Wavelet transform for near infrared spectral data mining: single spectrum mastitis diagnosis

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Introduction

Mastitis is a widely spread disease of the mammary gland. In the dairy industry, it causes the deterioration in milk quality, reproduction loss and about 25% decrease in milk production.[1,2]

A variety of diagnostic tests for mastitis are available which differ with respect to sensitivity, specificity, speed and cost. The world standard for cow's mastitis diagnosis is the somatic cell count (SCC) in the milk measured at-line. Absolute electrical conductivity (AEC) and differential electrical conductivity (DIF) of quarter milk samples are another mastitis indicator used for screening.[3–6]

Near infrared (NIR) spectroscopy has been applied to measure the content of various constituents in milk.[7–11] NIR in a short wave region has been examined as a method, not only for quantitative milk analysis, but also for mastitis detection.[12-14]

Wavelet transform (WT) gives local frequency information and involves studying certain phenomena at different scales.[15,16] Wavelets are an extension of Fourier analysis. The goal is to turn the information of a signal into coefficients that will tell in what way the analysing wavelet needs to be transformed in order to describe that signal. Wavelets automatically adapt to the different components of a signal, using a small window for high-frequency components and a large window for low-frequency components. The procedure is called multi-resolution and usually several scales are used. Together, all the coefficients at all the scales give a picture of the signal.

The purpose of this investigation was to find out if WT could be used as an extension of the NIR spectrum and a tool for further spectral data mining. The final goal was to perform early mastitis diagnosis by using WT of a single quarter milk spectrum in the NIR range from 1100 to 2500 nm.

Material and methods

A total of 64 quarter foremilk samples, from morning milking, were collected from four Holstein cows for four consecutive days. One of the cows was in her third lactation, one in her fourth, one in her fifth and one her in sixth lactation, respectively. Quarter milk samples were marked as front right (FR), rear right (RR), front left (FL) and rear left (RL).

All samples were analysed for somatic cell count by Fossomatic 90 (Foss-Electric, Tokyo, Japan) and for absolute electrical conductivity by Milk Checker (Oriental Instruments Ltd., Tokyo, Japan). Electrical conductivity measurements were carried out simultaneously with the NIR spectral measure-

Table 1. Somatic cell count and differential electrical conductivity values of tested quarter milk samples.

Cow No.	Quarter	Somatic cell counts × 1000 cell ml^{-1}				differential electrical conductivity			
		Day				Day			
		30.07	1.08	3.08	5.08	30.07	1.08	3.08	5.08
35	FR	3960	3577	1114	3250	1.8	2.7	2.5	1.3
	RR	24	102	40	36	0.3	1.2	0.5	0.5
	FL	2641	2399	4295	10904	1.6	2.7	2.5	1.7
	RL	10	124	15	21	0	0	0	0
39	FR	5	20	23	33	0.5	0.5	0.5	0.8
	RR	5	7	23	45	0	0.5	0	0
	FL	5	7	15	27	0.2	0.5	0.5	0.5
	RL	5	11	35	21	0	0	0.3	0
40	FR	3	8	29	13	0.8	0	0	0.3
	RR	46	41	40	30	1	0	0.3	0
	FL	5	18	33	26	0.5	0	0	0
	RL	5	26	27	51	0	0	0	0
46	FR	36	26	35	47	0.3	0.5	0.5	1
	RR	15	15	21	15	0	0	0	0.8
	FL	26	25	40	38	0.3	0.3	0.5	0
	RL	29	15	28	24	0	0.3	0.3	0.8

ments. For each cow, DIF, differences between milk and AEC of udder quarter with lowest value and values obtained from other quarters, were calculated.

Near infrared milk spectra were obtained for all samples by InfraAlyzer 500 spectrophotometer (Bran+Luebbe, Norderstedt, Germany), using a transflectance measured mode in the spectral region from 1100 to 2500 nm with 2 nm interval and were recorded in the linked computer as absorbance i.e. log (1/*T*). Prior to spectral analysis each sample was warmed up to 40°C in a water bath.

