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On-line Near-Infrared Spectroscopic Sensing Technique for Assessing Milk Quality during Milking

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Abstract. *There has been a need in recent years for a method that will enable dairy farmers to assess milk quality of individual cows during milking. We constructed on-line near-infrared (NIR) spectroscopic sensing system on an experimental basis. This system enables NIR spectra of unhomogenized milk to be obtained during milking over a wavelength range of 600 nm to 1050 nm. We also developed calibration models for predicting three major milk constituents (fat, protein and lactose), somatic cell count (SCC) and milk urea nitrogen (MUN) of unhomogenized milk, and we validated the precision and accuracy of the models. The coefficient of determination (r^2) and standard error of prediction (SEP) of the validation set for fat were 0.95 and 0.42%, respectively. The values of r^2 and SEP for protein were 0.91 and 0.09%, respectively; the values of r^2 and SEP for lactose were 0.94 and 0.05%, respectively; the values of r^2 and SEP for SCC were 0.82 and 0.27 log SCC/mL, respectively; and the values of r^2 and SEP for MUN were 0.90 and 1.33 mg/dL, respectively. These results indicated that the NIR sensing system developed in this study could be used to assess milk*

quality in real time during milking. The system can provide dairy farmers with information on milk quality and physiological condition of individual cows and therefore give them feedback control for optimizing dairy farm management.

Keywords. Near-infrared spectroscopy, dairy farming, milk fat, protein, lactose, somatic cell count, milk urea nitrogen.

Introduction

Dairy farming is labor-intensive and involves many tasks such as feeding, milking, livestock management, feed crop production and manure treatment. Large-scale dairy farmers manage their livestock in groups, a system known as herd management. But monitoring information of each cow, a system known as individual cows management, is also necessary for production of high-quality milk. Recently, there has been a need for a method that will enable dairy farmers to assess milk quality of individual cows during milking.

Near-infrared spectroscopy (NIRS) is a new nondestructive method for obtaining qualitative information of food and agricultural commodities. NIRS has already been put in practical application for assessment of the quality of rice grain (Kawamura et al., 2002; Kawamura et al., 2003). NIRS has also been used to assess milk quality (Sato et al., 1987; Tsenkova et al., 1999; Tsenkova 2001a; Tsenkova et al., 2001b; Tsenkova et al., 2001c; Natsuga et al., 2002), but it has been difficult to apply NIRS to real-time on-line monitoring of milk quality during milking.

We have constructed on-line NIR spectroscopic sensing system on an experimental basis and have demonstrated the precision and accuracy of calibration models developed by the sensing system in this paper.

Materials and methods

Near-infrared spectroscopic sensing system

On-line near-infrared (NIR) spectroscopic sensing system for assessing milk quality of individual cows during milking was constructed on the experimental basis. The system consisted of an NIR instrument, a milk flow meter and a milk sampler (Figure 1 and Figure 2). The system was attached to between a teatcup cluster and a milk bucket of a milking machine. Unhomogenized milk from the teatcup cluster continuously flowed into the milk chamber of the spectrum sensor and flowed out through an outlet pipe for surplus milk to the milk flow meter. The volume of milk sample in the chamber was about 230 mL. The spectrum sensor acquired diffusion transmittance (interactance) spectra through the milk. The diffusion transmittance spectra were recorded in the range of 600 to 1050 nm at 1-nm intervals every 10 seconds during milking. Six continual spectra were averaged to obtain a spectrum for one minute. The optical axes of halogen lamp and optical fiber were set in the same level (Figure 3 and Table 1).

