Selection of the information parameter for the thermography method of diagnostics of dairy cows mastitis

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Abstract: *In the paper are presented experimental results of exploring the thermography method of diagnostics of dairy cows mastitis depending on the basic used information parameter. Prospects for embedding the information on the udder thermography results into the herd management system are discussed.*

KEY WORDS: *DIAGNOSTICS, MASTITIS, THERMOGRAPHY, DAIRY COW, STATISTICS.*

Introduction

In the information support of dairy cattle breeding, an urgent task is to determine the subclinical mastitis of cows in real time. There are different methods of diagnosis of subclinical mastitis, for example, direct measurement of the somatic cells count (SCC) or California mastitis test (CMT). However, both these methods have poor promptness at loose cow housing conditions. So, it is necessary to develop new technologies and improve existing methods and technical means for diagnosing mastitis allowing identification diseases during milking process and providing individual service to animals in order to prevent the mixing of milk from healthy and sick animals and timely start of veterinary treatment. A thermography method of diagnostics of dairy cows mastitis is of great scientific and practical interest as it is contactless and multifunctional [1-15]. But this method is indirect, therefore, it is necessary to make its experimental research under real production conditions of a dairy farm.

Description

Experimental studies were carried out on an operating dairy farm in the Republic of Belarus. In total, 580 black-and-white cows of the dairy herd were examined. The Inter Clean kenotest was used as a reference option for the diagnosis of mastitis [16]. Experimental studies included two stages. At the first stage, the animals were subjected to a comprehensive clinical examination by the veterinarian specialist. Further, according to the kenotest, there were identified 4 groups, of 30 cows in each one, with different levels of disease. The first group consisted of healthy animals with a negative kenotest test (-); in the second group were cows with a questionable kenotest (+); the third group included animals with a subclinical stage of mastitis (++), and the fourth one – with a clinically pronounced stage of mastitis (+++).

At the second stage, single measurements of udder temperature were carried out by analyzing a thermographic image of each of 30 cows belonging to different animal groups (table 1). Thermographic images of a cow's udder were made during milking process by a handheld thermal imager DT 9875 [17]. The thermal imager was installed on a tripod at a predetermined distance of 0.6 meters. The device allows you to create digital images – thermograms, which makes it possible for their subsequent analysis using a computer. The measurements were carried out with an accuracy of 0.02 °C.

As an informational parameter, the where analyzed the following ones: maximum udder temperature, the difference between maximum temperature values of 4 shares of the cow's udder, dynamics of changes in the maximum temperature of the udder during the milking process and temperature distribution along the length of the cow udder nipple.

The analysis of thermographic images of the udder illustrates the distributed nature of the temperature field (fig. 1). Locally the temperature rises in places with inflammatory processes. Therefore, the maximum temperature of individual udder areas was considered as the information parameter for classification.

