Arch Lebensmittelhyg 65,
98–103 (2014)
DOI 10.2376/0003-925X-65-98

ISSN 0003-925X

Korrespondenzadresse:
heyde@htw-dresden.de

University of Applied Sciences Dresden (HTW Dresden), Faculty Agriculture/Landscape Management, Pillnitz, Germany

Investigations of infrared thermography and its application on dairy cows

Untersuchungen zur Infrarotthermographie und deren Anwendung bei Milchkühen

Ulrike Heyde, Steffi Geidel

Summary

Currently in the focus of research there is the application of infrared thermography (IRT) as possibility of an automatic health monitoring on dairy cows. Relating to this, for the last years at HTW Dresden several studies at different dairy farms to analyze udder disease, claw disorders and fever were performed. With selection of most meaningful results of the research project VIONA (Development of a **v**eterinary **i**nfrared-based **on**line **a**nalytic system; supported by the German Federal Ministry of Education and Research, BMBF) the potential of IRT are shown. Concerning udder health significant differences between IRT temperature of various udder health states could be determined. Analyzed udder quarters with mastitis had lower IRT temperatures compared to healthy udder quarters. There were no correlations between IRT temperature and electrical conductivity as well as IRT temperature and somatic cell count. Additionally there was no correlation between IRT temperature and rectal temperature. Claws with several diagnostic findings, with sole ulcer and with dermatitis digitalis showed significant higher IRT temperatures than healthy claws. Identification of animals with claw diseases using IRT seems to be promising. The application of IRT as part of monitoring claws health especially for early detection of claw diseases is the subject of current research. Besides IRT additional parameters are included, which also indicates the presence of claw diseases. Increasing of sensitivity and specificity are expected by linking individual parameters.

Keywords: infrared, health monitoring, udder disease, claw disease, fever

Zusammenfassung

Die Anwendung der Infrarotthermographie (IRT) als eine Möglichkeit der automatischen Gesundheitsüberwachung bei Milchkühen steht aktuell im Fokus der Forschung. An der HTW Dresden wurden hinsichtlich der Erkrankungskomplexe Euter, Klauen und Fieber in den letzten Jahren Untersuchungen in verschiedenen Milchproduktionsbetrieben durchgeführt. Mit der Auswahl wichtiger Ergebnisse aus dem Forschungsprojekt VIONA (Entwicklung eines **v**eterinären **i**nfrarotbasierten **On**line-**A**nalysesystems; gefördert durch das Bundesministerium für Bildung und Forschung, BMBF) wird das Potential der IRT aufgezeigt. Bezüglich der Eutergesundheit konnten signifikante Unterschiede der Infrarottemperatur festgestellt werden. Untersuchte Euterviertel mit einer Mastitis wiesen geringere Infrarottemperaturen im Vergleich zu gesunden Eutervierteln auf. Es konnten keine statistischen Zusammenhänge zwischen Infrarottemperatur und elektrischer Leitfähigkeit sowie somatischer Zellzahl herausgestellt werden. Ebenfalls konnte kein korrelativer Zusammenhang zwischen Infrarottemperatur und Rektaltemperatur festgestellt werden. In Bezug auf Klauenerkrankungen zeigten sich signifikant höhere Infrarottemperaturen bei Klauen mit mehreren diagnostizierten Erkrankungen, Klauen mit Rusterholzschem Sohlengeschwür und Klauen mit Dermatitis Digitalis gegenüber gesunden Klauen. Die Erkennung klauenerkrankter Tiere mithilfe der IRT zeigten vielversprechende Ergebnisse. Aktuell wird die Nutzung der IRT zur Überwachung der Klauengesundheit im Hinblick auf die Früherkennung von Klauenerkrankungen intensiv erforscht. In der Untersuchung werden neben der IRT weitere tierindividuelle Parameter einbezogen, die ebenfalls Hinweise auf Klauenerkrankungen geben. Durch Verknüpfung der einzelnen Parameter werden eine Erhöhung der Sensitivtät und Spezifität erwartet.

Schlüsselwörter: Infrarot, Gesundheitsüberwachung, Eutererkrankungen, Klauenerkrankungen, Fieber

Introduction

The trend of higher efficiency in milk production involves increasing dairy herd size associated with decreasing labours. This leads to more automation of processes. Especially health monitoring systems of dairy cows are necessary to ensure requirements for animal health, welfare and food safety. The most important diseases of dairy cows are udder inflammations (mastitis) and claw disorders (e. g. digital dermatitis, sole hemorrhage, sole ulcer), which are related to economic losses (decreased milk yield, treatment costs, reduced body condition and fertility, involuntary culling).

