Near infrared monitoring of biological objects on a dairy farm

R. Tsenkova, K. Itoh, M. Natsuga and J. Himoto
Faculty of Agriculture, Hokkaido University, Sapporo 060, Hokkaido, Japan.

Introduction

Dairy farming is labor intensive with numerous biological and physical processes that need to be monitored. The links between livestock and crop production include the opportunity for flexible feedback, differential appropriate feeding of animals and use of crop residues, manure and animal traction.[1] Also, robotics and artificial intelligence (AI) offer potential for dramatic changes in the milking systems of the future.[2,3]

Near infrared (NIR) spectroscopy is a growing technique for non-destructive analysis of agricultural products, feed composition and rumen degradation. NIR spectroscopy is applied in the field and the factory because it has the potential for robust and instant analysis.[4]

There is a need for uniform, multi-dimensional measuring technology to be used to control parameters of a variety of biological objects on a farm—on-line, non-destructively and without sampling or sample preparation.

NIR spectroscopy for automated monitoring on the farm

If we consider the dairy farm as a food plant, where the main product is milk, it is important to control, on-line, the product quality in order to manage the biotechnology of milk production, to produce milk with consistent quality and meet market requirements. NIR spectroscopy has been used for determination of a number of parameters on a dairy farm. The NIR region of the spectrum has proven useful in the study of biological objects (BO) because their absorbance in this region is not obscured by the absorbance due to water content.[4] The spectrum contains information about the major constituents of the BO,[5] and changes regarding to the water activity and structure. NIR spectroscopy is ideally suited for qualitative and quantitative analysis. On the other hand, the complex BO with variable characteristics, and the empirical nature of NIR spectroscopy require an intelligent approach to be applied. Therefore, NIR spectroscopy combined with an AI approach could be used on a dairy farm as an uniform, multi-dimensional measuring technology for BO monitoring.

When NIR analysis is applied to measure feed components, according to the published applications, the following constituents can be measured:[6–8] moisture, protein, oil, ash, amino acids, nitrogen, crude protein (CP), crude fiber, carotene, lignin, ether extract, starch, nitrogen detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), *in vivo* dry matter digestibility (IVDMD), digestible crude protein (DCP), digestible cell wall substance (DCW), total digestible nutrients (TDN), digestible energy intake (DEI), metabolisable energy etc. The analysis of CP and ADF by NIR spectroscopy has been certified as an “official method” by the Association of Official Analytical Chemists.[9]

NIR spectroscopy has been established as a method for analyzing the ingredients in dairy products. NIR spectroscopic prediction of fat and protein content in homogenized, single milk samples appears as accurate as classical determinations.[10] NIR spectroscopy is a suitable method also for the analysis of unhomogenized raw milk composition— fat, protein, lactose and total soluble solids.[11,12]

For component analysis, NIR has the same accuracy as a conventional method when using individual calibrations for each variety.[5,11] It has been used for the determination of a number of quality parameters in forage that have evolved in an attempt to stimulate animal performance. The results of such NIR determinations have been used to formulate a complete ration plan.[13,14]

Milk spectra from an individual cow can be assumed to be qualitative in a similar way to her physiological condition and milk quality.[11,15]NIR has been demonstrated as a simple and sensitive method for mastitis diagnosis with high repeatability and pathogen identification.[15,16] Also, NIR was found to have potential as a quick and simple method for qualitative and quantitative assessment of animal waste compost.[17] In a preliminary study, it has been demonstrated that it is feasibile for oestrus detection.[18]

All the examples cited above illustrate that on-line NIR sensors located at different points of the dairy farm, and implemented in an AI system, could provide input to adjust appropriate parameters for on-line process control based on interpretation of their readings. These interpretations could be programmed using human expertise combined with data from respective biological objects.

It can be stated that intelligent measurement technology on a dairy farm, based on NIR monitoring of biological objects, appears attractive and feasible. Expert systems and an AI approach incorporating physiological responses and including neural networks and genetic algorithms, are expected to be used in the future for processing data originating from automatic monitoring. If an automated system exists on a dairy farm and is equipped with NIR sensors for feed, milk and other parameters for on-line analysis, it could be possible to organize feedbacks in a uniform measurement system to optimize the feeding, cow treatment, environment, milking, waste management and crop production (Figure 1). In this regard, we describe below how NIR monitoring has been studied for on-farm mastitis diagnosis.

Materials and methods

Milk samples and spectra

In this study, a total of 200 unhomogenized "bucket milk" samples from 20 different cows, at different stages of lactation, for five consecutive months were collected from the corresponding milk yield meters at the end of the morning and evening milking, and then mixed.

A total of 220 quarters foremilk samples was collected before milking from five cows for five consecutive months (once a month) and from five mastitic cows for four consecutive days. Prior to the spectral analysis, each sample was warmed to 40°C in a water bath. NIR transmittance spectra (T) were collected on an NIRSystems 6250, in terms of optical density, with a wavelength range of 680–1235 nm [short wave (SW) NIR range], with 700 data points and 50 scans per sample. For NIR data a quartz cuvette with walls 1 mm thick and containing a milk sample 4 mm thick was used. Milk samples were obtained at Obihiro and Hokkaido University farms.

