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# On-line Near-Infrared Spectroscopic Sensing Techniques for Assessing Milk Quality in Automatic Milking Systems

**Shuso Kawamura, Associate Professor**

Agricultural Process Engineering Lab. Hokkaido University, Sapporo 060-8589, Japan, shuso@bpe.agr.hokudai.ac.jp

**Masataka Kawasaki, Graduate Student**

Agricultural Process Engineering Lab. Hokkaido University, Sapporo 060-8589, Japan, kawasaki@bpe.agr.hokudai.ac.jp

**Shigeru Morita, Professor**

Faculty of Dairy Science, Rakuno Gakuen University, Ebetsu, 069-8501, Japan, smorita@rakuno.ac.jp

**Michio Komiya, Associate Professor**

Faculty of Dairy Science, Rakuno Gakuen University, Ebetsu, 069-8501, Japan, komiya@rakuno.ac.jp

**Kazuhiko Itoh, Professor**

Agricultural Process Engineering Lab. Hokkaido University, Sapporo 060-8589, Japan, kazu@bpe.agr.hokudai.ac.jp

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**Abstract.** *We constructed an on-line near-infrared (NIR) spectroscopic sensing system on an experimental basis. The sensing system enables NIR spectra of unhomogenized milk to be obtained in automatic milking systems over a wavelength range of 600 nm to 1050 nm. Calibration models for determining three major milk constituents (fat, protein and lactose), somatic cell count (SCC) and milk urea nitrogen (MUN) of unhomogenized milk were developed, and the precision and accuracy of the models were validated. The coefficient of determination ($r^2$) and standard error of prediction (SEP) of the validation set for fat were 0.95 and 0.27%, respectively. The values of $r^2$ and SEP for protein were 0.72 and 0.15%, those for lactose were 0.85 and 0.18%, those for SCC were 0.62 and 0.32 log SCC/mL, and those for MUN were 0.68 and 2.08 mg/dL, respectively. These results indicate that the NIR sensing system developed in this study could be used to assess milk quality in real time in automatic milking systems. 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. By using the system dairy farmers will be able to produce high-quality milk and dairy precision farming will be realized*

**Keywords.** dairy precision farming, quality control, diagnosis, 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. However, monitoring milk quality of each cow and managing each cow, a system known as individual cows management, is also essential 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 on foods and agricultural commodities. NIRS has already been put to practical use in automatic rice-quality inspection systems in Japan (Kawamura et al., 2002; Kawamura et al., 2003a). 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 of individual cows during milking.

We have constructed an on-line near-infrared (NIR) spectroscopic sensing system on an experimental basis to assess milk quality. We (Kawamura et al., 2003b) reported that the NIR sensing system can be used for real-time assessment of milk quality during milking with sufficient precision and accuracy. Based on our results, we installed the NIR sensing system in an automatic milking system (a milking robot system). In this study, the precision and accuracy of the NIR sensing system for assessing milk quality during milking by a milking robot were validated.

## Materials and methods

### *Near-infrared spectroscopic sensing systems*

An on-line near-infrared (NIR) spectroscopic sensing system for assessing milk quality of individual cows during milking was constructed on an experimental basis. The system consisted of an NIR instrument, a milk flow meter, a milk sampler and a laptop computer (Figure 1). The system was installed in a milking robot system (Astronaut, Lely Industries NV, Maasland, Holland) (Figure 2). Unhomogenized milk from the milking robot 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 optical axes of a halogen lamp and an optical fiber were set at right angles to each other at the same levels (Figure 3). The spectrum sensor acquired spectra of diffusion transmittance (interactance) through the milk. The diffusion transmittance spectra were recorded in the wavelength 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 (Table 1).

### *Cows and milk samples*

Seventeen Holstein cows in the stage of early lactation to late lactation were used in the experiment (Table 2). The experiment was conducted all day and night on October 20th and 21st, 2003. Milking was automatically started whenever a cow walked into the milking robot. Milk samples were collected from the 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 and environmental temperature.