For control of udder health there exist some automatic monitoring systems (e. g. measurement of electrical conductivity of the milk). Besides regularly functional claw trimming there are not many methods to control claws health. Still locomotion scoring as manual monitoring is usual. But this method is very time-consuming in case of large herd size and it is impacted by subjective evaluation. In the past, great efforts were made to develop automated systems for assessment of lameness (Leroy et al., 2008; Song et al., 2008). Stepmetrix™ is one automated monitoring system, practical application is known. Both methods (manual and automated) have the disadvantage that claw diseases are only recognized after the animal is already lame due to the pain.

The technology of IRT promises a new approach to automatic health monitoring. As a contactless method, IRT is able to measure body surface temperature and to detect changes of such, which can be caused by diseases. Using a thermal camera it could be possible to identify sickening dairy cows at an early stage. Animal welfare will be improved because of the early detection: A prompt treatment can minimize pain, use of medicines and economic losses. In the past numerous studies have been performed, which attest a high diagnostic potential to the IRT. Regarding udder diseases Schaefer et al. (2004), Colak et al. (2008), Glas (2008) and Hovinen et al. (2008) could determine increased udder surface temperatures caused of an udder inflammation. IRT seems to be sufficiently sensitive to detect changes of the udder surface temperature in relation to different severities of udder inflammation (Colak et al., 2008). Barth (2001) could not determine a significant relation between somatic cell count and udder surface temperature, while udder quarters with enhanced somatic cell count had a significant higher IRT temperature compared to udder quarters with somatic cell count below 100 000/ml (> 34.1 °C vs. 33.6 °C). Further studies investigate IRT as a diagnostic tool of claw disorders in dairy cows. It was proven that limbs with claw lesions showed an increased IRT temperature (Nikkhah et al., 2005; Gschröderer et al., 2006; Ahnert and Richter, 2007; Alsaaod and Büscher, 2012). Wilhelm (2010) could not find a correlation of higher claw temperature depending on the state of the claw health. It should be noted, using IRT, an accurate diagnosis is not achieved, but noticeable animals can selected for a clinical examination in due time (Gschröderer et al., 2006).

Materials and Methods

For the development of an automatic health monitoring system in dairy cows using IRT, HTW Dresden carried out several investigations at dairy farms since 2007. Various studies with focus and database are shown in Table 1. Studies were realized in cooperation with industry partners (Fraunhofer – Institut für Verkehrs- und Infrastruktursysteme IVI, Dresden, Germany; DIAS Infrared GmbH, Dresden, Germany; Ralle Landmaschinen GmbH, Großschirma, Germany; YOO GmbH, Großschirma, Germany).

The investigations were conducted at four different commercial farms (farm A with 1900 cows, farm B with 395 cows, farm C with 1600 cows, farm D with 700 cows) in Saxony and Thuringia, Germany.

As part of the research project VIONA, IRT temperatures were analyzed by depending on various environmental influences (ambient temperature, relative humidity, wind speed, pollution of body surface, time of IRT-measurement). Investigations included the relationship between IRT temperature and udder diseases, feverish disorders and claw diseases. In addition, an identification system for diseased cows by using diagnostic algorithms was tested. For references clinical examinations were included. Clinical signs of the udder were estimated of foremilk for each quarter by measuring electrical conductivity (Mastitissen-

