeh.2009.09.019.

Stygar, A.H., Gómez, Y., Berteselli, G.V., Dalla Costa, E., Canali, E., Niemi, J.K., Llonch, P., Pastell, M., 2021. A systematic review on commercially available and validated sensor technologies for welfare assessment of dairy cattle. Frontiers in Veterinary Science 8, 1–15. https://doi.org/10.3389/fvets.2021.634338.

Tangorra, F.M., Redaelli, V., Luzi, F., Zaninelli, M., 2019. The use of infrared thermography for the monitoring of udder teat stress caused by milking machines. Animals 9, 384.

Wang, F.K., Shih, J.Y., Juan, P.H., Su, Y.C., Wang, Y.C., 2021. Non-invasive cattle body temperature measurement using infrared thermography and auxiliary sensors. Sensors (basel) 21, 2425. https://doi.org/10.3390/s21072425.

Westermann, S., Buchner, H., Schramel, J., 2013. Effects of infrared camera angle and distance on measurement and reproducibility of thermographically determined temperatures of the distolateral aspects of the forelimbs in horses. Journal of the American Veterinary Medicine Association 242, 388–395. https://doi.org/10.2460/javma.242.3.388.

Whay, H.R., Shearer, J.K., 2017. The impact of lameness on welfare of the dairy cow. Veterinary Clinics: Food Animal Practice 33, 153–164. https://doi.org/10.1016/j.cvfa.2017.02.008.

Wirthgen, T., Zipser, S., Geidel, S., Franze, U., 2011. Precise IR-based temperature measuring - a case study for the automatic health monitoring of dairy cows. Proceedings of the SENSOR+TEST Conferences, 7–9 June 2011, Nürnberg, Germany, pp. 51–56.

Wood, S., Lin, Y., Knowles, T.G., Main, D.C.J., 2015. Infrared thermometry for lesion monitoring in cattle lameness. Veterinary Record 176, 308. https://doi.org/10.1136/vr.102571.