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A review on utilization of infrared thermography in cattle production

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Abstract

Thermal imaging is 'real-time' as it permits very fast scanning of the objects. Infrared thermography (IRT) is a noninvasive technology that provides real-time thermal data. Heat detected from the body is measured by IRT and displayed as a temperature distribution image. Each pixel in radiometric thermal image represents a temperature measurement that can be monitored, recorded and analyzed. Its uses in the livestock sector, principally in bovine include early identification of inflammatory condition as in case of mastitis, lameness and bovine respiratory disease virus; determination of the appropriateness of milking equipment, assessment of animal welfare concerns such as tail docking. This review mainly focuses on the veterinary aspects of the thermal imaging and its uses in the veterinary field.

Keywords: Animal welfare, IRT, lameness, mastitis, thermal image.

Introduction

Infrared thermography; is an example of a visualization technique that can be used in many different areas of science. Infrared thermography (IRT) is a safe, simple, non-contact, non-invasive disease diagnostics technique with high accuracy and effectiveness in the field of veterinary medicine. The infrared thermographic method has found abundant applications largely to industrial and civil engineering (Tran *et al.*, 2023) ^[51], military and police patrolling (Kristo, 2016) ^[26], different rescue operation as well as biology (Harrap *et al.*, 2018) ^[19], ecology (Still *et al.*, 2019) ^[48] and human medicine (Kumar *et al.*, 2022) ^[27]. For the assessment of patho-physiological conditions various invasive methods like rectal temperature measurement, blood collection, respiration, heart and pulse rate measurement are commonly used. These invasive methods require adequate laboratory diagnostic resources and significant time also for reliable result. But Infrared thermography technique can be used very efficaciously in prediction and detection of disease, in research, and in other applications in the field of veterinary within due time (McManus *et al.*, 2022) ^[35-36]. In veterinary practice infrared thermography can be used by following different ways:

- **Diagnostic tool:** IRT becomes a physiological imaging method. The difference of 1 °C between two anatomically symmetric regions indicates inflammation.
- **Physical examination:** The possibilities of physical examination thermography can be used to determine doubtful areas where the heat is increased or decreased;
- **Routine monitoring programs:** Animals are monitored on a routine basis weekly. It can be used to detect subclinical problems, as clinical signs occur few days after thermographic changes.

Discovery and background of Infrared thermography

In 1800 British astronomer Sir William Herschel discovered Infrared radiation (IR); he conducted an experimentation evaluating the difference in temperature between the colors in the visible spectrum and found that an invisible radiation in the spectrum lower in energy than the red light. This radiation is termed as infrared radiation; this infrared word comes from the Latin word infra that means below and the English word red. These radiations are that part of the electromagnetic spectrum that is closely adjacent to the red light of approximately. 760 nm on the long-wave side of the visible spectrum. The infrared spectrum is usually divided into near, mid, and far infrared (Sangwan and Balhara, 2022) ^[44]. Near-

Infrared (NIR) begins just beyond the red portion of the spectrum at 0.7 micrometers to about 3 micrometers. The mid-infrared, consisting of wavelengths from around 3-15 micrometers, contains the region of the spectrum also known as thermal infrared (Figure 1). On the basis of fundamental physics, every object at any given absolute temperature above 0 Kelvin (-273.15°C) emits radiation (Balhara and Sangwan, 2022) [5].

The maximum radiant power that can be emitted by any object depends only on the temperature of the object. Therefore, this emitted radiation is called thermal radiation. We experience infrared radiation every day. The heat that we sunlight, a fire or a radiator is all infrared. The warmer the object, the more infrared radiation it emits.