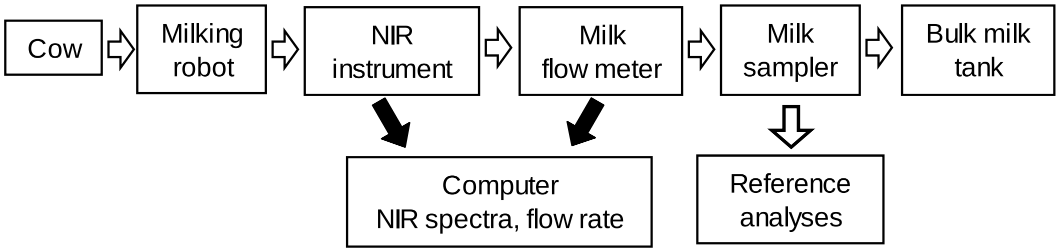


Figure 1. Flow chart of an on-line near-infrared spectroscopic sensing system for assessing milk quality in an automatic milking system.

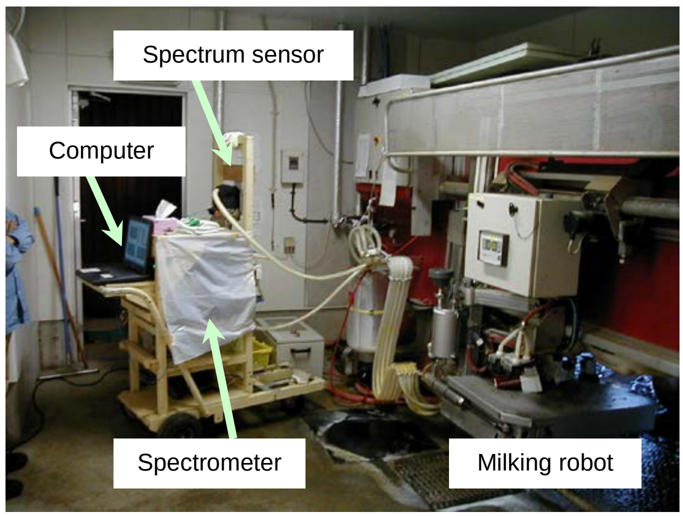


Figure 2. On-line near-infrared spectroscopic sensing system installed in an automatic milking system.

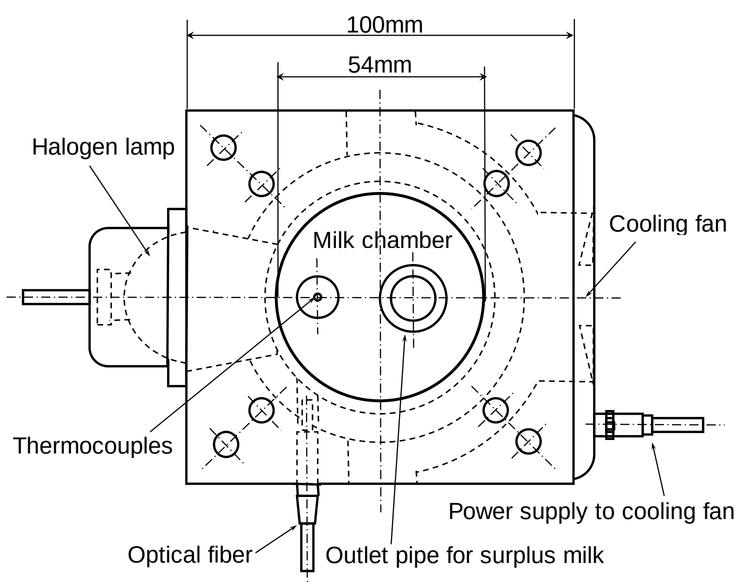


Figure 3. Plane view of the near-infrared spectrum sensor constructed on an experimental basis.

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 diameter |
| 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 256KB |
| A/D converter | 12 bit |
| Spectrum data acquisition | Every 10 seconds |

Table 2. Cows used in the experiment.

