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Detection of lameness in dairy cattle and buffalo using digital infrared thermography: A review

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Abstract
Infrared thermography (IRT) is a technique to detect surface temperature of body that can be used to detect hoof diseases and lameness. It is a non-invasive method that measures the emitted infrared radiation and represents thermal profile visualisation. It is a highly sensitive technique to evaluate small changes in animal body surface temperature, which can occur due to stress, induced-changes in blood flow. Evaluate the health status of hoof by measuring the skin surface temperature in cattle and other animal species in different parts using IRT. Which are able to detect lesions of limb of dairy cow associated with lameness by measuring the changes in coronary band temperature. The surface temperature of affected limb will be increased when presence of hoof lesion. IRT has been used as a non-invasive diagnostic tool for early detection of lameness based difference in temperature between affected and normal limb.

Keywords: Dairy cattle, hoof lesion infrared thermography, lameness, temperature

Introduction
Lameness in cattle is one of the commonest causes of reduce productive, reproduction performance of dairy cattle and it compromises with animal health and welfare. However, lameness is associated with body condition score, lesion of hock, leg hygiene and behavioural changes of animal (Sadiq *et al.,* 2017) [32]. The common cause of lameness in cattle is related with claw abnormalities which account approximately 90% of lameness with incidence of 76 to 84% of foot lesions occurred in the hind feet (Alsaaod *et al*., 2015) [3]. Locomotion score is a common subjective approach to assess lameness in cattle. However, score approach is a time consuming to use in larger herds and may not always be sensitive enough to detect foot lesions. Lameness is third most probable cause of the culling of dairy cows after mastitis and infertility due to low productivity (Kossaibati *et al.,* 1997) [17].

Infrared thermography
Infrared thermography (IRT) is a non-invasive and safe technique to show the temperature of surface of body, which can then be computer-analyse (Schaeer *et al*., 2012) [34]. IRT is used for early detection and assessment of lameness. In dairy cattle, lameness can be detected by measuring the temperature difference between healthy and affected feet. Lameness occurs due to changes in blood flow in particular region such as foot lesion (Alsaaod *et al*., 2015) [3]. Foot lesion lead to abnormal gait during locomotion and may occur due to faulty claw trimming. Early diagnosis of foot lesion is very important factor to reduce the incidence of lameness (Leach *et al.,* 2012) [19]. Increase in surface temperature of foot at the coronary band and it surrounding area due to increased blood circulation of the claws has been markedly recognized by thermography.

Advantages and Limitations of Infrared Imaging
IRT is a technique that measures heat emissions and display the information in a pictorial form called as thermogram. IRT is more sensitive to detect minor temperature difference on body surface. Thermography often reveals the different temperature pattern, physiological changes as they appear as clinical signs, thus provides early detection and allow for early treatment intervention. IRTs can measure body temperature with moderately to high accuracy (Nguyen *et al*., 2010; Chan *et al*., 2013) [22, 7]. Thermography helps in locating exact site of lesions (Cetinkya and Demirutku, 2012) [6].

In comparison with other diagnostic methods, thermography has become a most important economical and safe tool to evaluate surface temperature of body (Usamentiaga *et al.*, 2014) [42]. However, certain limitations need to be considered during use of IRT. Thermograms must be collected out of direct sunlight and wind currents (Usamentiaga *et al.*, 2014) [42]. The surface should be free from dirt, moisture and foreign material. The effect of weather conditions, circadian rhythms are also some important factors that need to be considered and require further investigation as part of validating IRT.

Table 1: Detection of lameness using infrared thermography

IR Model	Resolution	Distance	Animal	Region	Reference
FLIR 760	175 ×131	0.5 m	Dairy cow	Coronary band and skin of lateral and medial claws	Nikkhah *et al.*, 2005 [23]
FlukeTi25	640×480	1 m	Cow	Claw lesion	Nuss and Paulus, 2006 [24]
FLIR EX320	320×240	-	Cattle	bottom of the foot up to the top of claw	Rainwater-Lovett *et al.*, 2009 [27]
FLUKE Ti25	640×480	0.15 m	Dairy cow	Coronary band and skin for lateral and medial claws	Alsaaod *et al.*, 2015 [3]
Fluke Ti20TM	640×480	2 m	Cattle	Cranial and caudal left foreleg	Salles *et al.*, 2016 [33]