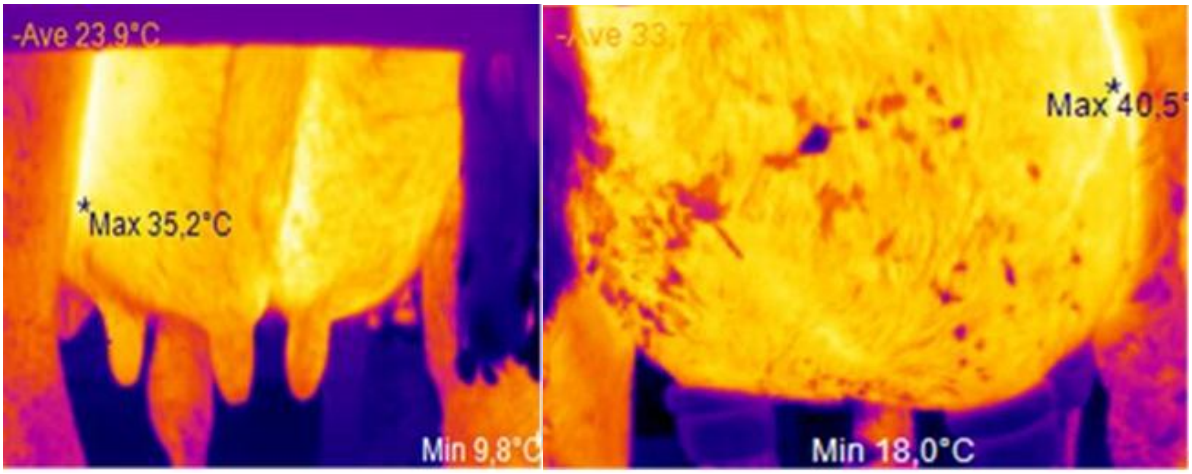

Figure 1 *– Examples of thermographic images of the cow's udder having maximum temperature values of 35,2^{0}C and 40,5^{0}C*

Statistical processing of experimental results shows that with an increase in the incidence of mastitis, an increase of the average temperature of the cow's udder is observed. Analysis of random sample values $Y_1, ..., Y_n$ for their belonging to the normal distribution of probability density according to the criterion of the mean absolute deviation (MAD), shows that they belong to the normal distribution law of random variable (tab. 1).

The experimental value of the MAD criterion is determined by the formulae:

$$\theta_{\exp} = \left| \frac{\text{CAO}}{S} - 0.7979 \right| = \left| \frac{\sum_{i=1}^{n} |Y_i - \bar{Y}|}{nS} - 0.7979 \right|.$$

The table value of the MAD criterion is:

$$\theta_n = \frac{0.4}{\sqrt{n}}.$$

According to MAD criterion, if $\theta_{\exp} < \theta_n$ then the random sample values $Y_1, ..., Y_n$ belong to the normal distribution law; if $\theta_{\exp} > \theta_n$ then they don't belong to it. The results of statistical data processing show that the normal distribution law can be used to describe the probability density distribution of the maximum udder temperature of cows for each of the 4 groups of animals (see tab. 1)

Table 1. *The results of experimental data processing on the maximum temperature of the udder for 4 groups of cows, obtained at a confidence level of p = 0,95%*

Experimental data parameters	Negative kenotest (-)	Questionable kenotest (+)	Subclinical kenotest (++)	Clinically pronounced knotest (+++)
Number of cows in a group, *n*	30	30	30	30
Average udder temperature by group of cows, ^{0}C, $\bar{Y}$	36,2	37,3	38,5	39,6
Dispersion, S^2	0,650	0,217	0,198	0,209
Normal distribution test	yes	yes	yes	yes

An important result of statistical processing of the experimental data is the conclusion about the normal nature of the probability density distribution of the maximum temperature of the udder of a cow for all 4 groups of animals. This makes it possible to use in further analysis well developed theoretical methods of statistical data processing for the normal distribution of a random variable. The probability density curves of the maximum udder temperature have overlapping zones (fig. 2). Therefore, the problem arises of finding an algorithm for making a decision on the classification of a particular cow to one of 4 groups of cows based on the results of measuring the maximum udder temperature.

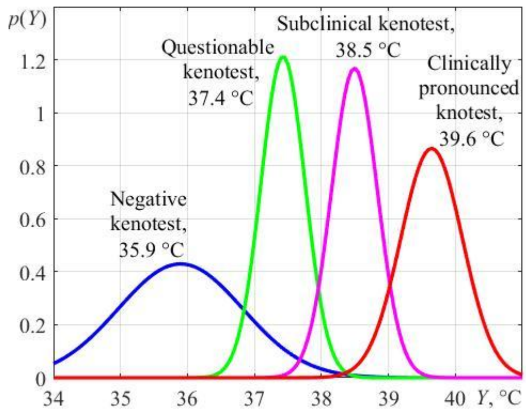

Figure 2 – *Distribution of the probability density of the maximum temperature of the udder for 4 groups of cows according to the stage of mastitis*

When making a decision on the classification of a particular cow based on the results of the analysis of an udder thermographic image, 4 options are possible:

- correct detection of the absence of mastitis;
- correct detection of the stage of mastitis;
- skipping the disease;
- false alarm about the disease.