WT was performed by Mathematica's Wavelet Explorer software package, Wolfram Research Inc., Champaign, Illinois, USA. Exponentially decaying discrete Battle, Lemarie 12-tap wavelet, was used. The wavelet frequency bands (scales) were defined as multi-resolution scales from 10 to 50, where: very low frequency scales (VLF) 10 and 20 were in the range of 128 to 256 nm and 64 to 128 nm, respectively; low frequency (LF) scales 30 and 40 were in the range of 32 to 64 nm and 16 to 32 nm, respectively; high frequency (HF) scale 50 was in the range of 8 to 16 nm.

Results and discussion

The examined quarter milk samples were defined as mastitic or not after SCC (SCC > 300 000 cell ml^{-1} for mastitic quarter) and DIF (DIF > 0.5 for mastitic quarter) test (Table 1) were carried out.

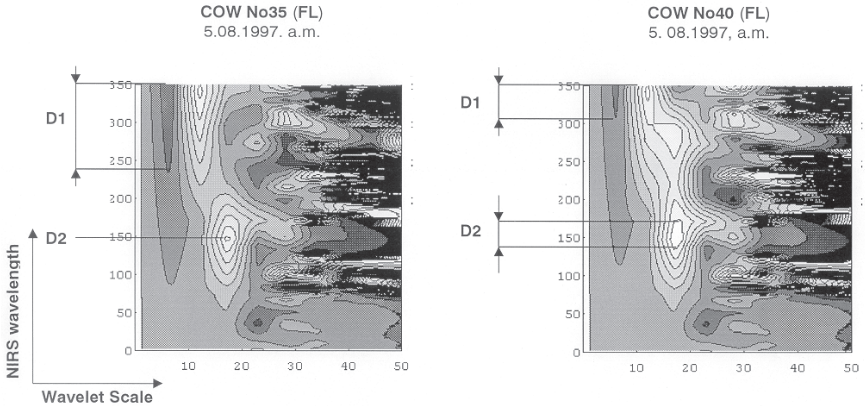

Figure 1. Wavelet transform of single milk spectra: (a) from a mastitic cow, (b) from a healthy cow.

Cow No 35 (FR, RR and FL quarters) was considered mastitic and cows No 39, 40 and 46 wer considered healthy.

We have found that the wavelet energy (WE) level as a function of the NIR wavelength showed a stable relationship between the cow and quarter's health condition, respectively. The WT NIR absorption spectra of quarter milk samples exhibited clear differences between normal and mastitic milk in both: the wavelet energy (WE) (Z) and the frequency (X) domains over the examined spectral region (Y: 1100–2500 nm). The WT results were consistent during the examined period of time. The results for WT of quarter milk spectra of one mastitic and one healthy cow are shown on Figure 1.

In order to identify the examined cow as healthy or having mastitis, we established a new variable, D1. For the healthy cow, the WE decreased slowly (in the low frequency area: X-axis) starting from the longest wavelengths (upper part of the Y-axis) and the highest WE part covered only a small NIR range under 2500 nm. This condition was described by D1 (Figure 1). The behaviour of D1 was opposite in the case of the diseased cow. The highest WE part covered a longer wavelength range starting from 2500 nm.

The examined quarter was identified as healthy or mastitic by the second variable, D2 (Figure 1) according to the WE in the next frequency scale and in the wavelength range around 1100–1700 nm (lower part of the Y-axis). The obtained values of D1 and D2 for the examined milk quarter samples are shown in Table 2.

As a result of these findings "Single Spectrum Mastitis Diagnosis Algorithm" has been developed as follows: If D1 >, the examined cow has mastitis. If D1 <, the examined cow is healthy. If M > and D2 >, the cow has mastitis, but the analysed quarter is healthy. If D1 > and D2 <, the cow has mastitis and the analysed quarter does, too. If D1 < and D2 >, the cow is healthy and the analysed quarter, too. If Dl < and D2 <, the cow is healthy, but the analysed quarter tends to have mastitis.

