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Thermal imagery for monitoring livestocks

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Abstract

Infrared thermography is a method which detects infrared energy emitted from an object and then converts it to temperature and displays the image of temperature distribution. That image is called a thermograph or thermogram. The image appears in a colour palette. Recently the thermal imagery has been used in wide category of veterinary sciences like diagnosis of foot and leg problems in cattle/ horses (Schmidt*et al.*, 2003), assessment of scrotal temperatures as a measure of fertility in bulls and rams (Gabor *et al.*, 1998), evaluating the heat stress in dairy cattle (White *et al.*, 2006), assessment of body condition score (Halachmi*etal.*, 2013), appraisal of meat quality (Tong *et al.*, 1995), assessment of productivity, including of heat and methane production (Montanholi*et al.*, 2008), Assessment of feed efficiency (Montanholi*et al.*, 2009), pregnancy detection (Hilsberg*et al.*, 1997) and to differentiate between pregnancy and pseudopregnancy (Durrant*et al.*, 2006). Using thermal imagery tool has many advantages in animal management *viz.* non-invasive and non-destructive, fast, accurate temperature measurements, easy to install, capable of catching moving targets and measuring temperature in inaccessible or hazardous areas. However, factors such as environmental variables, surface texture and condition, skin colour, age of animals are given due consideration while interpreting the results.

Key words- Thermal imaging, animal heath and livestocks

INTRODUCTION

Livestock is an important asset to farmers in terms of livelihood, to scientists in terms of research and overall to a nation in terms of GDP. Therefore it becomes an important for scientists and farmers to have more accurate knowledge of their animal's health. Physiological parameters need to be precisely monitored continuously in order to detect even the smallest changes, which will reflect the health and well-being of farm animals. Among all the parameters that are sensitive to the smallest changes in domestic animals, temperature is the most important indicator of animal health as it is related to a number of important varied functions such as nutrition, reproduction, activity, stress response and preservation of the health (Sellier *etal.*, 2014). Temperature though is very easy to monitor than other parameters but becomes difficult when we have to monitor it continuously to detect the tiniest change in temperature. Even the relatively simple task of taking the temperature through rectal route by a clinical thermometer requires animal restraint, which this is likely to cause stress responseand hence stress-induced hyperthermia.This decreases the accurate assessment of body temperature (Torrao *et al*., 2011).

To overcome these difficulties modern techniques like thermal imaging are introduced for monitoring of the animals. Thermal imaging is a time-saving technique and it can detect symmetric and asymmetric temperature gradients of surface areas in animals. The skin surface acts as a cooling system radiating heat and hence enables comparatively accurate measurement of temperature gradients through thermal imaging (Purohit *et al*., 1985). Infrared temperature measurement equipment (IRTME) is gaining popularity over time, as a diagnostic tool for evaluating humanand animal health. It has a relative advantage of reducing animal stress and also disease spread as anautomatic surveillance system and by a quick assessment of skin temperatures without the need for restraint or contact (Soerensen *et al*.,2015). This method detects the infrared energy emitted from source, converts it to temperature and then displays an image of distribution of temperature; called as thermograph or thermogram. The image appears in a colour palette showing blue for lowtemperature and white for maximumtemperature.

History

The infrared thermography has an old history since Sir William Hershel discovered infrared radiation back in 1800.The first infrared camera was developed by German army and it was used during the Second World War.Some studies during 1950-60 demonstrated that infrared cameras could visualise early stages of breast cancer as the tumour cells draw more blood, and thus creating a hot area in the thermal image(Luzi *et al*.,2013). First company to introduce an infrared camera commercially was the Barnes in America. It was followed a few years later by the Swedish company AGA which introduced an infrared camera with the brand name “Thermovision”.In the starting years, industrial andmedical cameras were heavy. The cameras weighed around 20kg and the processor weighed 18kg. In addition liquid nitrogen was required to keep the infrared detector cool and needed refilling after every two hours. Hughes Aircraft Corporation manufacturedsome cameras with cryogenic cooling, which used argon gas to cool the sensor.The first of portable cameras were introduced in the market in the late 1970s by a Swedish company named AGA.Thermoelectric cooled sensors with Peltier cooling were the next step in evolution of thermography. Thus the the portability of the devices was largely improved. In the year 1997, the first camera with an uncooled focal plane array microbolometer sensor was introduced in the market, which was a huge step in the infrared market as it had all the advantages required for infrared cameras (Luzi *et al.*, 2013).