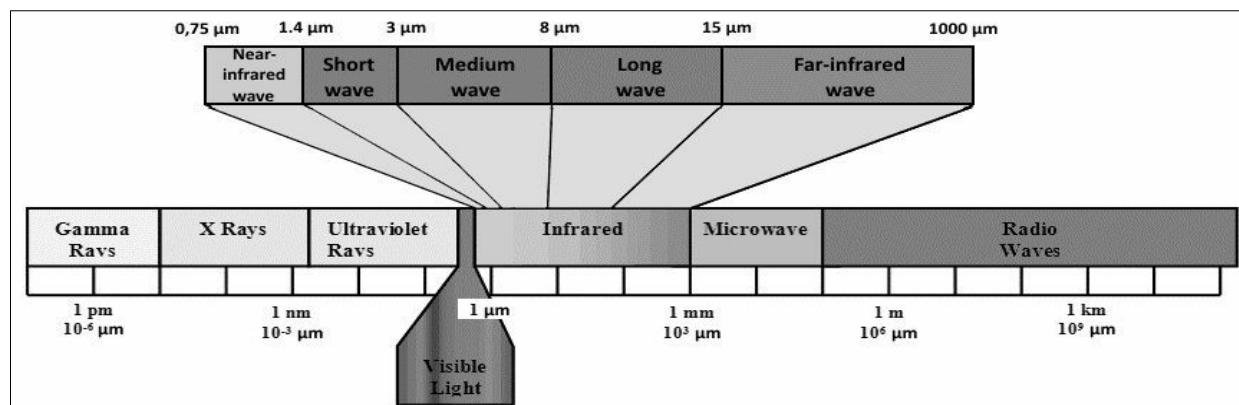


Fig 1: Electromagnetic spectrum showing Infra-red region (From: book “Infrared thermal imaging in animal research, health and welfare”)

Infrared radiation has its origin from the alteration in the movement of electrons (Sangwan and Balhara, 2022) [44]. Radiation Wave type is, Transverse Wave and has its Speed of 3×10^8 m/s also exhibits the property of refraction. Absorption and Reflection characteristics of Infrared Radiation is that they can be absorbed, reflected or transmitted depending on the nature of the surface that it

strikes (Figure 2). Incident radiations are all the radiation that strikes an object from its surroundings, of the total radiation incident on a target, a certain proportion will be absorbed ($W\alpha$), reflected ($W\rho$) and transmitted ($W\tau$).

$$\text{Hence: } W\alpha + W\rho + W\tau = \text{WINCID} = 100\%$$

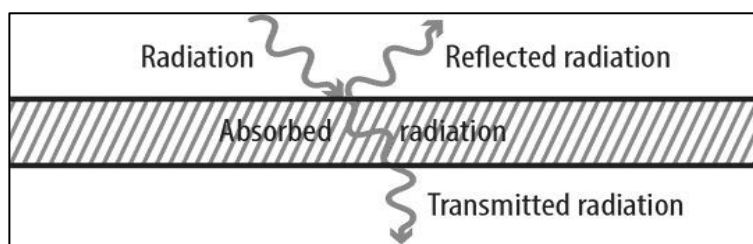


Fig 2: Showing the total IR radiations: Reflected, absorbed and transmitted depending on the nature of the surface that it strikes (From: book “Infrared thermal imaging in animal research, health and welfare”)

The coefficients α , ρ , and τ describe the object's incident energy absorption (α), reflection (ρ), and transmission (τ). Each coefficient can have a value from zero to one, depending on how well an object absorbs, reflects, or transmits incident radiation. For example, if $\rho = 0$, $\tau = 0$, and $\alpha = 1$, then there is no reflected or transmitted radiation, and 100% of incident radiation is absorbed. This is called a perfect blackbody. In the real world there are no objects that are perfect absorbers, reflectors, or transmitters, although some may come very close to one of these properties. Nonetheless, the concept of a perfect blackbody is very important in the science of thermography, because it is the foundation for relating IR radiation to an object's temperature. Fundamentally, a perfect blackbody is a perfect absorber and emitter of radiant energy. This concept is stated mathematically as Kirchhoff's Law. The radiative properties of a body are denoted by the symbol ϵ , the emittance or emissivity of the body. Kirchhoff's law states that $\alpha = \epsilon$, and since both values vary with the radiation wavelength, the formula can take the form