Mutual overlapping of udder temperature distribution curves for different groups of cows can be explained by the biological nature of the controlled object and the influence of various disturbing factors such as stress, change in ambient temperature, lactation period, etc. Therefore, it is necessary to study the influence of various disturbing factors on the result of the analysis of an udder thermographic image and to explore the possibility of reducing the variance.

Obviously, udder temperature will be influenced by the effects of the milking machine during milking. Therefore, experimental studies were performed on the change in the maximum temperature of the udder in the process of milking for different groups of cows (fig. 3).

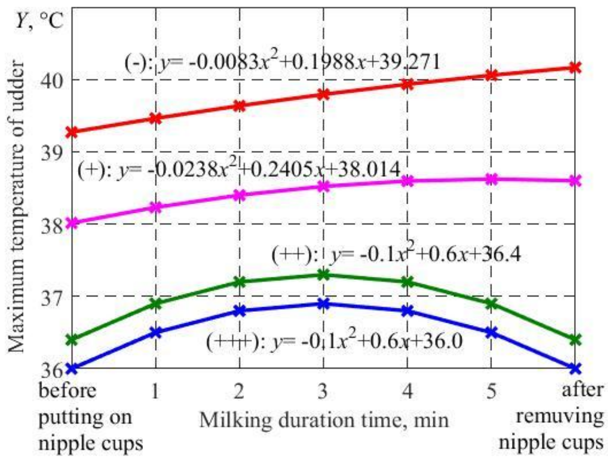

Figure 3 – *The dynamics of changes in the maximum temperature of the udder before putting on the nipple cups of milking machine, then every minute during milking and, finally, after removing the nipple cups*

Thus, as can be seen from Fig. 3, in the process of milking, the temperature of the udder of a cow changes significantly, which must be taken into account when obtaining an udder thermographic image used for the diagnosis of mastitis.

As the next informational parameter, we investigate the relationship between the temperature difference by quarters of the udder and the mastitis test group of cows. The criterion for the early detection of mastitis in cows is the difference in the maximum temperatures of the front and rear lobes of the udder.

$$\Delta T_{\max}^{f} = \Delta T_{\max}^{a} - \Delta T_{\max}^{b}$$

where $\Delta T_{\max}^{a}$ is the maximum temperature of the left anterior lobe of the udder, °C;

$\Delta T_{\max}^{b}$ is the maximum temperature of the right front lobe of the udder, °C.

For the rear lobes the corresponding formulae is the following one:

$$\Delta T_{\max}^{\mathrm{r}} = \Delta T_{\max}^{c} - \Delta T_{\max}^{d}$$

where $\Delta T_{\max}^{c}$ is the maximum temperature of the left rear lobe of the udder, °C;

$\Delta T_{\max}^{d}$ is the maximum temperature of the right rear lobe of the udder, °C.

As a result of the experiment, values were obtained for each lobe of the udder during milking (see tab. 2).

Table 2. *Change in the difference between maximum temperatures for each lobe of the udder of cows and the results of the kenotest*

№	Cow ID	Research method	Results of the research of udder lobes					
			front lobes			rear lobes		
			left	right	$\Delta T_{\max}^{\mathrm{f}}$	left	right	$\Delta T_{\max}^{\mathrm{r}}$
1	132	Kenotest	++	-		-	-	
		Thermal imaging test, ºC	38,6	37,0	1,6	36,8	36,4	0,4
2	736	Kenotest	-	-		-	-	
		Thermal imaging test, ºC	34,5	34,7	0,3	35,1	35,3	0,2
3	656	Kenotest	-	-		-	+++	
		Thermal imaging test, ºC	36,4	36,5	0,2	36.4	40,5	4,1
4	677	Kenotest	+	-		-	-	
		Thermal imaging test, ºC	37,8	36,8	1,0	36,2	35,9	0,3
5	517	Kenotest	-	-		+	-	
		Thermal imaging test, ºC	34,1	34,2	0,1	37,4	36,2	1,2
6	547	Kenotest	+++	-		-	-	
		Thermal imaging test, ºC	39,2	36,7	2,5	36,4	36,4	0
7	786	Kenotest	-	++		-	-	
		Thermal imaging test, ºC	37,0	38,5	1,5	36,5	36,9	0,4
8	862	Kenotest	-	-		-	-	
		Thermal imaging test, ºC	35.6	35,8	0,3	36,2	36,0	0,2
9	211	Kenotest	-	-		-	++	
		Thermal imaging test, ºC	35,1	35,6	0,5	36,6	38,4	1,8
10	314	Kenotest	-	+++		-	-	
		Thermal imaging test, ºC	36,7	39,1	2,4	36,2	36,7	0,5