| Cow number | Date of birth | Date of latest calving | Calving times | Experimental date and time in 2003 | Number of reference samples |
|---|---|---|---|---|---|
| 263 | Oct 01, 1998 | Jan 05, 2003 | 3 | Oct 20 20:22<br>Oct 20 22:40<br>Oct 21 7:11 | 9 |
| 281 | Apr 28, 1997 | Oct 20, 2002 | 4 | Oct 20 19:00<br>Oct 21 3:49 | 9 |
| 297 | Jan 01, 1999 | Aug 09, 2003 | 3 | Oct 20 15:59<br>Oct 21 5:11 | 11 |
| 300 | Mar 14, 1999 | Mar 08, 2003 | 3 | Oct 20 20:08<br>Oct 21 6:41 | 17 |
| 301 | Mar 18, 1999 | Apr 09, 2003 | 3 | Oct 20 21:32<br>Oct 21 8:05 | 12 |
| 304 | Apr 27, 1999 | Apr 16, 2003 | 3 | Oct 21 1:12<br>Oct 21 8:40 | 15 |
| 310 | Jun 25, 1999 | Jul 08, 2003 | 3 | Oct 20 15:38<br>Oct 20 23:06 | 9 |
| 311 | Apr 10, 1999 | Oct 08, 2003 | 3 | Oct 21 5:39 | 5 |
| 312 | May 18, 1999 | Sep 07, 2003 | 3 | Oct 20 14:45<br>Oct 20 22:24<br>Oct 21 6:10<br>Oct 21 8:16 | 16 |
| 320 | Sep 02, 1999 | Dec 18, 2002 | 2 | Oct 20 19:11 | 7 |
| 322 | Nov 04, 1999 | May 24, 2003 | 2 | Oct 20 20:46<br>Oct 21 7:02 | 13 |
| 325 | Feb 19, 2000 | Mar 03, 2003 | 2 | Oct 20 20:29<br>Oct 21 5:50<br>Oct 21 8:46 | 9 |
| 326 | Oct 29, 1999 | Aug 07, 2003 | 2 | Oct 20 19:47<br>Oct 21 6:00 | 20 |
| 331 | Mar 03, 2000 | Mar 03, 2003 | 2 | Oct 21 6:52 | 8 |
| 333 | Mar 23, 2000 | Sep 02, 2003 | 2 | Oct 20 20:57<br>Oct 21 4:58 | 19 |
| 334 | Mar 27, 2000 | May 26, 2003 | 2 | Oct 21 1:35 | 7 |
| 344 | Jul 25, 2000 | Sep 13, 2003 | 2 | Oct 20 15:08<br>Oct 20 22:08<br>Oct 21 4:09 | 30 |

### *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 and MUN were determined using a Milkoscan 4000 (Foss Electric, Hillerod, Denmark), and SCC was determined using a Fossomatic 5000 (Foss Electric). The total numbers of samples used for reference analyses were 216 for milk constituents and SCC, and were 210 for MUN. SCC was converted into common logarithms.

### *Chemometric analyses*

Chemometric analyses were carried out to develop calibration models for milk quality items 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 the 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 of the spectra such as smoothing or derivatives was not performed.

## Results and discussion

### *Near-infrared spectra*

Figure 4 shows an example of an original NIR spectra set of unhomogenized milk from cow number 304 during milking on October 21, 2003. The deep dip of the spectra in the wavelength range of 970 to 990 nm in Figure 4 indicates second-overtone absorption by water molecules. The two dips in the spectra around 740 nm and 840 nm indicate overtone absorptions by C-H strings and C-C strings.

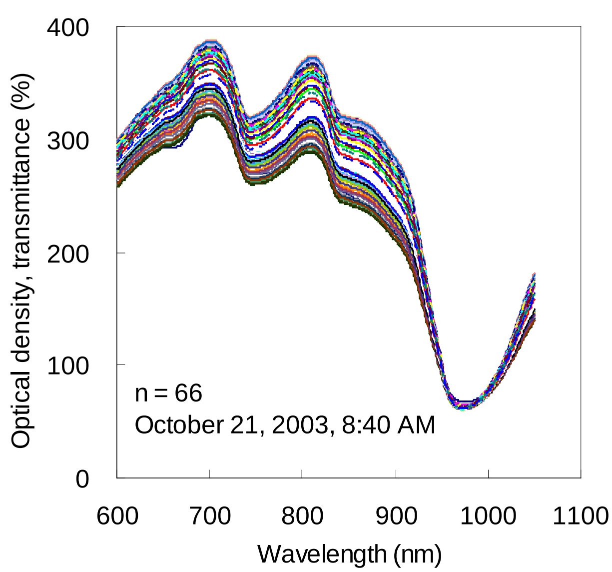


Figure 4. Original spectra of unhomogenized milk from cow number 304 during milking on October 21, 2003.

### *Precision and accuracy of calibration models*

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

The coefficient of determination ($r^2$), standard error of prediction (SEP) and bias of the validation set for fat were 0.95, 0.27% and 0.05%, respectively. The values of $r^2$, SEP and bias for protein were 0.72, 0.15% and 0.00%, respectively, and the values of $r^2$, SEP and bias for lactose were 0.85, 0.18% and -0.01%, respectively. Sufficient levels of precision and accuracy for predicting the three major milk constituents were indicated by the high values of $r^2$ and the small values of SEP compared with the range of each constituent and by the negligible values of bias (almost zero). The results indicated that the NIR sensing system constructed in this study is useful for real-time on-line assessment of milk constituents during milking by a milking robot.