Chemical analysis

The duplicate samples sent to the Milk Testing Laboratory were analyzed for somatic cell count (SCC) by Foss-somatic (N. Foss Electric A/S, Hillerod, Denmark). Log (SCC) was used for the calibration work.

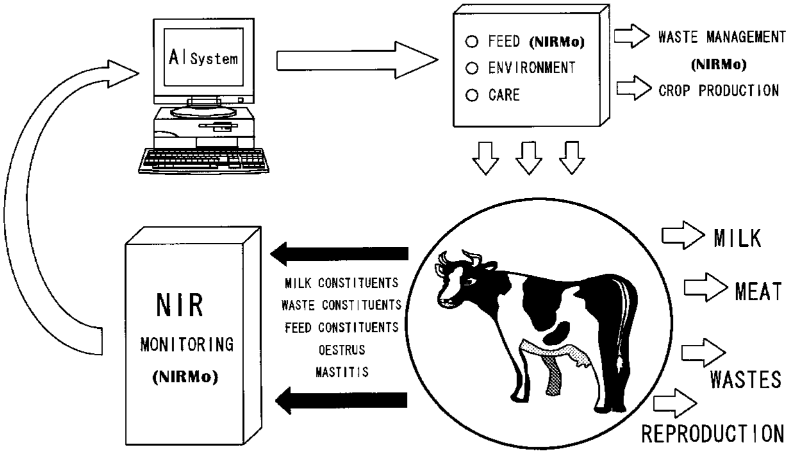


Figure 1. NIR measuring technology for biological object's monitoring at the dairy farm.

Data treatment

To highlight the spectral differences when one or more quarters of the same udder were mastitic, a spectral function was created using mathematical treatment of raw absorbance spectral data at four informative wavelengths in the SW NIR range. The examined milk samples were defined as mastitic samples when their *SCC* > 350,000 mL^{-1}.

Results and discussion

An example of NIR monitoring of "bucket milk" spectra of mastitic cow no. 664 and healthy cow no. 698 (Figure 1, Table 1) showed that all spectral patterns from a healthy cow were similar. When mastitis occurred (cow no. 664 in Nov., Dec. and Feb.) the spectra did not follow the pattern of the nonmastitic milk spectra of the same cow no. 664 (Sept. and Oct.). On the other hand, the spectral patterns of each cow were different. Differences in the shape of the spectral curves were most apparent between 750 nm and 970 nm (the lactose, protein and water absorption bands), also, between 1018 nm and 1188 nm (the protein and fat absorption bands).[4]

Mastitis causes changes in milk composition[19] which occur as corresponding variations of milk spectral patterns [Figure 2, Figure 4(b)]. As an example, we will discuss some results of the milk spectral analysis of a representative cow no. 686. In September and October, when all udder quarters of this cow were not mastitic, her bulk milk had a low level of *SCC* (Figure 3). The foremilk spectral patterns were also similar [Figure 4(a)]. In November and December, the *SCC* of the foremilk samples of rear right (RR) and rear left (RL) quarters increased. Different patterns of the foremilk spectra of the cow's healthy (FL and FR) and mastitic (RL and RR) quarters, respectively, were observed [Figure 4(b)]. Spectra changed in the same range of wavelengths as was found for the individual "bucket milk" of the other cows examined (Figure 2).

For better farm management, mastitis diagnosis has to be available at the farm level: on-samples or in-line. For both purposes, NIR spectroscopy could be applied with success. If a simple optical device is needed for mastitis diagnosis, a spectral function based on a spectral characteristic at specific wavelengths could be used instead of the whole spectrum's pattern recognition. An illustration of mastitis diagnosis using the spectral function created in this study is shown in Figure 5 and Figure 6. Mastitis causes physical and chemical abnormalities in milk. Milk spectra in the

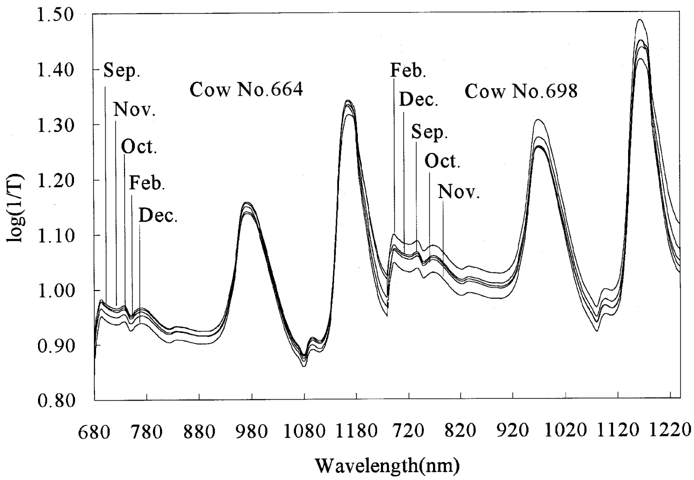


Figure 2. Raw spectra of bucket milk samples of mastitic cow no. 664 and healthy cow no. 698.