For calculations, the difference between the maximum temperature values for each lobe of the udder of cows was taken into account. For the case of subclinical mastitis the difference between the maximum temperature values for the anterior lobes of the udder was $\Delta T_{\max}^{\mathrm{f}} = 1.6$ ºC, and for the corresponding difference for rear lobes of the udder was $\Delta T_{\max}^{\mathrm{r}} = 1.8$ ºC. At more severe stages of mastitis (pronounced inflammatory process), the above difference for the anterior lobes of the udder was $\Delta T_{\max}^{\mathrm{f}} = 2.4$ ºC, and for rear lobes of the udder it was $\Delta T_{\max}^{\mathrm{r}} = 4.1$ ºC, that indicates an acute form of the disease.

The difference within the range of up to 0.5 ºC between the maximum temperature values for each lobe of the udder corresponds to a healthy udder, the difference in temperature values of 1.0 ºC and more indicates the presence of an inflammatory process. The greater the difference in temperature, the more pronounced the inflammatory process. Thus, the maximum temperature of the afflicted lobes with clinically expressed mastitis (confirmed by kenotest) was 4.1 ºC more high compared to other healthy lobes of udder.

Thus, this parameter - the difference between the maximum temperature values for each lobe of the udder – is informative and can be used in the decision-making algorithm. In this case are required the use of several sensors (thermal imagers) and a rational construction design.

As the next informative parameter in the diagnosis of mastitis, we studied the temperature distribution along the length of the udder nipples for healthy (fig. 4) and sick cows.

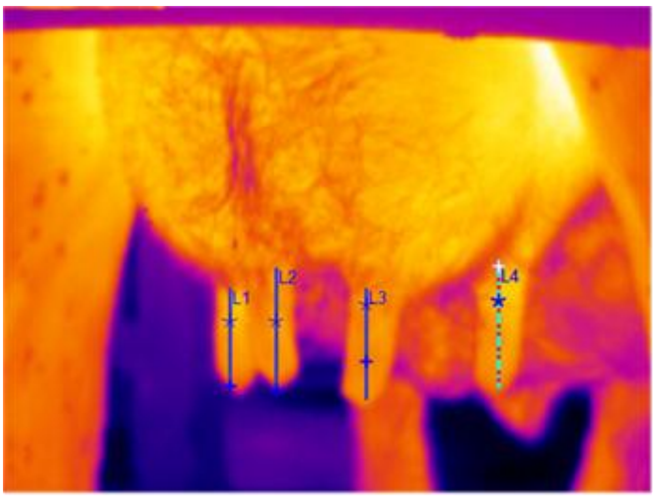

Figure 4 – Infrared image of mastitis-free udder nipples after milking; L1 is left anterior nipple length; L2 is left rear niplle

length; L3 is right rear nipple length;
L4 is anterior right nipple length

It can be seen from the graphs that the temperature distribution along the udder nipple length of a healthy cow is even along the entire nipple length. The maximum temperature was observed at the top of the nipple and it was 34,8 °C (fig. 5).