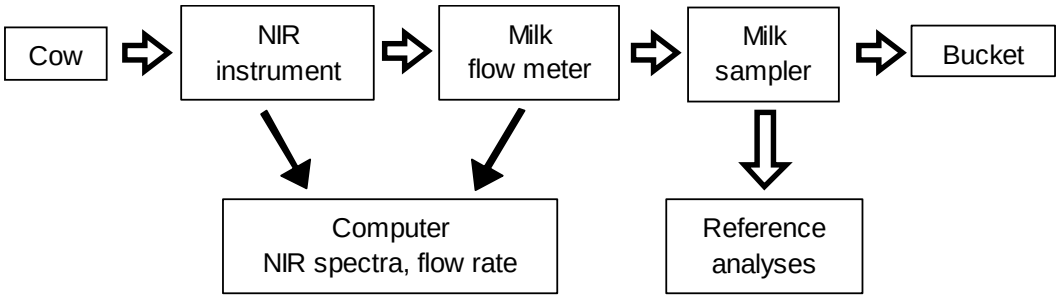

Figure 1. Flow chart of the on-line near-infrared spectroscopic sensing system for assessment of milk quality during milking.

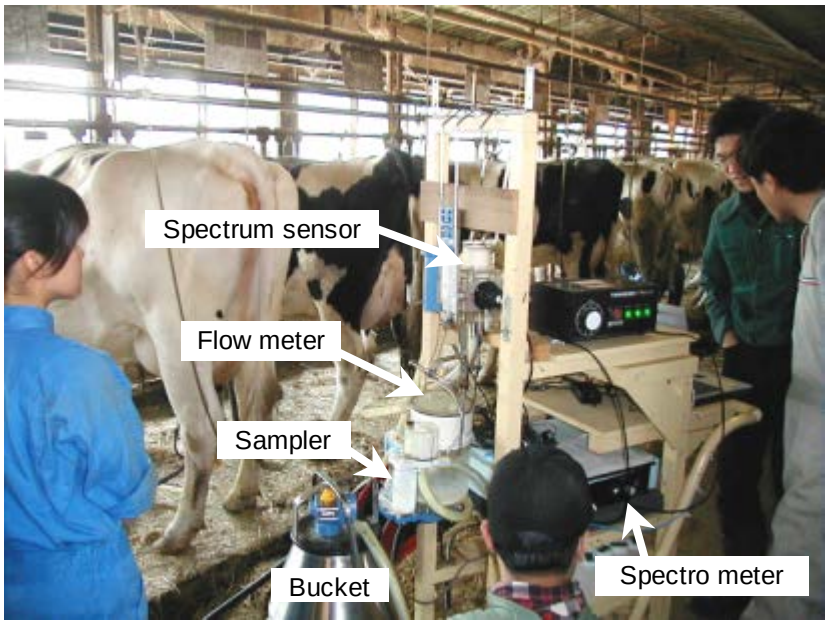

Figure 2. On-line near-infrared spectroscopic sensing system.

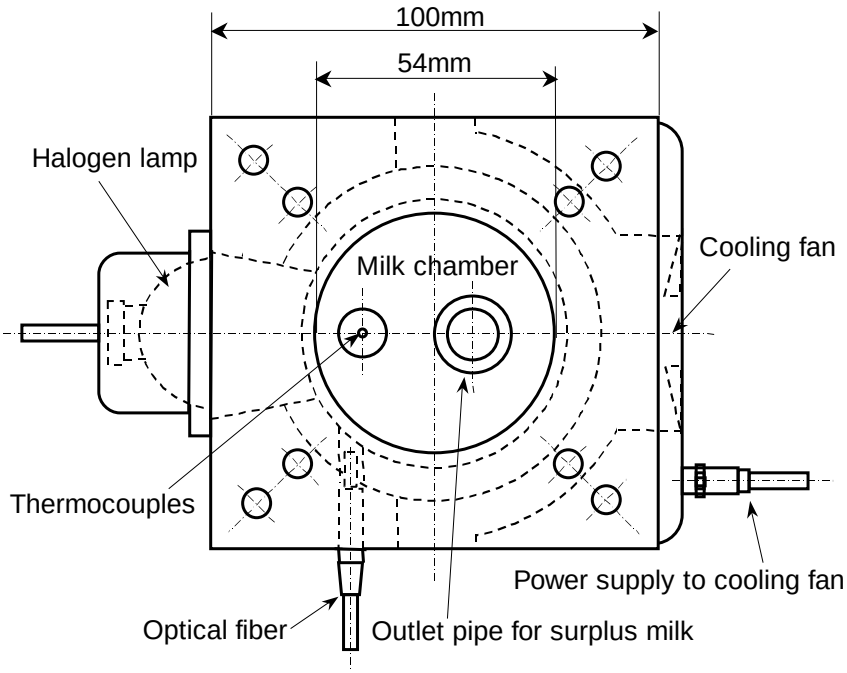

Figure 3. Plane view of the NIR spectrum sensor constructed on an experimental basis.

