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THE APPLICABILITY OF INFRARED THERMOGRAPHY IN DEER FARMING

Jagoda Czajkowska

ORCID: 0000-0001-8371-8461
Department of Fur-Bearing Animal Breeding and Game Management
University of Warmia and Mazury in Olsztyn, Poland

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Abstract

The popularity of deer farming has increased in recent years. However, research into dedicated methods for diagnosing deer in view of their specific behavior, including low levels of domestication and high susceptibility to stress, is still scant. Infrared thermography could be a useful tool for assessing the behavior of farmed animals, including deer. This non-invasive diagnostic method has numerous applications, and it could facilitate farming operations without compromising the animals' welfare. Therefore, the aim of this study was to assess the applicability of infrared thermography in deer farming and to identify breeding practices where thermal imaging can be effectively applied.

Introduction

Infrared thermography is a non-invasive diagnostic method that relies on electromagnetic radiation sensors. Thermographic cameras register and process infrared emissions into graphic images presenting surface temperature distribution (SPEAKMAN and WARD 1998). Infrared radiation can be used for remote sensing of animals (IJICHI et al. 2019, SALLES et al. 2017, MCCAFFERTY 2007). This method can be a valuable tool for examining livestock and wild animals without premedication (POTRAPELUK et al. 2021). However, the applicability of infrared thermography for diagnosing farmed deer species such as red deer (*Cervus elaphus*), sika deer (*Cervus nippon*) or fallow deer (*Dama dama*) has not been thoroughly investigated to date. The growing popularity of deer farming poses new challenges for scientists who have to modify the existing research methods and expand the knowledge about the physiology and behavior of the farmed species.

Address: Jagoda Czajkowska, University of Warmia and Mazury in Olsztyn, ul. Oczapowskiego 5, 10-957 Olsztyn, Poland, e-mail: jagoda.czajkowska@student.uwm.edu.pl

Deer are not domesticated animals, which is why thermal imaging cameras can significantly facilitate daily farming operations as well as specialist diagnostics.

This article reviews the literature on thermographic measurements in various species of farm and wild-living animals with the aim of formulating methodological assumptions for the use of thermal imaging as a diagnostic tool in deer farms.

Observation and localization of deer in grazing paddocks

Animal welfare should be the most important consideration in every farm. In deer farms, the layout of all farm facilities, including paddocks, should be adapted to the animals' needs. Grazing paddocks should feature clusters of trees and shrubs where deer can rest and hide (JANISZEWSKI et al. 2016). However, such visual obstacles complicate animal observations.

OISHI et al. (2018) developed a method for monitoring the presence and movement of wild animals based on thermograms. The proposed method was tested in a relatively large area. Thermal images revealed the presence of 24 objects that had not been detected during a local survey. The study demonstrated that infrared cameras can be helpful in localizing individual animals as well as entire groups. However, the cited authors concluded that further research was needed to define the optimal conditions for thermographic observations.

Similar conclusions were formulated by MATSUURA et al. (2017) who relied on infrared thermography to identify wild sika deer camouflaged by vegetation. Measurements were conducted early in the morning. Differences were noted in the number of animals that were identified with and without an infrared camera. The study demonstrated that thermal imaging considerably improves and facilitates the search for individual animals and their groups without causing disturbance. These conclusions were validated by MCCAFERTY (2007) who analyzed the usefulness of infrared thermography in a study of livestock and wild-living animals. According to the cited author, thermography is a non-invasive diagnostic tool with a growing range of applications. Measurements made at a distance of less than 1 m supported examinations of specific sites of heat loss, whereas images captured over distances greater than 1000 m enabled the researcher to count large mammals. However, thermography has certain limitations in open areas where surface temperatures are influenced by solar radiation, humidity and evaporative cooling. To minimize these risks, measurements should be conducted at night or on cloudy days with low insolation.

FAYE et al. (2016) provided interesting insights about thermographic measurements in deer farms. They observed that distance to the measured object affects the reliability of thermographic images. The cited authors formulated general guidelines for ecological studies to minimize inaccuracies resulting from distance to the examined surface.

Thermal imaging can be used to monitor animal movement patterns as well as hiding behavior which is particularly common in young animals in the first weeks of their life (JANISZEWSKI et al. 2016). These behaviors can lead to injury or even death in wild-living animals. CUKOR et al. (2019) analyzed the effectiveness of thermography in reducing the mortality of roe deer fawns. Hiding deer were identified with an infrared camera carried by an unmanned aerial vehicle (UAV). Fawns were detected with 100% accuracy. The authors noted that the reliability of thermal imaging can be affected by the height of flight (the optimal height was estimated at 40 m), land form and time of day.