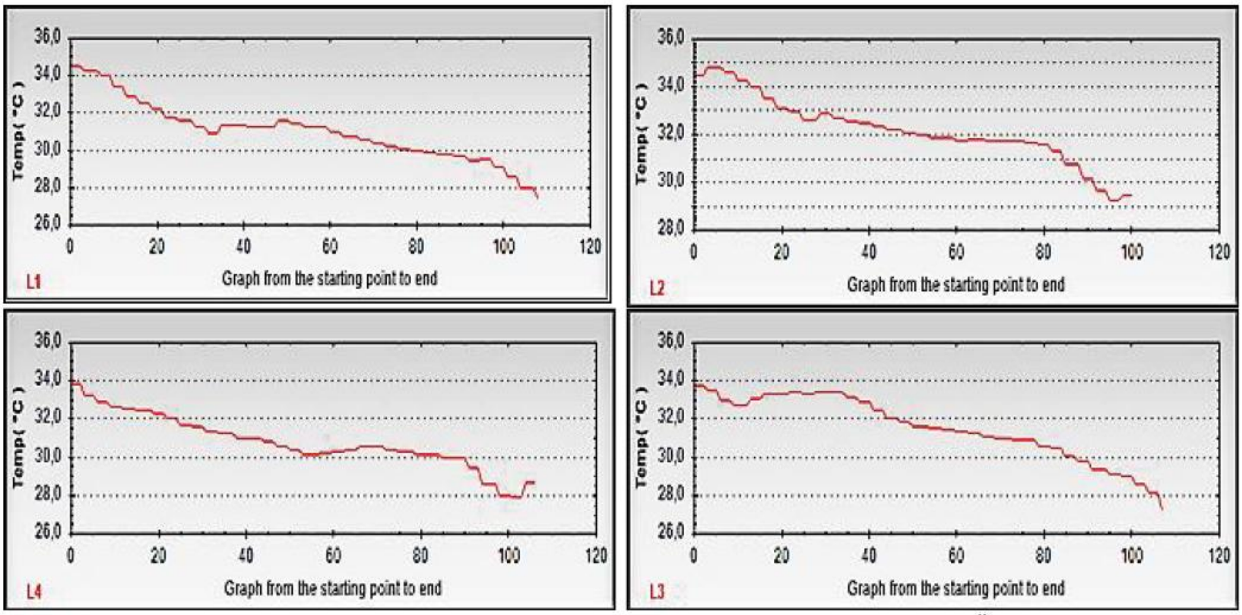

***Figure 5** – Temperature distribution graphs along the length of the mastitis-free udder teats after milking*

At the same time, for a cow with mastitis, it can be seen that the temperature distribution along the length of the udder nipples is uneven at the beginning of the apex of the nipples. The maximum temperature was observed at the top of the nipples and it was 36.2 ° C (fig. 6).