Cows and milk samples

Four Holstein cows in the stage of their early lactation to late lactation were used in the experiment (Table 2). The experiment was started on October 23, 2001 and continued until June 12, 2002. Measurements were carried out in two consecutive milkings, i.e., milking in the evening and the next morning every two weeks during the experimental period. Milk samples were collected from milk sampler every minute during milking. The experiment was conducted to cover variations in milk spectra caused by cow individuality, calving times, lactation stage, milking time, physiological conditions, feeding stage and environmental temperature.

Table 1. Specifications of the near-infrared spectroscopic instrument constructed on an experimental basis.

Devices	Specifications
Spectrum sensor	Diffusion transmittance spectrum sensor
Light source	Halogen lamp
Optical fiber	Silica glass fiber, 0.6 mm
Milk chamber surface	Glass
Volume of milk sample	Approx 230 mL
Distance between optical axis and milk level	93 mm
Spectrometer	Diffraction grating spectrometer
Optical density	Transmittance
Wavelength range	600 - 1050 nm, 1-nm intervals
Wavelength resolution	Approx 5 nm
Photocell	Linear array CCD, 2048 pixels
Thermocontroller	Peltier cooling system
Data processing computer	DELL, Windows XP, Celelon 1.06GHz, RAM 384MB
A/D converter	12 bit
Spectrum data acquisition	Every 10 seconds

Table 2. Cows used in the experiment.

Number of cows	Birthday	Calving day	Calving times	Experimental period Days after calving
1110	1997/4/24	2001/10/25	3	13 - 210
1116	1998/4/6	2001/10/16	2	9 - 240
1119	1998/4/21	2001/11/1	2	34 - 139
1141	1998/2/3	2001/10/26	2	12 - 230

Reference analyses

Three major milk constituents (fat, protein and lactose), somatic cell count (SCC) and milk urea nitrogen (MUN) of unhomogenized milk were measured as indices of milk quality in this study. The milk constituents were determined using a Milcoscan S54A (Foss Electric, Hillerod, Denmark), SCC was determined using a Fossomatic 5000 (Foss Electric), and MUN was determined using a Milcoscan 3000 (Foss Electric). The total numbers of samples used for reference analyses were 455 for milk constituents, 404 for SCC and 236 for MUN. SCC was expressed to be transformed into common logarithms.

Chemometric analyses

Chemometric analyses were carried out to develop calibration models for each milk quality item and to validate the precision and accuracy of the models. Spectral data analyses software (The Unscrambler, Camo AS, Trondheim, Norway) was used for the analyses. The reference samples were randomly divided into two sample sets: a calibration subset containing two-thirds of all samples and a validation subset containing remaining samples (one-third). The statistical method of partial least squares (PLS) was used to develop calibration models from the transmittance spectra and reference data. Pretreatment such as smoothing or derivatives was not done on the spectra.

Figure 4 shows an example of an original spectra set of unhomogenized milk from cow number 1141 in morning milking on February 20, 2002. The bottom of the spectra around 970 nm wavelength in Figure 4 indicated the second overtone absorption by water molecular.