Unmanned aerial vehicles carrying thermographic cameras can be a useful tool for monitoring the behavior of farmed deer, but drones move rapidly and emit noise that could generate additional stress for the animals. It should also be noted that fallow deer fawns tend to hide behind nettles and small shrubs (JANISZEWSKI et al. 2016) that grow in clusters to a height of up to 1.5 m. However, the study by CUKOR et al. (2019) was conducted in alfalfa fields; therefore, the proposed method where thermal imaging cameras were carried by UAVs flying at a height of 40 m should be modified to account for local conditions.

Body temperature analysis

Thermographic methods can be used to examine physiological parameters in animals (KASTBERGER and STACHL, 2003, STEWART et al. 2005, BARROS et al. 2016). Accurate measurements of body temperature are very difficult to perform in farmed deer. The examined animal has to be immobilized in a crush, but temperature can be measured only in upper parts of the body. Immobilization also generates considerable stress which can influence the results.

OKADA et al. (2013) analyzed factors that affect the accuracy of body temperature measurements in cattle, including hair, body surface temperature, surface temperature of the eyeball, rectum temperature and ambient temperature. The surface temperature of the flank was also measured at different time points after eating. The authors determined the optimal conditions for each measurement. They concluded that the distance between the thermographic camera and the object should be fixed, and the camera should be positioned at a 45° angle relative to the monitored object. Measurements should not be conducted in extreme cold or heat, direct sunshine, high humidity or wind. Thermographic images should be acquired under identical conditions, and hairless body parts can be used if this is not achievable. Factors that affect temperature measurements in animals were also investigated by Roy et al. (2020). They concluded that infrared thermography provides more reliable estimates of surface temperature when performed in a controlled environment. According to McCafferty (2007), variations in infrared emissivity, the animals' physiological responses and diseases can induce changes in temperature, and these potential sources of error should be taken into account. Despite these limitations, thermographic imaging supports non-invasive temperature measurements in farm and wild-living animals.

The cited studies indicate that infrared imaging can be applied in deer farms, but external factors such as ambient temperature and insolation, have to be considered when interpreting the results.

Salles et al. (2017) demonstrated that infrared thermography supports the identification of differences in body temperature resulting from varied proportions of fiber in ruminant diets. However, the observed differences were small, and further research is needed to establish the relationship between changes in body temperature and fermentation dynamics in ruminants. In deer, such a novel approach would require methodological modifications as well as alternative research studies to validate the results.

Deak at al. (2019) relied on digital infrared thermography to evaluate the impact of season and pregnancy stage on the temperature of different body parts in dairy cows. Considerable differences in temperature were noted between seasons and the stages of pregnancy. A significant correlation was found between pregnancy stage and the temperature of external reproductive organs, rectum, muzzle, eyeball and flank. These results contribute important information for deer farming, but seasonal changes in coat insulation should be taken into consideration in these animals.

Reproduction

The physiological processes associated with reproduction are difficult to examine and monitor in deer because these animals are not domesticated and are reared in extensive paddocks.

DHANASEKARAN et al. (2017) examined the applicability of thermal imaging for analyzing male fertility, diagnosing pregnancy and estrus, localizing animals, and evaluating the impact of environmental factors on the behavior of various farm animals. Reproductive problems, including infertility and stillbirth, are also encountered in deer farms. According to the cited authors, these risks can be minimized through thermographic evaluations. The impact of environmental conditions on the surface temperature of the examined objects was regarded as the main limitation of thermal imaging.

Similar conclusions were drawn by CILULKO et al. (2018) in a study investigating the applicability of thermography for estrus detection in farmed fallow deer (*Dama dama*). An increase in temperature was noted in the area of reproductive organs. The main limitations of the study were the distance from the measured object and the examined site. These findings indicate that thermal imaging can be applied in deer farms as well as in zoos where animals are semi-domesticated. OKADA et al. (2013), MCCAFERTY (2007) and DHANASEKARAN et al. (2017) emphasized that to maximize the reliability of the results, thermographic measurements should be conducted in indoor premises with constant temperature, humidity and lighting. According to CILULKO et al. (2018), estrus can be most reliably detected when thermographic measurements are conducted at a distance of 1 m, which implies that the researcher has to directly approach the animal. Therefore, the applicability of thermal imaging is reduced in wild and undomesticated animals.

The advantages and limitations of thermal imaging in animal breeding and reproduction were also discussed by DOMINO et al. (2022), DEAK et al. (2019), GEORGE and CHACUR (2017), DHANASEKARAN et al. (2017), SILVA et al. (2018) and RUEDIGER et al. (2016). Domino et al. (2022) relied on infrared thermography to detect estrus in horses. Heat emissions from body surfaces increased in successive stages of pregnancy due to an increase in blood flow and metabolic activity in uterine and fetal tissues. The resulting changes in temperature were captured in thermographic images. According to the authors, the developed digital image processing method supports early pregnancy detection in mares. In theory, the method described by DOMINO et al. (2022) could be used in deer farms, but the proposed approach would have to be modified to account for the specific characteristics of deer.