Principle of thermal camera

The principle of thermal imagery is that every object with a surface temperature above absolute zero will emit anelectromagnetic radiation. The electromagnetic radiation can be characterised by two distinct features*viz.* wavelength (λ)and intensity (Q). Both ofthese features are related by simple physical laws to the surface temperature of an object (Holman, 1986). This made it possible to non-invasively use the intensity and wavelength of radiation emitted by an object to measure the surface temperature of the object. Intensity and wavelength of emitted radiation vary with the surface temperatures of the emitting source.Thus, objects at a particular temperature emit radiationsspread over a range of different wavelengths.

Types of thermal cameras

Cooled thermal imager: Cooled thermal imager is contained in vacuum sealed case and is cryogenically cooled. This type of imagerprovides a superior image quality. However, there are some limitations of this imager that it is bulky and expensive. Time consumed is also more in this case as imager needs time to cool after use so that it can begin working again.

Uncooled thermal imager: This type of imager uses a sensor sensor stabilized at room temperature or operating at ambient temperatures. But the resolution and image quality of this imager are lower than that of the cooled one. In modern practice,we mostly use the uncooled thermal imagers as they are smaller and less costly than the cooled ones. This is a fast operation because imager needs not to be cooled before every operation. It also consumes less power.

Applications

Recently the thermal imagery has been used in a wide category of veterinary applications.

Estrus Detection:

Animals are aggressive and restless when in estrus. So it becomes difficult to restrain the animal for monitoring. The restlessness and aggressiveness may not be always due to estrus some other reasons may also be involved so to get it confirmed whether an animal is in heat or not,the thermographic camera can be used in this case. The vulva of animals is cleaned and imaging is done at least 30 min after that. Same focal distance is maintained for each data collectedby the camera. Thermal images of the vulva are taken using an FLIR ThermoCAM S60 camera (FLIR Systems, Inc., Boston, MA, USA) at time of first standing estrus and 10 days poststanding estrus (diestrus) with the emissivityset at one. Where, emissivity is the ratio of the energy radiated from a surface to that radiated from a blackbody, at a same temperature and wavelength and under the same viewing conditions(Sykes *et al.*, 2012).Frandson *et al.* (2003), used the thermal images of vulva from defined regions of interest and analyzed them for maximum, minimum, and average temperatures using the Thermo- CAM Research Professional 2.7 software (FLIR Systems, Inc.). They calculated the standard deviation of temperatures within regions of interest to analyse variation inthe temperature gradients at each

imaging and thermal imaging differentiated standing estrus from those in diestrus asduring estrus, the blood flow to the vulva increaseddue the influence of increased circulating estradiol from the developing follicles. This increase in blood flow also increasedthe surface area temperature of the vulva. Images were stored in a memory card and then transferred to a computer for analysis.

However, the latest softwares allows the user to obtain temperature at a specific area on the image and calculates the

minimum, maximum, average temperatures and standard deviation for measuring fields. The software considers each pixel within the given shape and calculates standard deviation of each image within a defined shape (Talukder, 2015).

Foot lesion diagnosis:

For the diagnosis of any foot lesions, each animal was moved in the farm crush and three thermal images (ThermaCAM E2, FLIR Systems) were captured from the plantar aspect of each foot at the pastern. The three images were ofuncleaned foot in the standing

position,standing foot after being thoroughly cleaned with a high-pressure hose and dried with a paper towel, andcleaned foot while lifted using the crush.

Each hind foot is lifted,trimmed using the functional foot trimming method to give a gold standard observation of lesion’s presence (Toussaint Raven, 1985),and lesions (Dermal dermatitis, sole haemorrhage, sole ulcer, white line disease, interdigital growth) are recorded. Recordings are to be taken on different days at the same time of day, because the body temperature in cattle exhibits a pronounced circadian rhythm with minimum in the morning and a maximum in the afternoon (Kendall and Webster, 2009).

Digital dermatitis (DD) is a highly infectious skin disease of the foot. Early detection of DD is the primary step towards therapeutic declaration, by rapid treatment and subsequentdrop in infection reservoir within the herd. Clinical evaluation requires lifting each foot using a crush. This is both logistically and economically challenging on a large scale. Locomotion scoring is used to spot developing limb pathologies with no lifting of the foot but DD is often present in the absence of lameness (Laven and Proven, 2000). Infrared thermography (IRT) gives a pictorial illustration of the surface temperature of an object. The difference in emitted heat is reflected by a colour gradient (Purohit and McCoy,1980; Turner *et al.*, 1986). Heat, a cardinal mark of inflammation, is caused by an increase in circulation and tissue metabolism (Head and Dyson, 2001; Van Hoogmoed and Snyder, 2002). Temperature fluctuations can therefore be a potent recognition forthe development of inflammation in tissues. Thermal images can be taken at a distance from the subject, avoiding temperature artefacts allied with capture and confinement (Stewart *et al.*, 2005).