$$\alpha(\lambda) = \epsilon(\lambda)$$

where λ denotes the wavelength. The total radiation law can thus take the mathematical form $1 = \epsilon + \rho + \tau$, which for an opaque body ($\tau = 0$) can be simplified to $1 = \epsilon + \rho$ or $\rho = 1 - \epsilon$ (i.e., reflection = 1 – emissivity). Since a perfect blackbody is a perfect absorber,

$$\rho = 0 \text{ and } \epsilon = 1.$$

The radiative properties of a perfect blackbody can also be described mathematically by Planck's Law. Since this has a complex mathematical formula, and is a function of temperature and radiation wavelength, a blackbody's radiative properties are usually shown as a series of curves. These curves show the radiation per wavelength unit and area unit, called the spectral radiant emittance of the blackbody. The higher the temperature, the more intense the emitted radiation. However, each emittance curve has a

distinct maximum value at a certain wavelength. This maximum can be calculated from Wien's displacement law,

$$\lambda_{\max} = 2898/T$$

where T is the absolute temperature of the blackbody, measured in Kelvin (K), and $\lambda_{\max}$ is the wavelength at the maximum intensity. Using blackbody emittance curves, one can find that an object at 30°C has a maximum near 10 μ m, whereas an object at 1000 °C has a radiant intensity with a maximum of near 2.3 μ m. The latter has a maximum spectral radiant emittance about 1400 times higher than a blackbody at 30°C, with a considerable portion of the radiation in the visible spectrum. From Planck's law, the total radiated energy from a blackbody can be calculated. This is expressed by a formula known as the Stefan-Boltzmann law,

$$W = \varepsilon \sigma A T^4 \text{ (W/m}^2\text{)}$$

where σ is the Stefan-Boltzmann's constant (5.67×10^{-8} W/m² K⁴), A is the area of surface.

As a rule of thumb, the effective body surface is 1m², and radiates about 0.5kW—a substantial heat loss. The equations described in this section provide important relationships between emitted radiation and temperature of a perfect blackbody. Since most objects of interest to thermographers are not perfect blackbodies, there needs to be some way for an IR camera to graph the temperature of a “normal” object.

For real targets, we must always consider that radiation from two sources exit the object, first is radiation emitted from the object itself (W_{ε}) and reflected (W_{ρ}) from the surroundings as expressed by the given formula:

$$W_{\rho} + W_{\varepsilon} = W_{\text{EXIT}} = 100\%$$

Here ε , is emissivity

Emissivity is the ratio of the radiation emitted by a real body, compared to the radiation emitted by a Blackbody, both at the same temperature, and at the same wavelength.

$$\varepsilon = W_{\text{RB}}/W_{\text{BB}}$$

where W_{RB} is the real body radiation and W_{BB} is the black body radiation.

Hence infra-red thermography may be defined as the science of acquisition and analysis of thermal information from non-contact thermal imaging devices. Infrared thermography is the art of transforming an infrared image into a radiometric one, which allows temperature values to be read from the image. So every pixel in the radiometric image is in fact a temperature measurement. In order to do this, complex algorithms are incorporated into the thermal imaging camera.

Infrared thermal camera

Thermal cameras capture infrared energy (heat) and use that energy to create images through digital or analog video outputs. The camera is made up of a lens, a thermal sensor, processing electronics, and a mechanical housing. Infrared energy (A) coming from an object is focused by the optics (B) onto an infrared detector (C). The detector sends the information to sensor electronics (D) for image processing. The electronics translate the data coming from the detector into an image (E) that can be viewed in the viewfinder or on a standard video monitor or LCD screen (Balhara, 2022) (Fig. 3).