Table 2: Application of infrared thermography for detection of lameness and hoof abnormalities in livestock

Breed/species	Evaluation	Findings	Reference
Horse	Laminitis	1 to 2 ℃ rise in surface temperature of the coronary band	Turner 1991 [41]
Horse	Long bone injury	2 to 3 °C higher temperature on a lateral or medial aspect of metacarpal bone	Eddy *et al.*, 2001 [9]
Holstein cows	Sole infection	4.5 °C change in surface temperature of the coronary band	Nikkhah *et al.*, 2005 [23]
Horse	Laminitis	1-2 °C higher temperature in the coronary band	Yanmaz *et al.*, 2007 [47]
Cattle	Lameness (FMD)	4.4 to 7.1 °C elevated temperature in the coronary band	Gloster *et al.*, 2011 [12]
Dairy cow	Hoof lesion	0.64 to 1.09 °C change in surface temperature of the coronary band	Alsaaod and Buscher 2012 [1]
HF cows	Digital dermatitis	7.9 °C change in surface temperature of feet	Stokes *et al.*, 2012 [39]
Cattle	Lameness	3.10 °C change in surface temperature of feet	Renn *et al.*, 2014 [28]
Cattle	Lameness	0.62 °C change in surface temperature of the rear leg	Wood *et al.*, 2014 [45]
Dairy cow	Lameness	0.93 °C and 1.43 °C change in surface temperature of the medial and lateral claw.	Alsaaod *et al.*, 2015 [3]
Horse	Lameness	3.9 °C, 5.2 °C, 3.2 °C and 3.6 °C change in anterior, posterior, lateral and sole region of hoof	Rodriguez *et al.*, 2016 [29]
Buffaloes	Hoof lesion	0.72 °C change in surface temperature of hoof	Siddalingaiah *et al.*, 2022 [36]