CILULKO et al. (2018) relied on thermal imaging to monitor the progression of pregnancy in farmed deer. They acquired thermograms of the lower abdomen and the rump (control area) in pregnant fallow deer does. The examined areas differed in temperature, and the greatest differences were noted in the third trimester which is characterized by rapid fetal development. Thermal imaging facilitates pregnancy monitoring in fallow deer, but this method requires some degree of animal domestication. It should also be noted that fallow deer usually come into estrus in October, and offspring are born in June and July. Therefore, changes in coat insulation should be taken into account when monitoring the progression of pregnancy in this species. The winter coat is an effective insulator, which is why the temperature measured in the control area (rump) can differ from the actual skin temperature. Animal adaptations to environmental conditions can thus lead to differences in body temperature and measurement errors.

In deer farms, fawns and calves should be monitored in the early postpartum period. Such observations are conducted not only to assess the health and wellbeing of offspring, but also to localize hiding fawns and calves. Cilulko et al. (2018) demonstrated that thermal imaging is highly useful for monitoring young animals, but the results can be burdened with error. Thermograms are most reliable when measurements are conducted at a distance of up to 20 m to ensure that the heat emitted by the animal is clearly visualized. In deer farms, infrared measurements are performed outdoors; therefore, the influence of the time of day, insolation and ambient temperature should be taken into account.

Health assessments

According to Welligton et al. (2019), infrared thermography is similar to a body scanner because it can be applied to visualize variations in body temperature and metabolic changes associated with the onset of inflammatory processes. Thermal imaging has been applied to assess the health of sheep (D'Alterio et al. 2011, Sutherland et al. 2020, Gelasakis et al. 2021), pigs (Graciano et al. 2014), cows (Schaefer et al. 2012), horses (Kim and Cho 2021a) and calves (Lowe et al. 2020).

Godyń (2013) demonstrated that thermography can be a useful tool for diagnosing limb health in livestock. The observed temperature anomalies were indictive of pathological changes. According to the cited author, the presented approach supports early detection of foot and limb disorders in animals. This diagnostic method could be also applied in deer farms, but the animals must be sufficiently tamed for the researcher to perform the measurements at close range.

Samara et al. (2014) investigated the applicability of infrared thermography for early detection of subclinical mastitis in dairy camels. They concluded that this method is highly useful for distinguishing subclinical mastitic udders in lactating camels, which is crucial for early detection and effective treatment of the disease. Similar observations were made by Racewicz et al. (2018) who analyzed mastitis in dairy cows. However, the results of the cited studies are unlikely to have practical significance for deer farms due to udder location in hinds and does. In deer, the udder is localized in the region of the lower abdomen and reproductive organs; therefore, mammary gland temperature cannot be measured without direct human intervention, which is a source of considerable stress for the animal.

Schaefer et al. (2012) relied on an automated and non-invasive infrared thermography system to detect early stages of bovine respiratory disease in cattle. The system was installed around a water station that was accessible to all animals. Body temperature and drinking frequency were measured automatically without the need for direct animal handling. The study revealed that data collected non-invasively by the designed thermographic system were more reliable than the results of measurements that were performed on immobilized animals and caused stress. The cited authors also found that thermographic measurements of eye temperature facilitated diagnosis of respiratory disorders in calves.

Similar studies have not been conducted in deer farms which consist of outdoor paddocks. If a thermal imaging system were to be installed around water stations, the results could be influenced by environmental conditions. However, in the light of Polish regulations (Regulation of the Minister… Journal of Laws, 2004. No. 215, item 2188), red deer and fallow deer can be farmed indoors; therefore, health assessments based on thermographic measurements could be performed in a controlled environment.

Dunbar et al. (2009) relied on infrared thermography as a rapid and non-invasive tool for assessing the health of deer. The study was conducted on mule deer (*Odocoileus hemionus*) experimentally infected with foot and mouth disease. Body temperature was significantly elevated in infected animals. The described method can be applied in the farm setting to identify early symptoms of infection and minimize production losses.

Antler development

Antler trimming is performed routinely in deer farms. Antlers are cut when male deer rub the velvet off the newly acquired antler growth and when antlers are completely ossified. The treatment must be appropriately timed to prevent pain. Trimming times are determined based on observations of antler growth and development and testosterone levels in the blood (Chapman and Chapman 1975). In a study of red deer, Bowers et al. (2010) observed an increase in velvet antler surface temperature measured with a thermographic camera. The rise in temperature was indicative of antler growth, which suggests that infrared thermography could be useful for monitoring this process.