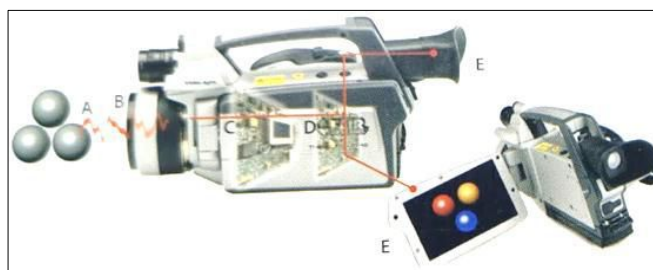


Fig 3: Thermal camera functioning (From: book “Infrared thermal imaging in animal research, health and welfare)

It is easy to operate the infrared camera and has very less chances of injury to animal and human (Westermann *et al.*, 2013) ^[52]. Infrared thermography was initially developed for army and engineering purposes. The first electronic infrared camera was developed by the Germany army and used during the Second World War on tanks for night vision.

Role of IRT in measurement of skin surface temperature in bovines

Thermographic evaluation of temperature distribution within the examined skin surface is useful in quick, real-time non-invasive judgment about the variation in temperature. Thermal cameras capture infrared energy (heat) and use that energy to create images through digital or analog video out puts. Hair is effective insulator of heat;

therefore, it is necessary to remove it to obtain reliable measurement of skin temperature in case the animal has high hair density or involves organs with high density of hair. IRT play significant role in the bovine diagnostics sector by means of measurement of skin surface temperature (Figure 4). IRT is supportive in early detection of mastitis (Machado *et al.*, 2021) ^[32], determination of the correctness of machine milking (Alejandro *et al.*, 2014) ^[2], bovine respiratory viral disease (Lowe *et al.*, 2019) ^[31], lameness (Alsaod *et al.*, 2015); evaluation of productivity, including of heat and methane production (Jabbi *et al.*, 2022) and feed efficiency (Lage *et al.*, 2020) ^[28], assessment of scrotal temperature for fertility traits (Yadav *et al.*, 2019) assessment of animal welfare issues such as tail docking sensitivity (Talled *et al.*, 2019) etc.