Detection of diseases:*The infrared thermal(IRT) camera can also be used to detect various diseases like:*

Bovine Viral Diarrhea(BVD)

Calves that were positive for Bovine Viral Diarrhea virus (BVDV),were subjected to the infrared thermal camera(IRT). IRT was able to identify body temperature changes consistent with the disease as early as the very first day(Schaefer AL. 2004). Temperature is the most reliable indicator of disease progression; the orbital IRT temperature readings peaked in conjunction with abnormal clinical scores (ie, at that time the clinical signs of disease were most severe). Use of IRT to measure the rate of change in temperature at a specific anatomic site resulted in the detection of BVDVinfected calves before other diagnostic tests yielded positive results or clinical signs of disease were manifest. Thus, IRT can be used as a screening toolfor cattle herds and can identify BVDV-infected animals up to 1 week before the onset of viral shedding. Infected animals can then be isolated from the rest of the herd prior to becominginfectious, which should minimize virus transmission within the herd and decrease the economic impact of the disease.

Bovine Respiratory Disease Complex (BRDC)

Bovine respiratory disease complex is a commonmultifactorial disease, in which various viruses, bacteria, and physiologic and environmental factorscontribute to the pathogenesis. Successful treatment of BRDC is dependenton early disease recognition and appropriate intervention.IRT of theeye is able to identify cattle with BRDC several daysbefore the manifestation of clinical signs of disease at arate comparable to that of the more invasive methodslike rectal temperature and serial blood tests(Schaefer AL. 2007). Additionally, the use of IRT in conjunction with radiofrequencyidentification tags that were applied to each animaland sent a signal to a remote computer whenever theanimal approached the water station in the pen furtherfacilitated detection of cattle in the early stages ofBRDC (Schaefer AL. 2012). Activation of the IRT camera whenever an animalvoluntarily approaches the water station obviatesthe need for the capture and restraint of individualanimals, which makes IRT more appealing, comparedwith other traditional testing methods such as rectaltemperature monitoring or blood sampling. This systemcould potentially allow producers and veterinariansto isolate and treat cattle for BRDC during theearly stages of the disease, which would increase theprobability of treatment success and minimize transmissionof the disease within the herd.

Foot and Mouth disease (FMD)

Cattle are eexperimentally inoculated with FMD virus.It was concluded that IRT, in combination withother traditional rapid diagnostic tests, could be usedto detect FMDV-infected cattle during an outbreak (Rainwater L.K, 2009). Early identification of FMDV infected cattle duringan outbreak will facilitate control and hasten diseaseeradication and recovery. A pen-side screening toolsuch as IRT could be used for selective on-site testingof animals suspected of being infected with FMDV andwould complement the current gold-standard FMDVtesting protocol, which involves virus isolation withconfirmation by PCR assay but PCR and virus isolation are time-consuming andlabour-intensive. Following the establishment of adequatestandard operating protocols, IRT and pen-sidediagnostic tests could be used for early detection ofFMDV-infected animals, which would facilitate quarantineor even preemptive culling.IRT was used to monitor temperatureincreases associated with inflammation at the coronaryband of FMDV infected cattle as the disease progressed,the coronary bandtemperature increased in FMDV infected cattle 24 to48 hours before the appearance of vesicular lesionsand was not affected by floor temperature. (Rainwater*et al.*, 2009). However,an abnormally increased coronary band temperatureis not pathognomonic for FMDV infection and can becaused by other inflammatory processes. Experimentsare currently being conducted in an attempt to identifya specific thermographic signature for animals infectedwith FMDV. In pigs experimentally infected with FMDV, disease progression is positively correlatedwith temperature increases in the extremities as determinedby IRT (Bashiruddin *et al.*, 2006). It is unknownwhether IRT will be able to identify FMD infectedanimals in a field setting where confoundingfactors cannot be controlled as effectively as it did in arigidly controlled laboratory setting.The maximum eye temperature asdetermined by IRT can be used to identify pyrexicanimals because it is not affected by ambient temperatureand may be indicative of the early stages ofdisease caused by FMDV or other pyrexia-inducing viruses(Dunbar *et al.*, and Gloster *et al.*,).Also, an abnormally increased hoof temperaturerelative to other animals within a herd in combinationwith an abnormally increased eye temperature mightbe used as a threshold to identify diseased animals.