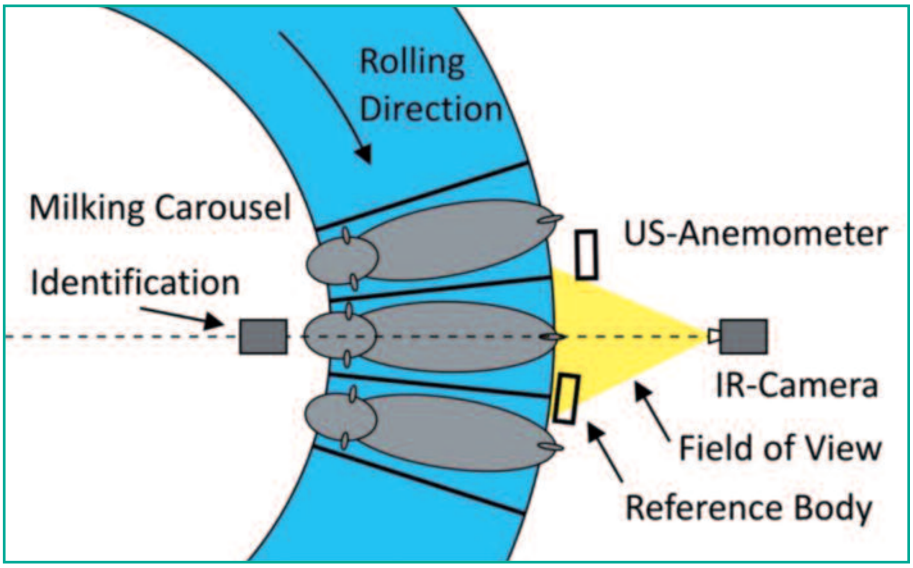

FIGURE 1: *Measuring configuration at the rotary parlor (Franze et al., 2011).*

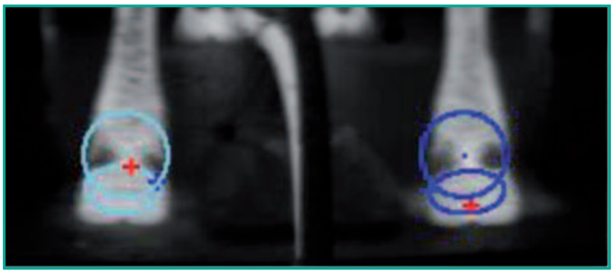

FIGURE 2: *Infrared image with marked and reviewed surfaces areas for the left and right rear claws.*

Journal of Food Safety and Food Quality 65, Heft 4 (2014), Seiten 85–112

TABLE 1: *Overview of studies at HTW Dresden about health monitoring by using IRT.*

	period of measurement month/year	animals	number of measurements/ number of IRT-data	focus and content: investigation of IRT temperatures in connection with …
diploma thesis: Early diagnosis of diseases by dairy cows using infrared thermography (Ahnert and Richter, 2007)				
study 1 (farm A)	03/07–04/07	180 (HF)	20/3515	– … claw diseases, feverish disorders – investigation of correlation between rectal temperature and eyes surface temperature
research project VIONA: Development of a veterinary IR-based online analytic system (2008–2011) **dissertation: Health monitoring in dairy herds using infrared thermography (Passarge, 2013)**				
study 2 (farm A)	04/09–05/09	160 (HF)	41/ udder: 8386 fever: 4221 claws: 8036	– … udder diseases, feverish disorders, claw diseases
study 3 (farm A)	12/09	84 (HF)	1/ claws: 168	– … claw diseases
study 4 (farm A)	05/10–07/10	249 (HF)	65/ udder: 15327 fever: 7665	– … udder diseases, feverish disorders
study 5 (farm B)	09/10	138 (HF)	1/ claws: 472	– … claw diseases
study 6 (farm C)	03/11	359 (HF)	25/ udder: 10092 fever: 4974	– … udder diseases, feverish disorders
study 7 (farm C)	02/11–05/11	176 (HF)	100/ claws: 23320	– … claw diseases
research project: Early detection of claw diseases (since 2013; supported by Saxony Ministry of Science and Art, SMWK)				
study 8 (farm D)	05/13–06/13	120 (HF)	20/ claws: 1242	– … claw diseases

(HF) = Holstein Friesian

TABLE 2: *Mastitis categories (according to Hamann and Fehlings, 2002).*

SCC per ml milk	udder pathogens negative	udder pathogens positive
< 100000	normal secretion	latent infection
> 100000	unspecific mastitis	mastitis

TABLE 3: *Level of significance for means of different mastitis categories for IR-TempMax_corr* of rear udder quarters (Franze et al., 2011).*

mastitis category	normal secretion	latent infection	unspecific mastitis	mastitis
normal secretion	–	0.62	<u>0.00</u>	<u>0.08</u>
latent infection	0.62	–	0.30	0.48
unspecific mastitis	<u>0.00</u>	0.30	–	0.76
mastitis	<u>0.08</u>	0.48	0.76	–

TABLE 4: *Sensitivity and specificity of diagnostic test (Passarge et al., 2013).*

	sensitivity	specificity
algorithm 1 difference of measured IRT temperature between claws > 2K	21.9 %	81.6 %
algorithm 2 measured IRT temperature today > IRT temperature 10-days-mean + IRT temperature 10-days-standard deviation	7.6 %	95.0 %
algorithm 3 measured IRT temperature today > IRT temperature 21-days-mean	46.6 %	66.7 %

sor SMS 4010, IFU Diagnostic Systems GmbH, Lichtenau, Germany), analyzing somatic cell count (SCC) and analyzing udder pathogens. Diagnostic findings of SCC and udder pathogens were assigned in four mastitis categories (according to Hamann and Fehlings, 2002; Table 2).