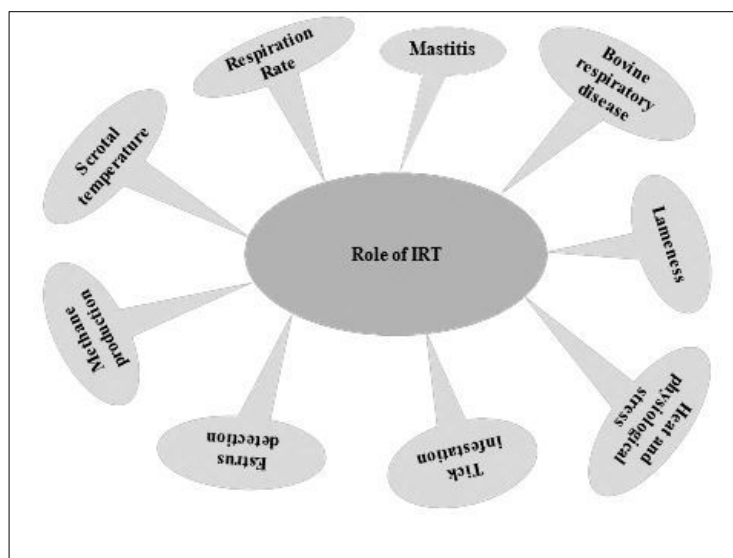


Fig 4: Role of Infrared Thermography

Scrotal temperature: it is important parameter for evaluation of breeding soundness of bull. More number of morphologically normal spermatozoa is required for proper reproductive function for artificial or natural insemination. Change in testicular temperature leads to reduced sperm production, alteration in sperm motility and change in percentage of morphologically abnormal sperm (Indriastupi *et al.*, 2020). Since the 80s, infrared thermography a noninvasive, noncontact technique has been used to evaluate the temperature of the scrotal skin surface in bulls for the examination or comparison of temperature distribution in clinically normal bulls and bulls with testicular abnormalities (De Ruediger *et al.*, 2016, Kastelic, 2014) ^[11, 24]. Preceding studies had shown that the IRT has been used as a tool in the evaluation of breeding soundness in male animals (Menegassi *et al.*, 2018) ^[37]. It has high sensitivity in determining temperature differences across the skin surface including the scrotal surface temperature (Belay *et al.*, 2016) ^[7]. A thermal image encompassing infrared emissions could be used to assess scrotal thermoregulation in bull (De Ruediger *et al.*, 2016) ^[11]. The surface temperature of the scrotum is highly correlated with deep testicular temperature (Kastelic, 2014) ^[24] and the infrared temperature thermograms provide accurate information about testicular thermoregulation (Indriastuti *et al.*, 2020; De Ruediger *et al.*, 2016; Menegassi *et al.*, 2018) ^[22, 11, 37]. It has proven that under normal conditions, scrotal surface temperature is 5-6°C lower than abdominal temperature (Menegassi *et al.*, 2018; Junior *et al.*, 2015) ^[37] and there is a positive top-to-bottom gradient on scrotum - top warmer than the bottom (Kastelic and Rizzoto, 2021) ^[25] and it could be because the scrotum is vascularized from the top to the bottom.

Core body temperature: The core body temperature is related to the body's internal temperature and it may evaluate from the internal organs, the thorax, the abdomen, central nervous system. Normally mammals have an internal body temperature between 36.5 °C to 39.5° C and this temperature is comparatively constant. The core body temperature is regulated mainly by reflexes in the body, which is an impulsive motor pattern that the spinal cord or the extended marrow triggers as a respond to a specific sensory stimulus. Core body temperature is an accepted

indicator of normal health or illness in animals. Homeothermic animals, under standard physiological conditions, are capable to continue a constant body temperature independently from adjacent environmental temperature. The measurements of internal body temperature play an important role in clinical examination of animal. Various methods are used for assessing core body temperature, by approaching through the rectum (Farrar *et al.*, 2020) ^[12], rumen (Lees *et al.*, 2019) ^[29], abdominal cavity (Giro *et al.*, 2019) ^[16] and tympanic membrane of the ear (Schmid *et al.*, 2021) ^[46]. The use of rectal thermometer is a common method and more standardized practice used by veterinarians and farmers for the evaluation of internal body temperature, although this method has some limitations (Kang *et al.*, 2022) ^[23]. Usually the rectal temperature obtained by inserting rectal thermometer can be subjective to the presence of fecal material, it can cause stress to animal and may be harmful also and it can be difficult in restless animals (Hall, 2017; Opersteny *et al.*, 2017) ^[18, 40]. Areas of the eye, specifically around the inner corner or the region of lacrimal gland, have large capillary network that respond to alterations in flow of blood resulting in change in temperature (Lokesh Babu *et al.*, 2018) ^[30] possibly because the proximity of eyes to the thermosensitive site of hypothalamic, which decreases lag time in response. Cows have been reported to have approximately 2°C lower reading of ocular surface temperature as compared to rectal temperature (Lokesh Babu *et al.*, 2018) ^[30]. McManus *et al.* (2022) ^[35-36] and Hoffmann *et al.* (2013) ^[20] reported that the surface temperature of the orbital region can be used to measure the rectal temperature in bovine as an indicator of core body temperature. Likewise, Barros *et al.* (2016) ^[6] conclude that the maximum temperature of the orbital area revealed highest correlation (0.58, $P < 0.0001$) to the rectal temperature in buffalo bulls.

Heat and physiological stress: body temperature and rate of respiration are the main physiological parameters which are mainly used for the assessment of heat tolerance and adaptability in animals (Costa *et al.*, 2015) ^[10]. Nevertheless, proper restraining is required for the evaluation of these parameters and which can causes handling stress. Thus, infrared thermography; a noninvasive and remote sampling

tool can be used for the detection of animal stress. Stressful environmental condition correlates with change in body temperature that leads to change in blood flow and this change in blood flow assessed by infrared thermography. Therefore the temperature at the particular region like eye, ear, dewlap, flank, rump, udder and feet may be used for the prediction of physiological parameter and stress in bovines. (Gabbi *et al.*, 2022, Idris *et al.*, 2021)^[14, 21].