Potrapeluk et al. (2021) analyzed changes in velvet antler temperature and the timing of the velvet shedding period in fallow deer (*Dama dama*). The measurements were conducted at three points on the main beam. The stages and rate of antler growth were effectively captured by the obtained thermograms. This non-invasive method supported the determination of the velvet shedding period and the optimal antler cutting times. This method can be applied in deer farms and zoos to improve animal welfare and guarantee the safety of personnel during animal handling operations.

Behavior and stress

Deer are far less domesticated, more easily startled and more susceptible to stress that other farmed animals (Janiszewski et al. 2016). For this reason, non-invasive thermal imaging methods could be particularly useful for monitoring deer behavior in farming practice (Kastberger and Stachl 2003).

Farmed deer have to be immobilized during routine operations such as antler trimming, administration of medications and microchipping. For this purpose, the animals have to be diverted from grazing paddocks to raceways and holding pens. This process involves considerably physical exertion and high levels of stress, which can compromise future carcass quality.

Bartolomé et al. (2021) conducted an interesting study into effort and muscle recovery in sport performance. During a performance test, the authors used a thermographic camera to measure eye temperature in sport horses. An analysis of the obtained thermograms revealed that the greater the increase in eye temperature, the higher the horse's position in the ranking. The cited authors concluded that thermographic measurements of eye temperature could be a useful method of assessing effort and recovery in animals. Similar observations were made by Redaelli et al. (2019) who diagnosed physiological stress and documented the effects of endurance training in horses based on thermographic measurements as well as serum cortisol levels, blood counts and heart rate measurements.

The study demonstrated that thermography could be a useful non-invasive tool for evaluating physiological stress in animals.

These findings suggest that thermography can be applied as an additional method for assessing the health of deer, predicting weight gains and dressing percentage of primal cuts, evaluating the animals' susceptibility to stress and physical exertion during herding. However, thermographic methods have to be adapted to the tested species, and an adequate population sample has to be selected. According to REKANT et al. (2016), infrared thermography can replace other methods of disease detection in animals. It facilitates non-invasive health assessments, thus improving animal welfare and the farm's performance. Infrared thermography is a valuable diagnostic tool that continues to evolve and has a growing number of applications.

LOWE et al. (2020) observed that automated systems are increasingly used in the livestock industry. They designed an automated system for collecting thermal infrared images to monitor the health and welfare of calves. An infrared camera was integrated into an automated calf feeder. The authors developed an algorithm for automatically detecting and analyzing eye and cheek regions in thermographs. Data were collected automatically when the animals approached the feeder, with no human intervention. The authors concluded that thermography can be effectively used in cattle breeding, in particular for monitoring the health and welfare of calves.

In contrast, in the work of SUTHERLAND et al. (2020), infrared thermography was not superior to other diagnostic methods. The cited authors set out to determine whether eye temperature measured by infrared thermography is a reliable indicator of autonomic nervous system activity (ANS) in sheep. They concluded that heart rate variability was a more sensitive and effective method of measuring ANS activity than infrared thermography. The described approach would not be highly effective in deer farms due to low levels of domestication in red deer and fallow deer. In the described methodology, heart rate monitors were strapped around the thorax. When deer are immobilized in a crush, only selected parts of the upper body can be accessed; therefore, heart rate measurements cannot be conducted in the same manner. Prolonged immobilization would also increase stress levels and affect the reliability of the results.

As mentioned in the previous sections, thermograms are influenced by environmental conditions. IJICHI et al. (2019) investigated whether the position of an infrared camera impacts the recorded temperature and which camera positions are optimal for diagnosing stress responses in animals with anterolateral eyes. Thermographic images are commonly taken at an angle of 90° relative to the eye. The authors suggested that a 90° angle relative to the sagittal plane was the optimal position for measuring eye temperature. The cited study offers a validated protocol for using infrared thermography to measure stress and welfare in animals with anterolateral eyes.

KIM and CHO (2021b) demonstrated that thermograms of the eye are useful indicators of welfare in horses. The authors attempted to determine the most appropriate areas for measuring eye temperature. The effects of camera calibration, distance and angle of measurement were taken into account. The authors concluded that further studies were needed to evaluate the applicability of eye temperature measurements for assessing pain and stress levels in horses.

Similar studies are planned in farmed deer to validate the usefulness of eye temperature measurements as reliable stress indicators. The developed measurement protocol could be applied to improve rearing standards and, above all, animal welfare in deer farms.

Conclusion

The presented literature review indicates that infrared thermography has numerous applications for analyzing physiological and behavioral processes in animals. Non-invasive diagnostic methods are increasingly popular in animal rearing. Deer differ from other farmed animals in terms of behavior and level of domestication, and these factors should be taken into consideration when developing remote diagnostic protocols for deer. In deer farms, infrared thermography should be applied mainly to assess animal welfare, including stress responses to routine husbandry practices.

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