The result of applying the "Single Spectrum Mastitis Diagnosis Algorithm" to spectral data of a healthy and mastitic cow, respectively, is shown in Figure 2. Similar results were obtained for the rest of the examined cows and for all the spectral data that has been analysed by WT. Cow No. 46 had high D1 values, similar to those of cow No. 35. Her D2 values for FR and FL were low in some of the experiments. This information, seen together with the dynamics of SCC and DIF, and when compared to the rest of the cows and quarters, could be discussed as very early symptoms for mastitis diagnosis. There were some cases where the healthy cows No. 39 and No. 40 showed reverse WE (the stars in Table 2), i.e. D2 covered an area with WE pick, but not a valley as shown in Figure 2. It could be that D2, to-

Table 2. Variables D1 and D2 for tested quarter milk samples (stars represent reverse WE where D2 covered an area with WE pick, but not a valley).

Cow number	Quarter	D1 (nm)				D2 (nm)			
			Day				Day		
		30.07	1.08	3.08	5.08	30.07	1.08	3.08	5.08
35	FR	388	444	406	388	37	37	37	37
	RR	370	444	370	388	74	55	74	55
	FL	425	425	425	425	74	37	18	is
	RL	252	370	370	370	92	74	92	55
39	FR	185	240	166	222	111	92	92	74
	RR	166	222	222	240	*	92	92	74
	FL	166	240	166	240	92	92	111	74
	RL	166	277	222	240	111	925	92	74
40	FR	166	37	55	111	*	*	*	*
	RR	166	130	166	204	111	130	130	130
	FL	111	130	55	166	*	*	*	130
	RL	111	74	74	166	*	*	*	130
46	FR	463	518	481	518	74	55	55	37
	RR	370	463	407	407	ill	92	92	92
	FL	463	555	463	499	74	55	74	37
	RL	407	407	407	425	92	92	92	74

* Area with wavelet energy pick.

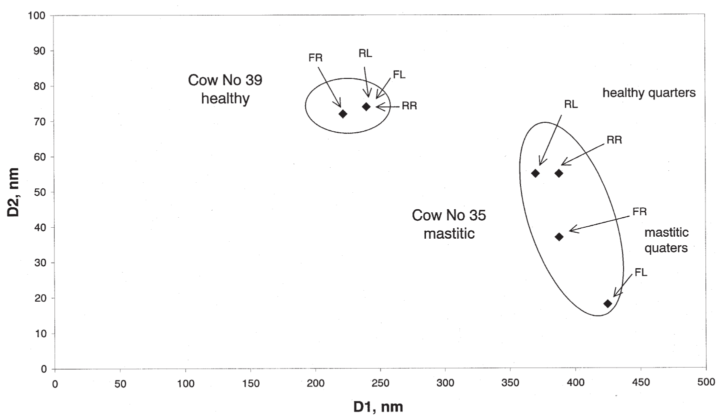

Figure 2. Illustration of "Single Spectrum Mastitis Diagnosis Algorithm".

gether with D1, could define very early and, also, different stages, of mastitis. The explanation of these phenomena could be the next step for further investigation.

Conclusion

It has been found that wavelet transform could be used as a powerful tool for further NIR spectral data mining. In this study WT has been utilised as a "microscope" to provide more detailed information from a single NIR spectrum.

An algorithm for an early diagnosis of cow's mastitis, based on WT of an udder quarter milk spectrum in the NIR range (1100–2500 nm), has been proposed. By using "Single Spectrum Mastitis Diagnosis Algorithm" it is possible to identify diseased cow, as well as the status of the respective udder quarter. Further investigation is needed to define quantitative criteria for mastitis diagnosis and its stages.

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