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 0.62 and 0.32 log SCC/mL, respectively. Milk containing more than 200,000 somatic cells per one mL (i.e., 5.3 log SCC/mL) is of 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 78% (Shenk et al., 1993). Thus, the calibration 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. On the other hand, too much protein eventually results in environmental contamination through urine and fecal output from the cow and in infertility of the cow. The values of $r^2$ and SEP for MUN prediction were 0.68 and 2.08 mg/dL, respectively. Thus, the calibration model could be used for monitoring the nutritional status of individual cows.

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

| Milk quality items | n1 | n2 | Range | $r^2$ | SEP | Bias | Regression line |
|---|---|---|---|---|---|---|---|
| Fat (%) | 216 | 72 | 1.0 - 7.4 | 0.95 | 0.27 | 0.05 | y = 1.02 x - 0.02 |
| Protein (%) | 216 | 72 | 2.7 - 4.4 | 0.72 | 0.15 | 0.00 | y = 0.89 x + 0.39 |
| Lactose (%) | 216 | 72 | 1.4 - 4.9 | 0.85 | 0.18 | -0.01 | y = 1.05 x - 0.25 |
| SCC（log SCC/mL） | 216 | 70 | 3.8 - 6.3 | 0.62 | 0.32 | 0.10 | y = 0.94 x + 0.40 |
| MUN (mg/dL) | 210 | 68 | 1.4 - 19.2 | 0.68 | 2.08 | 0.07 | y = 0.92 x + 0.96 |

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).

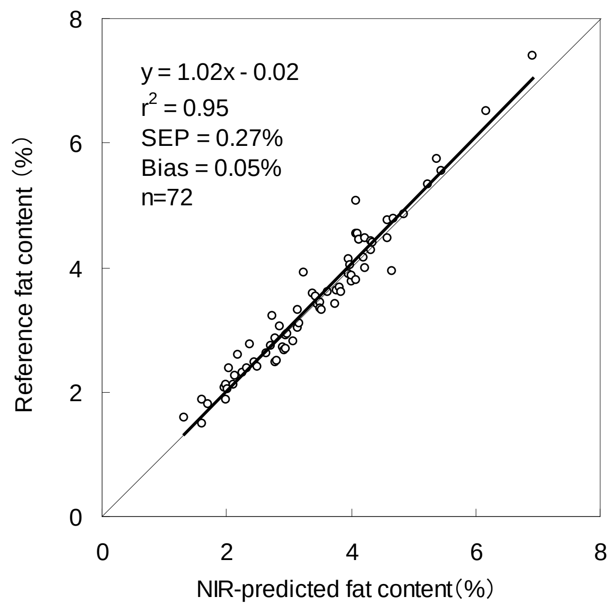


Figure 5. Correlation between reference fat content and NIR-predicted fat content.

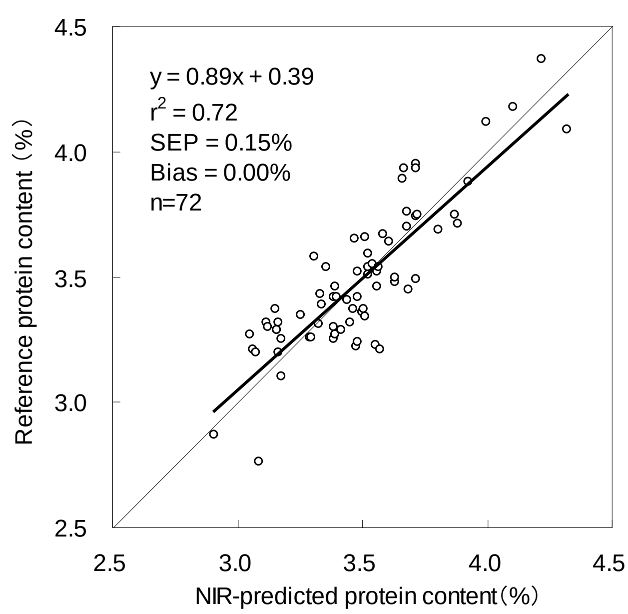


Figure 6. Correlation between reference protein content and NIR-predicted protein content.