Clinical sign of fever was determined as a body temperature above 39.5 °C by measuring rectal temperature. For assessment of claw health the clinical examination of claws was used (according to the diagnostic code by Deutsche Landwirtschafts-Gesellschaft, 2007), while cows were fixed by a treatment crush.

IRT measurements were performed once a day in a rotary parlor (type: side-by-side). Measuring at the rotary parlor enables examination of rear claws and rear udder quarters. The calibrated infrared camera (PYROVIEW 640L compact, DIAS infrared GmbH, Dresden, Germany) was positioned outside the rotary parlor to ensure a radial view to the rear surface of the cow (Figure 1). The camera operates in the 8 to 14 µm spectral band, supplies a measuring range of –20 to 120 °C and uses an uncooled micro bolometer sensor (640 x 480 pixel). The temperature measurement uncertainty was reduced from about 2 K to 0.5 K using a reference radiator (Wirthgen et al., 2012). Environmental effects like ambient temperature, relative humidity and wind speed were captured by a climate measurement instrument (W&T GmbH, Wuppertal, Germany) and by an ultrasonic anemometer (SICK AG, Reute, Germany), which were installed at the rotary parlor as well.

A special software (VIONA LabelEditor, Fraunhofer – Institut für Verkehrs- und Infrastruktursysteme IVI, Dresden, Germany) which supported semi-manual marking and checking of interested surfaces was used to analyze the infrared images. The reviewed surfaces, for example, are areas of the left and right hind limb respectively the left and right rear claws (Figure 2). These surface areas were used to generate the measured IRT temperatures (e. g. IR-TempMW = mean IR-Temperature of surface area, IR-TempMax = maximum IR-Temperature of surface area).

Statistic analysis of following results included the evaluation of correlation and regression, and the mean comparison test to find differences of IRT temperature of cows with diseases. The mean comparison test was operated with the t-test for two independent spot tests. All statistical analyses were conducted with the SPSS Statistics 17.0 for Windows. The IRT as a practical application for automatic health monitoring was revised by determination of sensitivity and specificity used algorithms.

Results and Discussion

Subsequently most meaningful results of several studies of the research project VIONA are represented. More results and details can take from dissertation by Passarge (2013).