Bluetongue virus

The sensitivity and specificity of IRTfor detection of sheep with pyrexia were 85% and97%, respectively(Perez de Diego *et al.*, 2013). It was concluded that the eye temperature asdetermined by IRT was strongly correlated with rectal temperature, which further validated the use of IRTin sheep. Further evaluation ofIRT in sheep in field settings is necessary.

Rabies virus

Rabies is a viral disease of substantial public healthconcern. In the United States, infected wildlife generallyact as vectors for rabies virus and rabies-infectedanimals that develop clinical signs of the disease almostinvariably die. Infrared thermography has beenused to detect raccoons that were in the infectiousstage of rabies disease.The maximumnose temperature of experimentally infected raccoonswith clinical signs of rabies was significantly higherthan that of uninfected raccoons, which allowed theinfectious raccoons to be visually identified in the IRTimages (Dunbar *et al.*, 2006). The increasein nose temperature in rabies-infected raccoons iscaused by an increase in the vascular permeabilityand blood flow to the nasal tissues subsequent tothe release of chemical mediators such as histamine.Because animals in the early stages of rabies do nothave the classic neurologic signs associated with thedisease, IRT detection of abnormally increased nosetemperatures might be used to identify potentially rabidanimals so that they can be managed to reducethe risk of viral transmission. However, an abnormallyincreased nose temperature is not pathognomic forrabies infections, and diagnosis of rabies must be confirmedby standard laboratory techniques.

Tuberculosis

Tuberculosis is a zoonotic bacterial disease thatis transmitted by contact with infected animals or theconsumption of unpasteurized milk or dairy products.Many countries impose strict regulations on the saleand transportation of animals with tuberculosis andthe products produced from those animals to mitigatethe risk of disease transmission. Traditional pre-movementtesting of animals for tuberculosis requiresa minimum of 72 hours to complete, which can beonerous for producers. The current tuberculosis testingprotocol consists of an intra dermal injection of a Mycobacteriumantigen and evaluation of the skin thicknessat the injection site 72 hours later(Johnson*et al*.,2008). In tuberculosis-infectedanimals, a local inflammatory response caused by delayed-type hypersensitivity to the antigen causesan increase in the skin thickness at the injection site.Infrared thermography might significantly shorten thetime required to screen animals for tuberculosis. Incattle that were hypersensitized to either *Mycobacteriumbovis* or *Mycobacterium avium* or not hypersensitizedand then underwent the traditional tuberculosistesting protocol, IRT identified a temperatureincrease associated with swelling or inflammation atthe mycobacterium injection site (Johnson*et al*.,2008). These findings suggest thatIRT may complement or possibly supplant traditionaltesting methods currently used to screen animals fortuberculosis.

Udder health

The region of udder surface "sinus lactifer"can be contoured with the help of the camera software.Sinus lactifer, located at starting just above the teat and centred according to the teat is chosen for thermogram as it expresses even the leastdeviation in temperature of the healthy udder (Barth, 2000, quoted by Hovinen, 2009). Before taking thermograms the cleanliness of udders is to be assessed on a 5-grade scale: 1 – clean, 2 - less than 10% of udder surface covered with litter or manure (unclean), 3 means 10–20% unclean, 4 means 20–50% unclean and 5 means more than 50% unclean. The mean, maximum and minimum temperatures within the couture is measured and analysed by Student t-test.

The 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 (Poikalainen, 2012). The cleanliness of udder surface influences the measurement results, especially the average temperature (Poikalainen, 2012).

Thus we can use IR camera to compare the temperatures of the udder before and after the milking and investigate the possibilities of thermograms applicability for the assessment of milking hygiene.