Mastitis: is a disease of dairy cow having persistent inflammatory condition in udder parenchyma that is responsible for huge economic losses for the dairy farmers. It is necessary to detect mastitis in early stage because it responsible for decrease in milk production, milk quality and increase in labor cost, medicine cost. Among various diagnostic test for mastitis like external examination of udder, pH and color milk, somatic cell count, California mastitis test, microbial culture test, infrared thermography has got a potential application (Sathiyabarathi *et al.*, 2016)^[45]. Machado *et al.*, 2021)^[32] studied daily variation in the udder surface temperature of Holstein-Friesian dairy cows during different stage of lactation by infrared thermography for the detection of mastitis. They conclude that infrared thermography shows potential in its application as an early detection method for mastitis. Machado *et al.* (2021)^[32] conducted an experiment using infrared thermography to evaluate subclinical mastitis and compare the results with California Mastitis Test and Somatic cell count in Brown Swiss dairy cows. The authors found that the udder skin surface temperature was positively correlated with the California Mastitis Test score so they concluded that the infrared thermography can be used as a quick and noninvasive tool for the detection of subclinical mastitis by measuring udder skin surface temperature.

Bovine respiratory disease (BRD): is the most common disease affecting bovine in all over the world and has significant economic impact in dairy farming. It is usually caused by variety of viral (Adenovirus, Bovine Viral Diarrhea Virus) and bacterial (*Pasteurella multocida*, *Mycoplasma bovis*) agents. Lowe *et al.* (2019)^[31] conducted a study to explore the use of infrared thermography in early diagnosis of bovine respiratory disease in weaned calves. They revealed that infrared thermography scans of the eye area in calves were effective as an early indicator of bovine

respiratory disease. During bacterial infection there is increase in body temperature and this increased body temperature is evaluated by infrared thermal camera. The observation that radiated heat increment can serve as an early indicator of disease conditions is perhaps logical. Lameness in bovines is one of the most serious welfare issues but it is over-looked in dairy industry. According to Schulz *et al.* (2016)^[47] duration of laying bouts and locomotion scoring may be used diagnosis of lameness in dairy cows. Traditional methods for the diagnosis of lameness are change in locomotion of animal and lifting the foot in a claw trimming chute. Basically, these are time consuming approaches so infrared thermography is used as non-invasive, non-contact diagnostic tool (Ramirez-GarciaLuna *et al.*, 2022)^[42]. The inflammation or injury accompanied with limb lesions have change in blood flow that leads to change in skin surface temperature and the thermographs can be used to recognize these thermal abnormalities in animals (Alsaod *et al.*, 2015)^[3]. The healthy hoof has lower surface temperature than the hoof with a lesion (Bobic *et al.*, 2017)^[8]. The coronary band and the skin surrounding this region has been used for the measurement of foot surface temperature because; (a) the coronary band has very much blood supply so any foot lesion or inflammation may be recognized through raised coronary band temperature, (b) during examination thermograph of coronary band and surrounding skin can be obtained with minimum stress and without physical contact of animal. In 2018, Ganesella *et al.* 2018^[15] conducted an experiment to investigate the potential role of using infrared thermography for detection of hoof lesions. The thermographs were analysed before and after claw trimming with respect to the temperature of skin and coronary band, and there was difference in temperature between skin and coronary band of the hind limbs. The authors accomplished that the infrared thermography may be used for the detection and prevention of hoof lesions. Wood *et al.* (2015)^[53] conducted an experiment whether infrared thermography could be used to detect feet with digital dermatitis. They revealed that there is increase in feet temperature related to feet having pathological lesions and suggested that thermography could be used as a monitoring tool for limb and hoof lesion. As a summary these findings may be tabulated as follow:

Table 1: Use of various infrared techniques for diagnosing lameness in dairy animals.