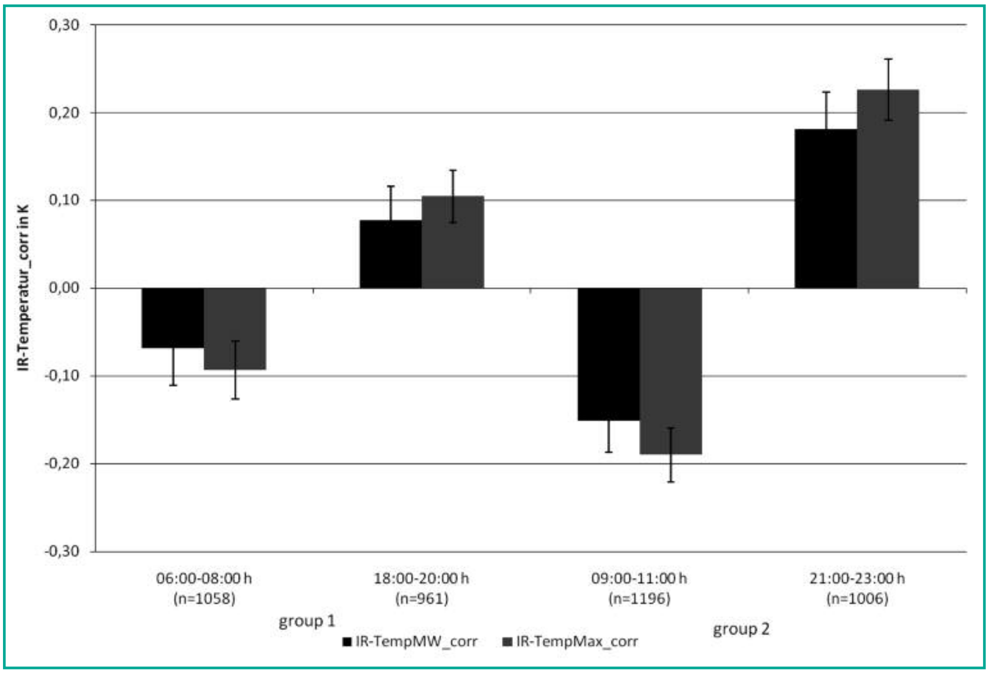

FIGURE 3: *Comparison of means for two IRT temperatures (IR-TempMW_corr*, IR-TempMax_corr*) and standard error depending on time of IRT measurement (Franze et al., 2011), *correction of measured IRT temperature.*

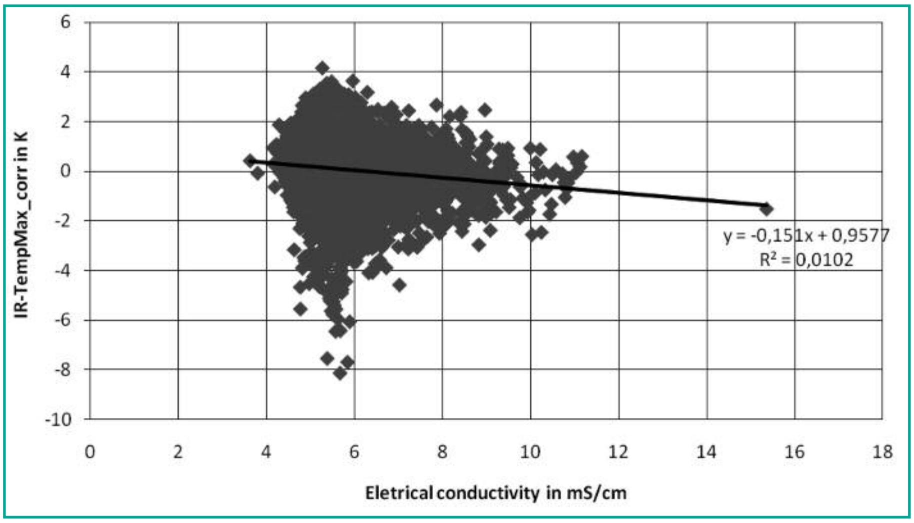

FIGURE 4: *Relation between IR-TempMax_corr* of rear udder quarters and electrical conductivity (n=11 644) (Franze et al., 2011),*correction of measured IRT temperature.*

Environmental factors

For analysis of the relation between IRT temperatures and environmental factors (ambient temperature, relative humidity, wind speed) correlation coefficients (r) from –0.26 to 0.73 and coefficients of determination (R^2) from 0.00 to 0.52 could proved. The highest correlations were found for the relation of IRT temperature and ambient temperature. Other factors (relative humidity, wind speed) could be ignored for further investigations caused by small correlation coefficients and coefficients of determination. But the IRT temperatures have to be corrected for the ambient temperature. A rising ambient temperature causes rising body surface temperatures. Using a model, which is based on the linear regression, the correction of actually measured IRT temperatures e. g. IR-TempMax was performed into IR-TempMax_corr. Thereby ambient temperature was considered at the same time of IRT measuring. Thus IR-TempMax_corr characterizes the difference between the actually measured IRT temperature and the result of regression equation with considered ambient temperature.

Another relation was found between IRT temperature and time of IRT measurement caused by circadian rhythm of cows. In Figure 3 two groups of cows are shown for two times of IRT measurements. In both observed groups the IRT temperatures were lower at morning measurement than at evening measurement. Therefore the daily infrared imaging of cows can be reduced to one daytime.

Udder

The analysis of correlation and regression of IRT temperatures and electrical conductivity of rear udder quarters showed small relations. For example the correlation coefficient of IR-TempMax_corr and electrical conductivity was r = –0.10 (Figure 4). Due to this small correlation coefficient it has to be concluded of none relation between IR-TempMax_corr and electrical conductivity. There was also no correlation between IRT temperatures and the somatic cell count.

For the detection of udder diseases the comparison of means showed differences between the four different mastitis categories (Figure 5). The mean IR-TempMax_corr of the categories unspecific mastitis (0.14 K) and mastitis (0.18 K) are significant different from the mean of the category normal secretion (0.37 K) ($p < 0.10$, t-Test; Table 3).