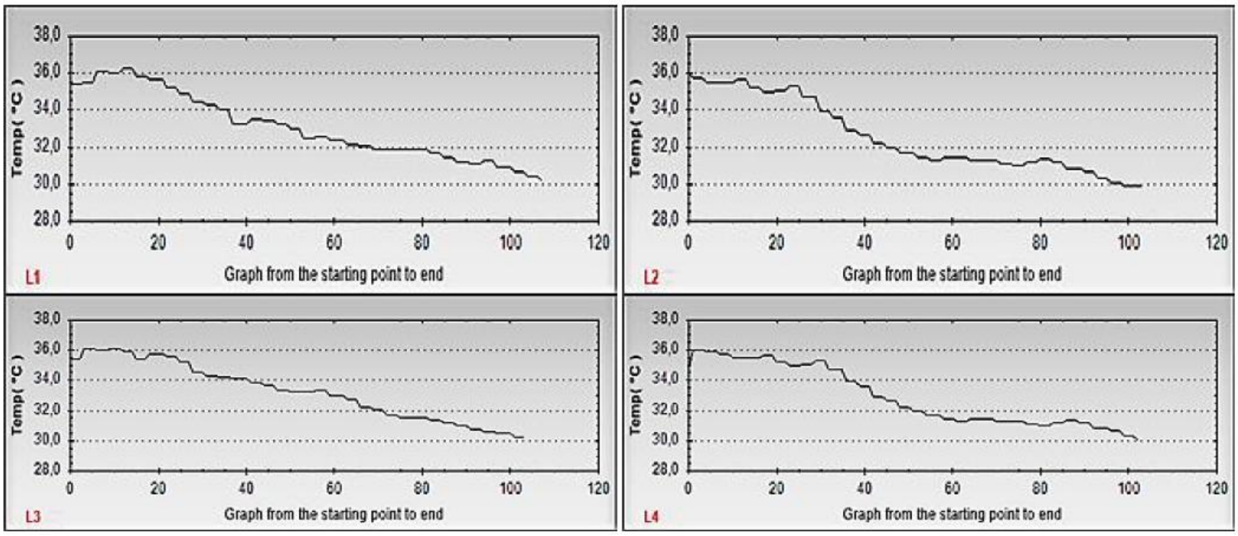

***Figure 6** – Temperature distribution graphs along the length of the mastitis afflicted udder teats after milking*

The use of this informative parameter – the temperature distribution along the length of the udder nipples – can be useful when testing gentle milking modes of various milking machines.

Due to the biological nature of the cow, various disturbing factors can affect the thermometry results, such as stress, ambient temperature, age, feeding time, etc. It is possible to increase the reliability of determining the mastitis disease in dairy cows by repeatedly measuring the maximum udder temperature with subsequent statistical processing of the results using decision theory methods.

The variance of the sample mean is known to be n times less than the variance of one sample. Hence follows the most important property of the result of multiple measurements: its uncertainty is less than the uncertainty of the result of a single measurement.

$$\sigma^2_{\bar{X}} = \frac{\sigma^2_X}{n} .$$

Experimental studies were performed to study the possibility of reducing the data variance by repeatedly monitoring the temperature of the cow udder followed by averaging over a certain time interval. Temperature measurements were carried out for selected 4 cows from different groups according to the degree of mastitis disease. Measurements were taken 2 times a day during morning and evening milking (see tab. 3).

Table 3. *Results of statistical processing of measurement of udder temperature of cows from different sample groups for a 10-day period*

Criteria		Negative kenotest (-)	Questionable kenotest (+)	Subclinical kenotest (++)	Clinically pronounced knotest (+++)
Sample mean	$\bar{Y}$	34,5	37,0	38,4	39,8
Sample variance	S^2	0,154	0,100	0,031	0,176
Experimental value of the MAD criterion	$\mathbf{Q_Э}$	0,0181	0,0246	0,051	0,012
Tabled value of the MAD criterion	$\mathbf{Q_n}$	0,1265	0,1265	0,126	0,126
Normal probability istribution test		positive	positive	positive	positive

Multiple measurements of udder temperature for a particular cow can significantly reduce the data variance and increase the likelihood of making correct decisions on the presence and the degree of mastitis. But, at the same time, it is necessary to find a compromise between the duration the period of collecting data on the cow udder temperature for a particular cow and the promptness of decision-making. At the same time, due to the statistical nature of the depending of cow udder temperature to the stage of mastitis disease, an urgent task is the development of decision-making algorithms based on the statistical theory [18].

Conclusion

Advantages of thermography compared to the other known methods of diagnosing mastitis are contactless, low labor and time costs and the capabilities of integration the information results to an automated herd management system.

At the presented work were performed in an operating dairy farm the experimental measurements of maximum temperature of a cow udder by thermographic method in 4 different groups of animals sampled according to the stage of mastitis determined by kenotest. The probability density function of udder temperature values in all sample groups of cows is described by the normal probability density law. Average maximum udder temperature during milking was 36,2 °C in healthy cows, and 38,5 °C at subclinical stages of mastitis, and 39,6 °C for clinically pronounced stages of mastitis.

It is advisable to accumulate thermographic data about cow udder temperature changes averaged over time over a certain time period. This will reduce the influence of random factors such as ambient temperature variations, lactation phase, stress on the animal, etc. As a result, this will increase the likelihood of correct decisions in identifying subclinical mastitis. In addition, the milking machine also affects the temperature of the cow udder, so it is necessary to take into account the moment of taking a picture during milking.

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