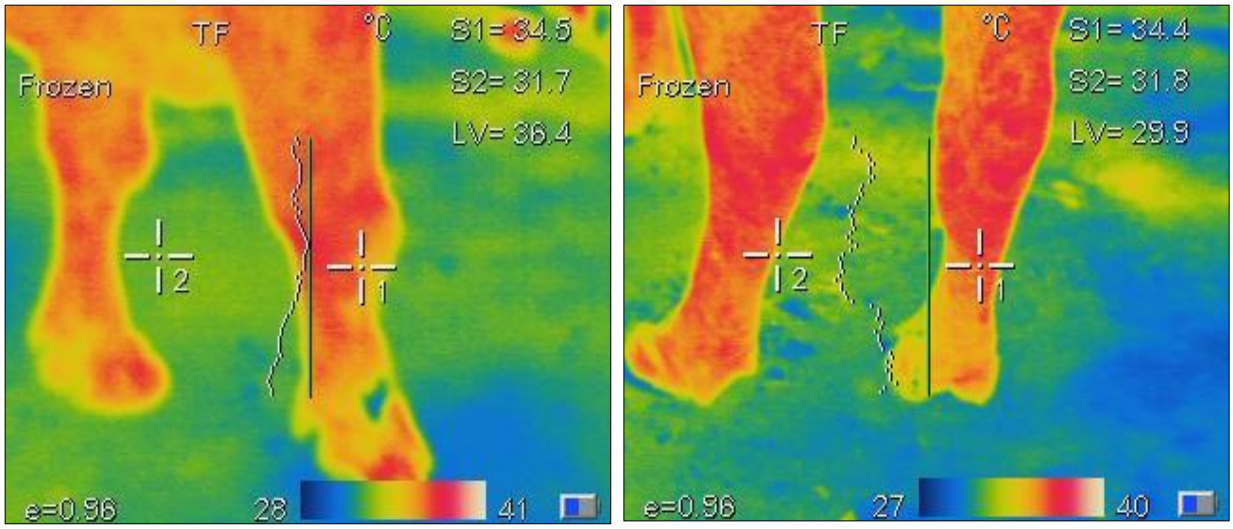

Fig 1: Infrared thermography image of the front and rear foot

Foot Lesions

Thermography is a non-contact method for early detection of foot and limb disorders in cattle by examining the temperature of the claw. Temperature is mainly examined at lateral aspects of the hind limbs at the metatarsal joint, mid tarsus and the abaxial aspect of claw horn capsule. The affected limb has more temperature as compared to normal limbs. Increased temperatures at the coronary band correspond to an increased incidence of sole ulcers (Kroustallas *et al.*, 2021) [18]. The local skin surface temperature increases in case of elevated metabolic activity and inflammatory conditions (Stewart *et al.*, 2007) [38]. IR thermography may also detect digital lesions such as dermatitis of dairy cows with high sensitivity and specificity (Alsaaod *et al.*, 2014) [2]. The measurement of foot temperature in early lactation may be useful for monitoring the hoof health problem. The radiated temperature measurement at the coronary band in cows without foot lesions have been demonstrated that there was no significant difference in surface temperature between left and right hind limbs but there was a significant difference in temperature when these limbs were affected by foot lesion (Oikonomou *et al.*, 2014) [25]. IR thermography detects elevated temperature

of the foot which is associated with foot lesions and claw abnormities without clinical inspection of the foot (Wood *et al.,* 2015) [46]. Results suggested a significantly higher foot temperature at the point of lesion identification. Thermography also monitors elevated temperature of the coronary band. The temperature distribution patterns may be used as a potential detector for sole haemorrhages in the lesions (Rainwater-Lovett *et al.,* 2009) [27]. Therefore, a low-cost infrared thermometer may be used to monitor claw temperatures of individual cows within herds.

IR thermogram, by detecting temperature on hoof (coronary band) and claws in dairy cows and relationship with visual abnormalities of the hooves used as an indicator of laminitis (Nikkhah *et al.,* 2005) [23]. IRT is able to detect hoof lesions associated with lameness by assess the changes in coronary band and hoof skin surface temperature (LokeshBabu *et al*., 2022) [21]. IRT may be useful for early diagnosis of laminitis particularly in earlier stage of lactation. Alsaaod and Buscher (2012) [1] found that a significant difference in temperature of the coronary band between cows with lesions and cows without lesions.

Detection of Lameness in Dairy Cows

Lameness in dairy animal is one of the most significant challenges of dairy cow because it affects animal welfare, causes pain, decline milk production and reproduction (Flower and Weary, 2009) [11]. Hoof disease can either be caused by infection, inflammation of the toe, with the development of digital dermatitis, necrobacillosis, and thymomas contributing to the development of lameness, necrosis of toe, white line disease, or a foot ulcer (Huxley *et al.,* 2012) [15]. Early detection of impairment of gait is important, locomotion score for successful treatment and reducing the overall severity of the disease (Alsaaod *et al*., 2014) [2]. The most common method for detection of lameness is visual inspection, which uses a locomotion score of animal, locomotion score has five levels 0 to 5, whereas score 0 corresponds to no lesion; score 1 corresponds to a hyperemic area with erect pili, score of 2 corresponds to a moist, exudative, and hyperemic area with intact epidermis, score of 3 corresponds to an exudative area, exposed corium, with no signs of healing; a score of 4 corresponds to an exposed corium, but in the process of healing, dried-up lesion; and a score of 5 corresponds to a dark brown scab, completely or almost completely healed lesion (Sprecher *et al.,* 1997; Haskell *et al*., 2006) [37, 13]. But now a day the use of infrared thermography as a non-invasive and safe diagnostic tool to detect lameness. The infrared technology helps to detect the increased temperature of localized areas characterised by inflammation.

Routine Claw Management

Functional claw trimming in dairy cows is performed as a routine management procedure to prevent the development of claw disorders by maintaining the balance between lateral and medial claws and treating lesions if necessary (Sadiq *et al*., 2020) [31]. In cattle, thermography was used to evaluate the effect of routine claw trimming in cows housed in shed before and after claw trimming (Van der Tol *et al.,* 2002, 2004) [43-44]. Thermography measures the temperature difference of coronary band and skin to elucidate the effect of claw trimming by measuring claw temperature. Decrease in superficial temperature between the medial and lateral claws of the hind feet was observed after claw trimming (Alsaaod *et al.,* 2015) [3]. Before claw trimming, the surface temperature of the lateral claws of the hind feet was significantly higher than that of medial claws, whereas such difference was not evident for the claws of the front feet. As a result, the attempt to equalize the weight bearing hind feet by preventive claw trimming is accompanied by a reduction in temperature differences between the hind claws that is measurable with thermography.