Although there are significant differences between diseased udder quarters and healthy udder quarters, it should be recognized that udder quarters with mastitis had lower IRT temperatures than healthy ones. In contrast, results of other studies (Barth, 2001; Schaefer et al., 2004; Colak et al., 2008; Glas, 2008; Hovinen et al., 2008) could determine increased udder surface temperatures. Whereby Schaefer et al. (2004), Glas (2008) and Hovinen et al. (2008) induced clinical mastitis with *Escherichia Coli.* This pathogen could not proved in the own investigation. Maybe the pathogen spectrum is decisively for changes of IRT temperatures.

Journal of Food Safety and Food Quality 65, Heft 4 (2014), Seiten 85–112

Fever

Analysis of correlations between IRT temperature and rectal temperature showed small correlations (r = 0.00–0.24). A significant difference between IRT temperatures of two groups (group 1 < 39.5 °C; group 2 ≥ 39.5 °C) could only be determined in one study ($p < 0.05$, t-test) (Passarge, 2013).

Claws

IRT measurements of claws were taken for one milking time under nearly the same environmental conditions. This means no correction of IRT temperature was required. In Figure 6 the comparison of means showed clearly higher IRT temperatures of claws with several diagnostic findings, sole ulcer and dermatitis digitalis ($p < 0.05$, t-test). Results of increased IRT temperatures are consistent with results of previous studies (Nikkhah et al., 2005; Gschröderer et al., 2006; Ahnert and Richter, 2007; Alsaaod and Büscher, 2012).

On the basis of IRT temperatures diagnostic algorithms were developed with the aim to evolve an automatic health monitoring system, which is able to detect noticeable cows. In Table 4 some of those algorithms are disclosed as an example for detecting claw diseases. Diagnostic test was carried out and showed, that algorithm 3 obtained best sen-

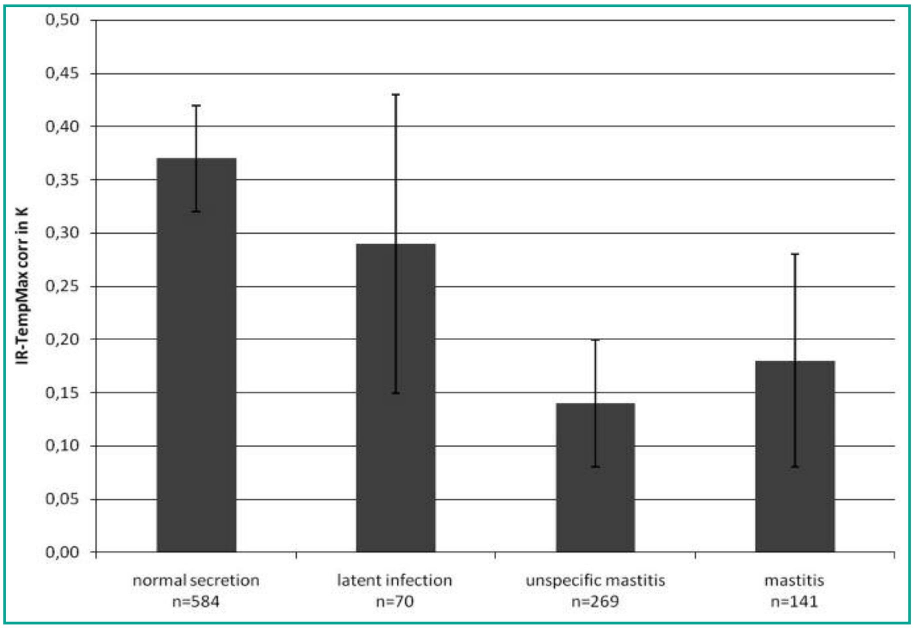

FIGURE 5: *Comparison of means for IR-TempMax_corr* and standard error of rear udder quarters depending on mastitis category (Franze et al., 2011), *correction of measured IRT temperature.*