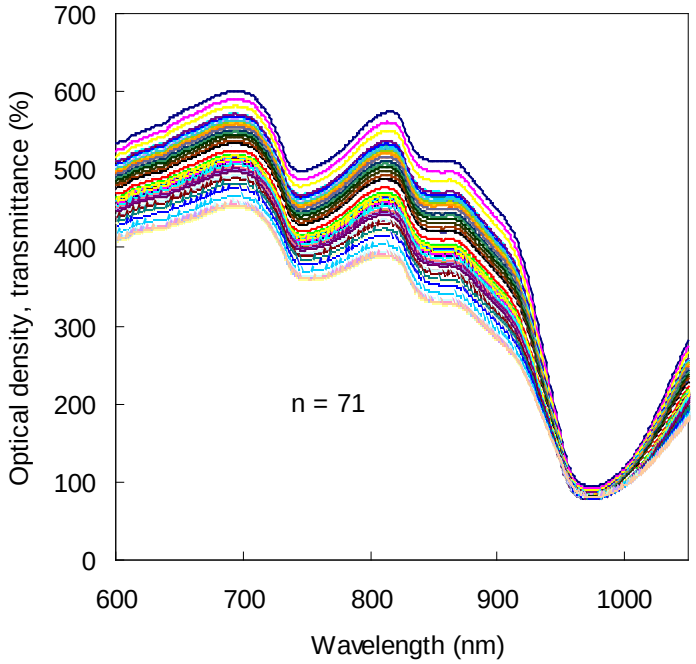

Figure 4. Original spectra of unhomogenized milk from cow number 1141 in morning milking on February 20, 2002.

Results and discussion

The validation statistics of the NIR instrument for determination of milk quality are summarized in Table 3. The correlations between reference and NIR-predicted values of fat, protein, lactose, SCC and MUN are shown in Figure 5 to 9, respectively.

In terms of the precision and accuracy for predicting the three major milk constituents, the values of the coefficient of determination (r^2) were higher than 0.9, the values of the standard error of prediction (SEP) were small enough compared with the range of each constituent, and the values of bias were almost zero. The results indicated that the NIR instrument constructed in this study is useful for real-time assessment of milk constituents during milking.

SCC has been accepted as the world standard for mastitis diagnosis and it is an important indicator of milk quality. The values of r^2 and SEP for SCC prediction were 0.82 and 0.27 log SCC/mL, respectively. The milk containing more than 200,000 somatic cells/mL i.e., 5.3 log SCC/mL is low quality. Using the calibration model for SCC to classify milk samples into two qualitative groups (high quality and low quality) gave a probability for classifying them correctly of 86% (Shenk et al., 1993). The model could also be used for diagnosis of subclinical mastitis.

MUN is an indicator of protein feeding efficiency in dairy cows. Too little protein in the diet results in poor milk production and infertility in cows. On the other hand, too much protein eventually contributes to environmental contamination through urine and fecal output from cows. The values of r^2 and SEP for MUN prediction were 0.90 and 1.33 mg/dL, respectively. The calibration model could be used for monitoring the nutritional status of individual cows.

Installation of the NIR spectroscopic sensing system developed in this study into a milking robot system would enable assessment of milk constituents, diagnosis of mastitis and assessment of physiological conditions of cows in real time during milking. The system could provide dairy farmers with information on milk quality and physiological condition of individual cows and therefore give them feedback control for optimizing dairy farm management. Using the NIR sensing system, dairy farm management could proceed to the next step towards dairy precision farming based on monitoring information of individual cows.

Table 3. Validation statistics of the near-infrared instrument for determination of milk quality.

Milk quality items	n1	n2	Range	r^2	SEP	Bias	Regression line
Fat (%)	455	151	0.9 - 8.3	0.95	0.42	0.01	y = 0.99x + 0.05
Protein (%)	455	151	2.3 - 3.8	0.91	0.09	0.00	y = 0.99x + 0.03
Lactose (%)	455	151	4.5 - 5.5	0.94	0.05	0.00	y = 0.99x + 0.06
SCC (log SCC/mL)	404	134	3.0 - 5.8	0.82	0.27	-0.03	y = 0.99x + 0.07
MUN (mg/dL)	236	78	1.4 - 19.3	0.90	1.33	-0.03	y = 0.98x + 0.19

n1: total number of samples. n2: number of validation samples. r^2: coefficient of determination. SEP: standard error of prediction. Regression line: regression line from predicted value (x) to reference value (y).