Joint Disorders

The affected limb had a higher temperature at the metatarso-phalangeal joint in all lateral, medial, plantar and dorsal projections as compared to healthy limb. The thermography identifies the inflammation and provides supportive evidence for using it as a tool for localisation of the site of inflammation.

Internal and External Factors

Thermography is an extremely sensitive indicator of variations in heat patterns. For this reason, thermography images must be performed under controlled environmental conditions. Internal and external influences can alter the dynamics of blood flow and temperature regulation. There may be individual animal variations that change at different times of the day. One approach to minimize individual animal's variation is to report data of scanning images as a difference between affected and healthy anatomical structures to define the consistency of abnormality (Pearson *et al.,* 2015) [26]. Several factor that affect the variability of infrared data such as ambient temperature, environmental condition, air flow, sunlight and humidity (Alsaaod *et al.,* 2015; Roy *et al.,* 2020) [3, 30]. In addition, hair length and the distance between lens and claw may have an impact on the reliability of thermal images. Ideally, the ambient temperature should be within the thermal neutral zone and without exposure to any direct sunlight or detectable airflow in a closed room. A chosen model corrected for the effect of ambient temperature improves the accuracy for measuring temperature. Before scanning, the claws must be clean and dry. If the feet are soiled then this has an effect both on surface temperature and emissivity value of the measured surface (Rainwater-Lovett *et al.,* 2009) [27]. Hair has been shown to be an effective insulator by blocking heat emissions from the skin (Turner, 1991) [41]. Foot temperature measured by thermography is strongly and positively associated with ambient temperature.

Comparison of IRT with other imaging techniques (Radiography and ultrasonography)

Radiography usually evaluates contrast of tissues to determine bone, ligament, tendon and cartilage injuries (Li *et al*., 2003) [20]. Most of the changes in bones are usually permanent and they are difficult to detect, especially chronic change, is the reason for pain and lameness. Basically, IRT detects heat at the site of inflammation, which commonly involves pain (Chen *et al.,* 2018) [8]. Therefore if the radiographic change is linked to inflammation, only then IRT will be useful for finding out the possible cause. Ultrasonography is compute imaging method in the *evaluation* of a palpable superficial soft-*tissue* mass (Jacobson *et al.,* 2022) [16].

Factors affecting IRT on hoof surface temperature

In general, increase in the distance from the object to position

of infrared camera will reduce the temperature of object (Faye *et al.*, 2016) [10]. Convective heat loss will be increase due to high wind, causing alteration in surface body temperature in animal (Schutz *et al.*, 2010) [35]. Animal with dark coat colour absorbs more solar radiation and animal with light coat colour absorbed less solar radiation resulting in variation in body surface temperature (Stuart *et al*., 2017; Anzures-Olvera *et al.*, 2019) [40, 4]. IRT is a non-invasive diagnostic technique used to identifying temperature change in animal body (Eddy *et al.*, 2001) [9]. Rate of blood flow and tissue metabolism affect the extremities and skin surface temperature (Berry *et al*., 2003) [5]. Therefore an amount of heat radiated, increased or decreased blood supply to extremities can be identified by thermal image indicates that there is inflammation or changes in metabolic activity of underlying tissues (Head and Dyson, 2001) [14].

Conclusion

Early detection of lameness in cattle and buffalo using IR thermography has gained interest due to non-invasive, non-contact, safe and rapid screening technique. It can be used automatically within a long-term monitoring program. Thermography may not depict specific pathology but it measures changes in temperature in the localized area of inflammation, injury and increased metabolism. Sensitivity assists with the diagnosis of foot lesions before the animal shows signs of pain, such as lameness. When thermography is used for detection, it is very important to consider the environmental conditions and animal individuality.

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