Type of animals	Type of infrared camera	Type of foot lesion observed	Area of animal	Author
Dairy cows	FLIR Inframetric	Healthy hooves	Hooves	Ganesella <i>et al.</i> , 2018 ^[15]
Cattle	TIR1 imager	Foot-and-mouth disease	Feet and Eye	Lokesh Babu <i>et al.</i> , 2018 ^[30]
Dairy cows	Ti25 Thermal Imager	Digital dermatitis	Foot	Alsaod <i>et al.</i> , 2015 ^[3]
Dairy cows	FLIR and 7	Sole ulcer, inter- digital hyperplasia, dermatitis digitalis	Hooves	Bobic <i>et al.</i> , 2017 ^[8]

Methane production: Emission of methane from livestock is through enteric fermentation and manure management. Total 8% of metabolic energy is lost through methane production in ruminant animals. Hence, by improving the efficiency of feed utilization by ruminant animals makes livestock industry more economic and environmentally sustainable. Calculation of residual feed intake is an important parameter for the assessment of feed efficiency but it is costly and laborious to measure residual feed intake

(Fitzsimons *et al.*, 2014)^[13]. Therefore, livestock industry requires an alternate method for the assessment of feed efficiency. Infrared thermography can be effectively used for evaluating methane and heat production (Gabbi *et al.*, 2022)^[14]. The authors conducted a trail with four lactating Holstein dairy cattle, the gas was measured by open-circuit indirect calorimetry system and ThermoCamTM SC2000; FLIR Systems, infrared camera was used for thermography. The images were taken from fore feet, left side of rump, left

and right flank area. In ruminant heat production and energy loss is correlated with methane production during microbial fermentative process (Morgavi *et al.*, 2023) ^[38]. The skin surface temperature depends on the body's internal circulatory activities and the tissue metabolic rate. So, the differences in the skin surface temperature captured by infrared thermography can be hypothetically used to measure the heat production and methane emission in ruminants (Guadagnin *et al.*, 2023) ^[17].

Estrus detection: incompetent detection of estrus in bovine causes lessening in reproductive efficiency and milk production where artificial insemination is practice (Reith and Hoy 2018) ^[43]. Several methods can be used for the detection of estrous *viz.* mounting activity, visual observation, variations in body temperature, alteration in vaginal mucus membrane. For measuring vaginal or rectal temperature and using implant within reproductive organs animals need to be restrain and this may cause animal stress that may change in body temperature. So, infrared thermography is an alternate and safe diagnostic technique with minimal discomfort (Racewicz *et al.*, 2018) ^[41]. Talukder *et al.* (2014) ^[49] reported that infrared thermography has potential in estrus detection when image was taken from vulval and muzzle surface.

Tick infestation: ticks are most significant ectoparasites of livestock that are accountable for large amount of economic losses either blood sucking parasite or a vector of toxin and pathogens. Heavy load of tick infestation leads to anemia, reduced body weight, and poor quality of hides (Naseem *et al.*, 2023) ^[39]. Usually, there are temperature variations between the surface of the animal and the surface of the parasite. Thus, this temperature variation is used to detect external parasite load in animals using infrared thermal camera (Cortivo *et al.*, 2016) ^[9].

Conclusion

Infrared thermography (IRT) is a new emerging, non-invasive and lowcost technique of thermal profile visualization. Each living and non-living object on earth produce radiation in the infrared part of the light spectrum and the intensity of these radiation depends on the temperature of its surface. IRT of animals comprises the measurement of the body surface temperature. In warm-blooded animals, the temperature values obtained in IRT depend on the impact of animal's thermoregulatory response because the change in body temperature depends on change in blood flow. In addition to the volume of blood perfusion, skin temperature depends on the intensity of tissue metabolism, the type and color of the hair coat, and the thickness of adipose tissue. Thermographic technique has found abundant advantages not only in military and industries, but also in human and veterinary medicine, predominantly for diagnostic purposes. The thermographic approach can be effectively used to evaluate the pathophysiological condition of different systems of animals. The infrared thermography has been used as a tool in the evaluation of breeding soundness in male animals and assessment of health conditions in dairy cattle.

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