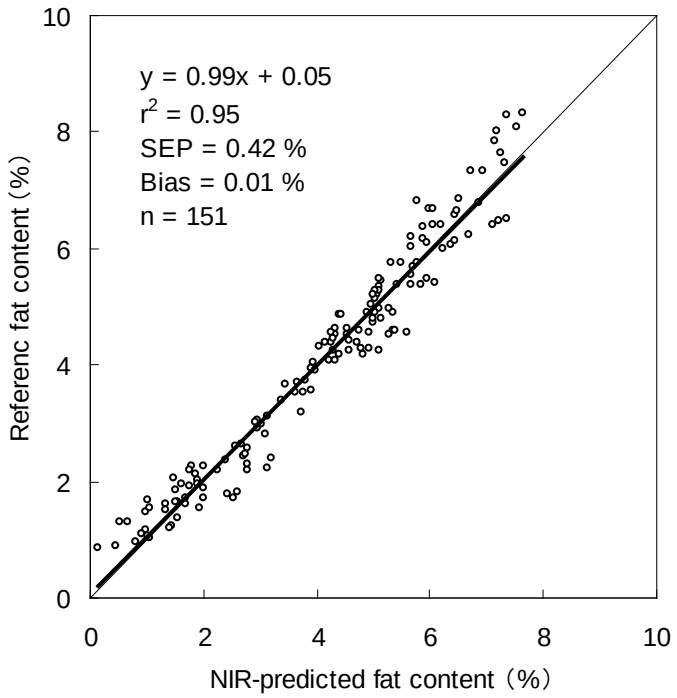

Figure 5. Correlation between reference fat content and NIR-predicted fat content.

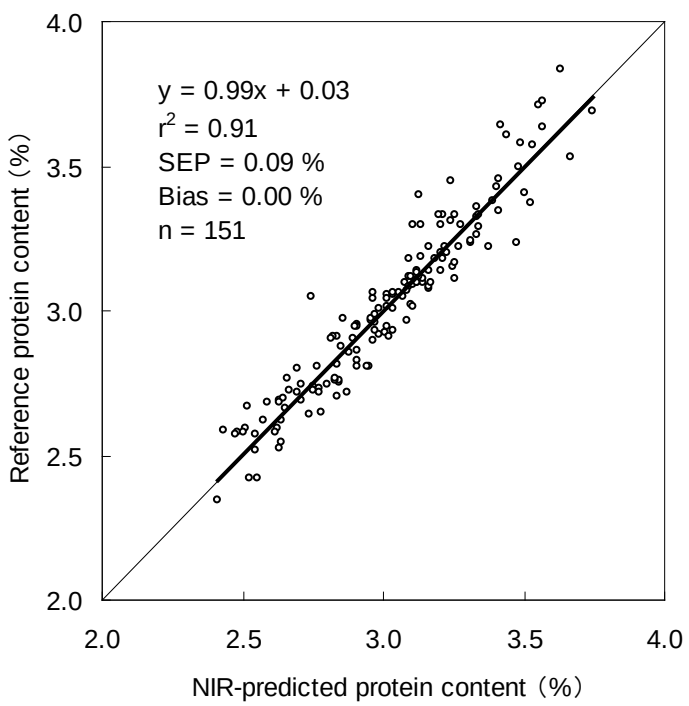

Figure 6. Correlation between reference protein content and NIR-predicted protein content.