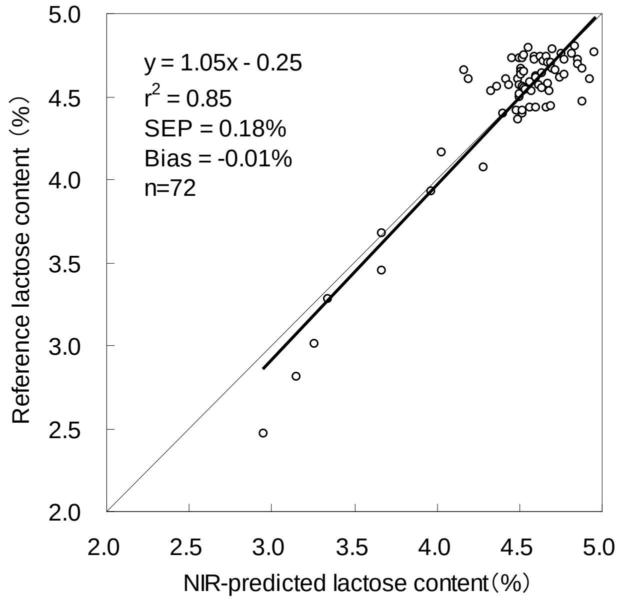


Figure 7. Correlation between reference lactose content and NIR-predicted lactose content.

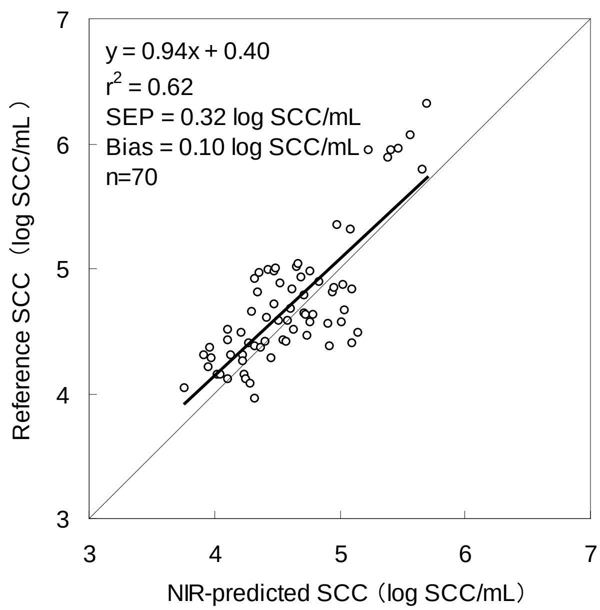


Figure 8. Correlation between reference SCC and NIR-predicted SCC.

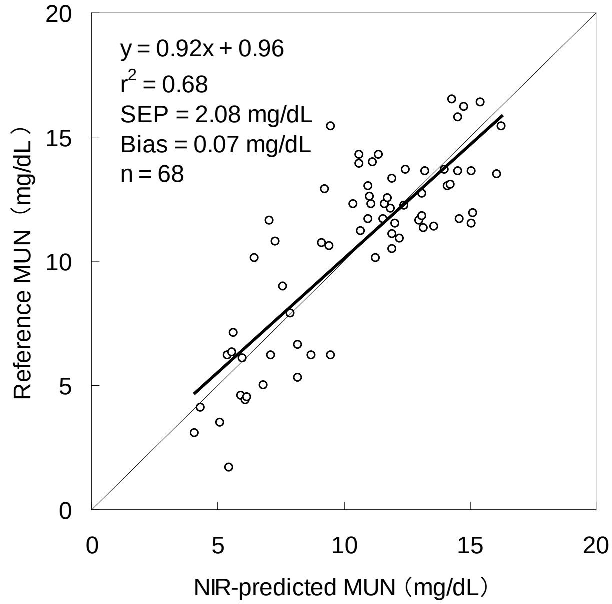


Figure 9. Correlation between reference MUN and NIR-predicted MUN.

### *Dairy precision farming*

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

## Conclusion

The on-line NIR spectroscopic sensing system developed in this study can be used for real-time on-line monitoring of fat, protein, lactose, SCC and MUN during milking by a milking robot with sufficient precision and accuracy. By using the NIR sensing system, dairy farmers will be able to produce high-quality milk and dairy precision farming will be realized.

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