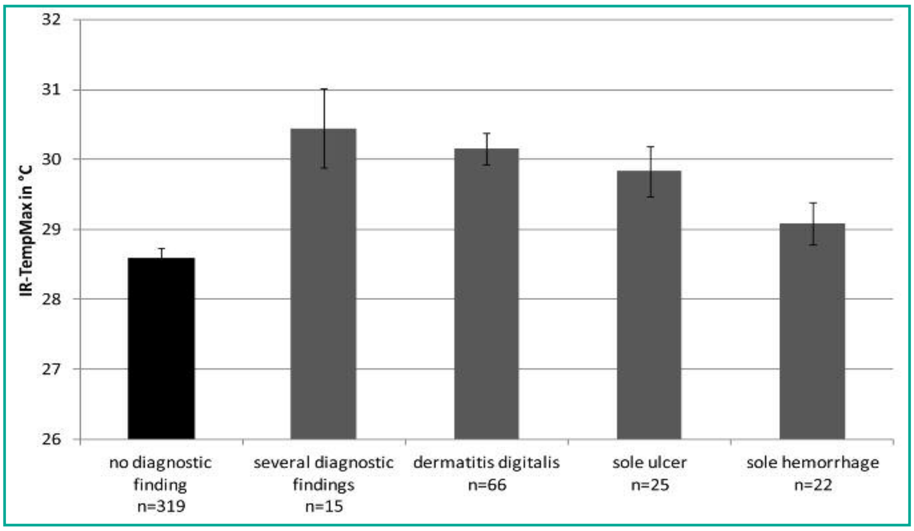

FIGURE 6: *Comparison of means for IR-TempMax and standard error of claws depending on different diseases (Passarge, 2013).*

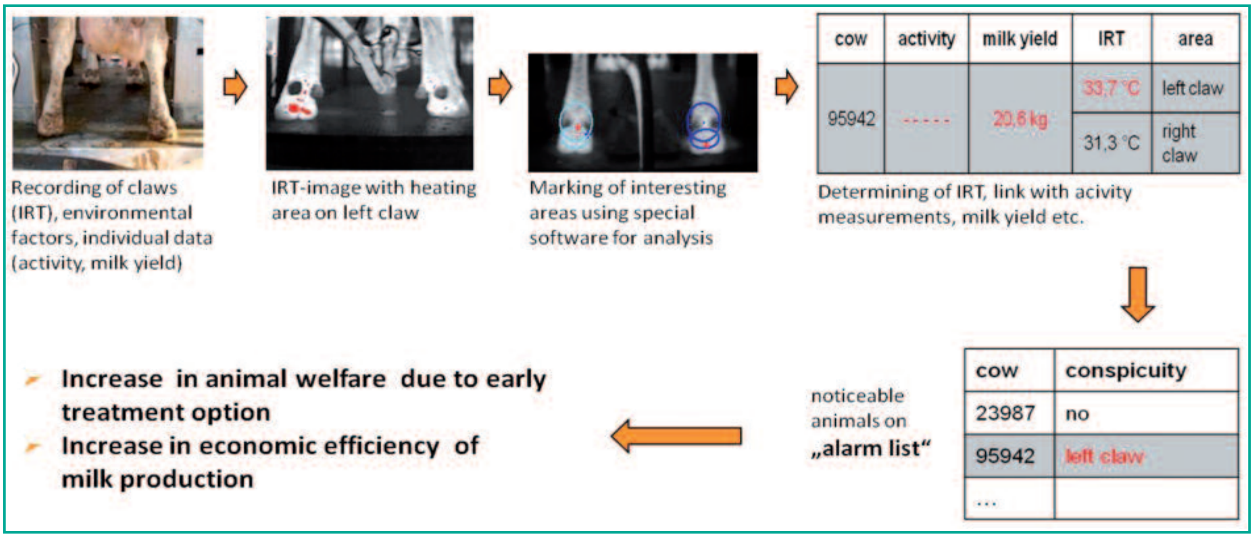

FIGURE 7: *Development of an early detection system for animals with beginning claw diseases.*

sitivity and specificity. Thereby algorithms are only valid for the individual cow, because every animal has its own temperature level.

Building on the knowledge of the previous studies, study 8 was realized to investigate early detection especially of claw diseases. With the application of several non-invasive technically methods highly rates of sensitivity and specificity are expected. To increase sensitivity and specificity rates it is important to use multiple sensitive parameters. Besides IRT in this study, activity measurements and milk yield were included to detect cows with claw disorders in early stages. Currently, measurement data from study 8 are analyzed concerning three parameters (IRT, activity measurement and milk yield) to work out an health monitoring system for claw disorders (Figure 7).

References

Ahnert S, Richter M (2007): Frühdiagnostik von Erkrankungen bei Milchkühen mit Hilfe von Infrarotthermographie. Dresden, HTW, Fak Landbau/Landespflege, Dipl.