Pregnancy detection

Restraining an animal for pregnancy diagnosis cause stress to the animal,so thermal cameras can act as a tool for detecting the pregnancy. Pregnant and non-pregnant mares are to be brought into an enclosed barn, and debris should be removed from the coat as it reduces the efficiency of camera.The mares are to be normalized to environmental temperatures in the covered barn for at least 30 min prior to imaging.On every collection day, pregnant and non-pregnant mares should be paired in a manner that a non-pregnant mare will be imaged first, between pregnant mares, and last.The focal distance should besame for allthe data collection between the camera and the mare (Bowers, 2009). The pregnant mare will have a higher flank/abdomen temperature than that of the non-pregnant mare. Theelevated temperatures will appear in white and multiple shades of red on the pregnant mare's flank in a thermogram. The heat signature inside the leg of both mares is emitted from the medial saphenous vein which should not be puzzled with pregnancy. The pregnant mares on average will have a 1.8 ^{O}C higher abdomen/flank temperature than that of the non-pregnant mares, with the highest difference reaching 3.09˚C (S. Bowers 2009). In case of a pregnant and non-pregnant black rhinoceros a difference of 1.7˚C will be found and a bigger difference (4 ^{O}C) between the pregnant and non-pregnant Grevy zebra will be found(Hilsberg S et al (2002).

Lameness

Lameness is a gravesubject in the dairy industry, economically as well as from an animal's welfare perspective.Earlier methods of testing lameness required to restrain the animal and make it stand still for a long period of time which becomes improbable, even during milking. Hence infrared camera can act as a finedeviceto detect lameness. Infraredthermogramtaken from a cow with lameness will show the differences in temperature between the distal and proximal ends of the right limb and of the left limb (Pezeshki *et al.* 2011).If a toe/heel abscess will be present IRT will show a warm area in the digital region suspecting white line disease. (Tarantino, 2013); (E. Valle 2013).

Male fertility

Thermography is used to studythe efficiency of testicular thermoregulation in stallions (Ramires-Neto *et al.*, 2012). Scrotal surface temperature changes in retort to GnRH administration in male alpacas are monitored by thermography (Stelletta *et.al*., 2009). Thermography also helps to assess the testicular biopsies in llamas (Heath *et.al.,* 2002).The reason of taking a thermogram during a GnRH stimulation test is to find out the changes in scrotal surface temperature which helps in assessing the male fertility (Gabor *etal*., 1998; Vencato *et al.*, 2012).A thermogram taken immediately before the GnRH administration and after every 45 minutesor every 15 minutes until 1 hour after GnRH administration shows an increase in scrotal surface temperature in sexually mature bulls (Vencato *et.al.*, 2012).Thus infrared thermography is useful for predicting the number and percentage of live spermatozoa (in association with testicular size and echotexture) (Gabor *et al*., 1998a).IRT is also used for performing GnRH test in young bulls with poor semen(Vencato *etal.*, 2012).

Body Condition Score

Body condition scoring (BCS) estimates mobilization of energy reserves of cattle. The BCS is used as a feed management tool(Gillund *et al*., 2001). BCS influences productivity, reproduction, health and longevity (Dechow *et al*., 2002; Pryce *et al*., 2006). To begin with isolate the animals which are to be examined.The thermal camera can be attached to the barn ceiling, at the exit of the milking parlour. The cows are identified electronically by the weigh station's radio frequency identification (RFID).We have to remove the unwanted objects from the image before analysing it. BSC is then estimated by Matlab software. A thermographic image of an animal is correlated with the contour as in the software. Mean absolute error is calculated (Halachmi *et al.*,2013). The reason why we need a thermal image for comparing with parabola is that if we use normal image and the cow and the background are of same colour there are possibilities of errors and parabola can't be fitted in. The degree of fitness of image with contour gives the body score condition.

Unhealthy milk and meat

Surface temperature distributions of pigs of different age groups and breeds in dissimilar environments aid in recognition of unhealthy pigs. Skin temperature progression at different stages in the course of fever for various diseases can be made. This enablesrevealing of the sick animals former to evidence of clinical symptoms (Soerensen, 2015).

Study of thermogenesisin the neonatal lamb

Lamb mortality is a serious issue which leads to economic losses. Lamb mortality is greatest in triplets (Everett-Hincks et al. 2005), and mortality rates in twin- and triplet-born lambs is greater than in singles, with many of these deaths occurring during the first 3 days of life (Everett Hincks and Dodds 2008). Hypothermia is thechief cause of lamb mortality in the first 3 days of life, particularly in adverse weather conditions. The internal heat generation by non-shivering thermogenesis due to energy derived from brown fat (Alexander and Williams 1968; Symonds and Lomax 1992) and reducing heat loss from the skin surface are important for maintaining core body temperature (Alexander 1978). Infrared thermography has been used as an early and dependablemeans for neonatal monitoring (Abbas and Leonhardt, 2014). Infrared thermography can beused to measure rapid changes in radiated heat (heat loss) froma newborn lamb.