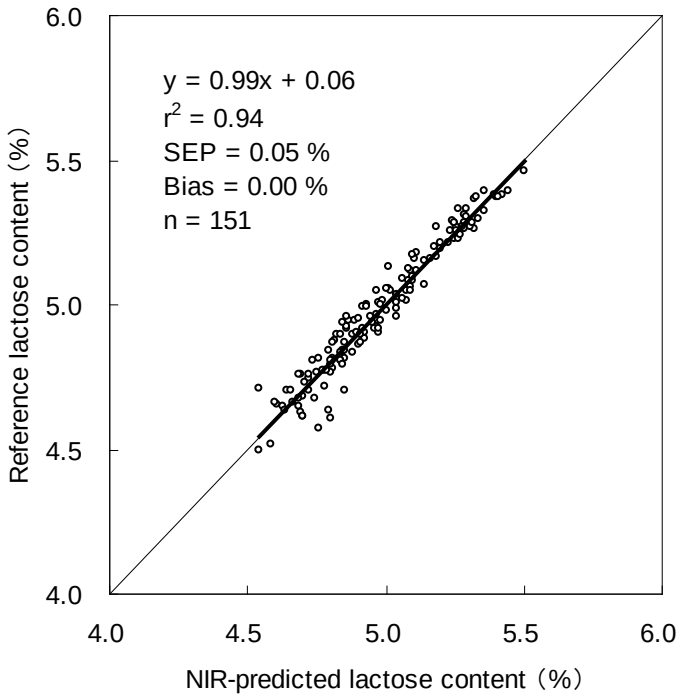

Figure 7. Correlation between reference lactose content and NIR-predicted lactose content.

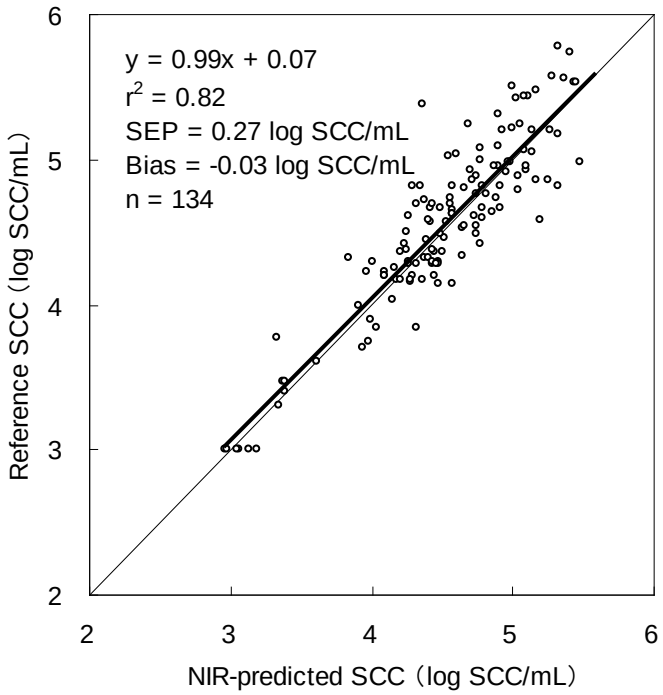

Figure 8. Correlation between reference SCC and NIR-predicted SCC.

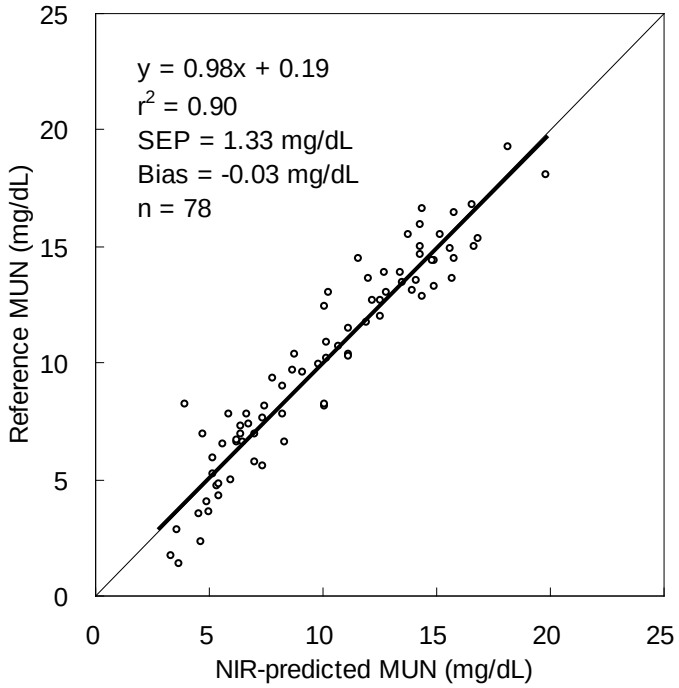

Figure 9. Correlation between reference MUN and NIR-predicted MUN.

Conclusion

The on-line NIR spectroscopic sensing system developed in this study can be used for real-time assessment of fat, protein, lactose, SCC and MUN during milking with sufficient precision and accuracy.

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