Alsaaod M, Büscher W (2012): Detection of hoof lesions using digital infrared thermography in dairy cows. J Dairy Sci 95: 735–742.

Barth K (2001): Untersuchungen zur Nutzung der Infrarot-Thermographie zur Eutergesundheitskontrolle bei Milchkühen. Proceedings of the 5th Conference of „Bau, Technik und Umwelt in der landwirtschaftlichen Nutztierhaltung", Institut für Agrartechnik Universität Hohenheim, 6.–7. Mrz 2001, 224–229.

Colak A, Polat B, Okumus Z, Kaya M, Yanmaz LE, Hayirli A (2008): Short communication: Early detection of mastitis using Infrared thermography in dairy cows. J Dairy Sci 91: 4244–4248.

Deutsche Landwirtschafts-Gesellschaft (2007): 2. DLG-Report Klauengesundheit. DLG-Verlags-GmbH.

Franze U, Geidel S, Heyde U, Schroth A, Wirthgen T, Zipser S (2011): Evaluation of the potential of infrared thermography for automatic animal health monitoring systems in milk production. Proceedings of the 17th European Conference of Information Systems in Agriculture and Forestry (ISAF), Czech University of Life Sciences Prague, 11.–14. Jul 2011, 38–46.

Glas A (2008): Vergleichende Untersuchung klinisch gesunder und mit *Escherichia coli* infizierter Euterviertel von Kühen mittels Infrarotthermographie. München, LMU, veterinärmed. Fak., Diss.

Gschröderer C, Ossovsky R, Grupp T, Schmidt E (2006): Präventive Klauenpflege unter Einsatz der Thermographie. Fleckvieh Welt 1: 4–9.

Hamann J, Fehlings K (2002): Leitlinien zur Bekämpfung der Mastitis des Rindes als Bestandsproblem (Guideline for Controlling Mastitis as a Herd Problem), Deutsche Veterinärmedizinische Gesellschaft (DVG) e.V., 4. Aufl., Verlag der Deutschen Veterinärmedizinischen Gesellschaft e.V., Gießen.

Hovinen M, Siivonen J, Taponen S, Hänninen L, Pastell M, Aisla A-M, Pyörälä S (2008): Detection of clinical mastitis with the help of a thermal camera. J Dairy Sci 91: 4592–4598.

Leroy T, Bahr C, Song X, Vranken E, Maertens W, Vangeyte J, Van Nuffel A, Sonck B, Berckmans D (2008): Automatic detection of lameness in dairy cattle – Image features related to dairy cow lameness. Proc. Measuring Behavior. Maastricht, The Netherlands, 26.–29. August 2008 (https://lirias.kuleuven.be/bitstream/123456789/218799/1/Lameness_Conference_Kuopio, 27.01.2014).

Nikkah A, Plaizier JC, Einarson MS, Berry RJ, Scott SL, Kennedy AD (2005): Short communication: Infrared thermography and visual examination of hooves of dairy cows in two stages of lactation. J Dairy Sci 88: 2749–2753.

Passarge U (2013): Gesundheitsmonitoring in Milchviehbetrieben mit Hilfe von Infrarot-Thermographie. Berlin, HU, Landwirtschaftlich-Gärtnerische Fak., Diss.

Schaefer AL, Scott SL, Lacasse P, Tong AKW (2004): Early detection of inflammation and infection using infrared thermography. United States Patent Applicaton Publication, Publication Number: US 2004/0019269 A1.

Song X, Leroy T, Vranken E, Maertens W, Sonck B, Berckmans D (2008): Automatic detection of lameness in dairy cattle – Vision based trackway analysis in cow s locomotion. Comput Electron Agric 64: 39–44.

Wilhelm K (2010): Die subklinische Klauenrehe beim Milchrind – thermographische Untersuchungen der Klaue und Beziehungen zum Energiestoffwechsel. Leipzig, veterinärmed. Fak., Diss.

Wirthgen T, Zipser S, Geidel S, Franze U (2012): Präzise IR-basierte Temperaturmessung – eine Fallstudie für die automatische Gesundheitsüberwachung von Milchkühen. tm – Technisches Messen 79: 168–174.

Address of corresponding author:
Dipl.-Ing. (FH) agr. Ulrike Heyde
Hochschule für Technik und Wirtschaft Dresden (HTW)
Fakultät Landbau/Landespflege
Pillnitzer Platz 2
01326 Dresden
heyde@htw-dresden.de