Thus it can be concluded thatthermal imaging is a great tool for monitoring of animals but there are certain conditions under which working of a thermographic camera is affected (Rekant *et al*., 2015). The factors are:

i. Environmental factors like ambient temperature, wind, sunlight, rain, and other weather conditions. Excess of humidity and peak of these environmental factors reduce the efficiency of a thermal camera.
ii. Haired and non-haired skin, hair absorbs some radiated heat and blocks energy from being detected by an infrared camera. So haired skin won't be able to get us proper temperature recording as that of non-haired skin.
iii. Skin colour: In black and white cattle, black areas are generally warmer than adjacent white areas and should not be confused with any inflammatory process.
iv. Age affects ocular temperatures determined by IRT. So as the age of subject increases the efficiency of IRT decreases.
v. Moisture and debris on the subject will also alter the thermographic image and results will be unclear.
vi. Change in humidity also has little effect on IRT readings when room temperature is held constant.
vii. Circadian, infradian, and ultradian rhythms affect body temperature. So it should be noted that if we are taking the thermographic images for a number of days the time of monitoring should be same for everyday.

References:

Bashiruddin, J. B., Mann, J., Finch, R. (2006). Preliminary study of the use of thermal imaging to assess surface temperatures during footand- mouth disease virus infection in cattle, sheep and pigs. In:*Report of the 2006 session of the Research Group of the Standing*

Technical Committee of the European Commission for the Control of Foot-and-Mouth Disease. Rome: Food and Agriculture Organization of the United Nations, 304–308.

Dechow, C.D., Rogers, G.W., Clay, J. S.(2002). Heritability and correlations among body condition score loss, body condition score, production and reproductive performance. *Journal of Dairy Science*, **85**: 3062–3070.

Dunbar, M. R., MacCarthy, K. A. (2006). Use of infrared thermography to detect signs of rabies infection in raccoons (*Procyon lotor*). *Journal ofZoo and Wildlife Medicine*,**37**:518–523.

Gabor, G., Sasser, R.G., Kastelic, J.P., Coulter, G.H., Falkay, G., Mezes, M., Bozo, S., Volgyi-Csik, J., Barny, I., Szasz, F.(1998). Morphologic, endocrine and thermographic measurements of testicles in comparison with semen characteristic in mature Holstein-Friesen breeding bulls. *Animal Reproduction Science*, **51**: 215-224.

Gillund, P., Reksen, O., Grohn, Y.T., Karlberg, K.(2001). Body condition related to ketosis and reproductive performance in Norwegian dairy cows. *Journal of Dairy Science*,**84**: 1390–1396.

Halachmi, Klopcic, M., Polak, P., Roberts, D. J., Bewley, J. M. (2013). Automatic assessment of dairy cattle body condition score using thermal imaging.*Computers and Electronics in Agriculture*. **99**: 35-40.

Johnson, S. R., Dunbar, M. R. (2008). Use of infrared thermography as an alternative method to evaluate the comparative cervical test (CCT) in cattle sensitized to *Mycobacterium bovis* or *M. avium*.In:*Proceedingsof* 112th Annual Meet US Animal Health Association, 101–102.

Pérez de Diego, A. C., Sánchez-Cordón, P. J., Pedrera, M. (2013). Theuse of infrared thermography as a non-invasive method for feverdetection in sheep infected with bluetongue virus. *Veterinary Journal*, **198**:182–186.

Poikalainen, V., Praks, J., Veermäe, I. and Kokin, E. (2012).Infrared temperature patterns of cow's body as an indicator for health control at precision cattle farming *Agronomy Research Biosystem Engineering, Special Issue* **1**: 187-194.

Pryce, J.E., Harris, B.L., Johnson, D.L., Montgomery, W. A.(2006). Body condition score as a candidate trait in the breeding worth dairy index. *New Zeeland Society of Animal Production*,**66**: 103–106.

Rainwater-Lovett, K., Pacheco, J. M., Packer, C. (2009). Detection of foot-and-mouth disease virus infected cattle using infrared thermography. *Veterinary Journal*, **180**:317–324.

Stewart, M., Webster, J.R., Schaefer, A.L., Cook, N.J., Scott, S. L.(2005). Infrared thermography as a noninvasive tool to study animal welfare. *Animal Welfare*, **14**: 319-325.

Sykes, D. J., Couvillion, J. S., Cromiak, A.(2012). The use of digital infrared thermal imaging to detect estrus in gilts. *Theriogenology*, **78**:147–152.