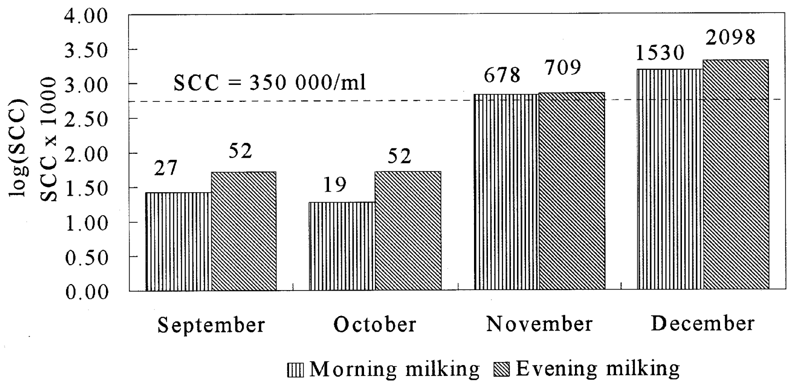
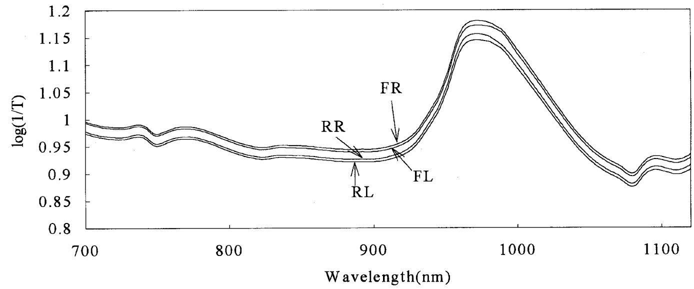
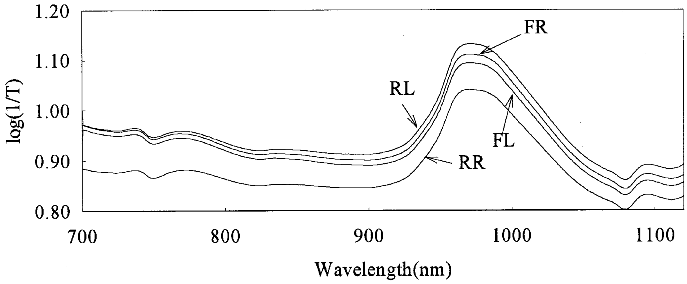


Figure 3. Log SCC of bucket milk samples of cow no. 686 for four consecutive months.

NIR range reflect the compositional and structural changes at different wavelengths in different ways. The spectral function we have created intensifies that effect. We have considered its value as a spectral image of the analyzed milk sample and the respective udder quarter. In October (Figure 3), the investigated milk had a low *SCC* and therefore the quarter milk spectra [Figure 4(a)] and the respective spectral functions (Figure 5) were similar. In November, when mastitis occurred, all quarters had different spectra [Figure 4(b)] and spectral images (Figure 5), especially those with higher *SCC*. The first symptoms of the disease has caused imbalance in the whole "biological system" of the cow. In December, when the cow has been back to its normal condition and had shown symptoms of recovering, the images of both healthy front quarters again became very similar and comparatively closer to those of the rear quarters. In our view, the main physiological disorder was in November when mastitis occurred, but not in December when the



a - October (SCC <350 000/ml)



b - November (SCC > 350 000/ml)

FL - front left; RL - rear left; FR - front right; RR - rear right

Figure 4. Raw spectra of the udder quarters foremilk samples of cow no. 686.

SCC had the highest level. It shows that the *SCC* cannot be the first symptom of subclinical mastitis. As a consequence of the disease, *SCC* remained at a high level, even though the spectral function showed a recovery. The same effect was observed in the experiment with other mastitic cows. The milk spectrum, as a multidimensional performance of the “examined object”, was more sensitive to the complexity of the physiological disorder when mastitis has occurred, than to the increase in the *SCC*. Another phenomenon has been discovered in the same experiment. For four consecutive days in December (Figure 6) the rear left quarter’s *SCC* had a considerable fluctuation. When it was in the range of the *SCC* of the front quarters, rather than the rear left quarter, the spectral image was also close to the front ones. In contrast, when the *SCC* was more than 50,000 mL^{-1}, its spectral image was closer to the mastitic RR quarter’s image.

The spectral function shows that the RL quarter has been influenced by the RR which suffered from heavy mastitis. In the future, research will be necessary to investigate the milk quality of quarters, like the RL quarter, which does not have high *SCC*, but when its *SCC* is more than 50,000, has very a similar spectral function to the rear mastitic one. It probably means that when mastitis occurs, the milk quality would change even though the *SCC* is not so high. In both cases (Figures 5 and 6), NIR monitoring gives an opportunity to observe all the changes in the examined object in real time and compare its condition. In the case of mastitis, initially the disease affects only one or two quarters of the same udder. It makes it possible to compare their spectra with the spectra of the other healthy quarters of the same udder and recognize the disease at a very early stage.

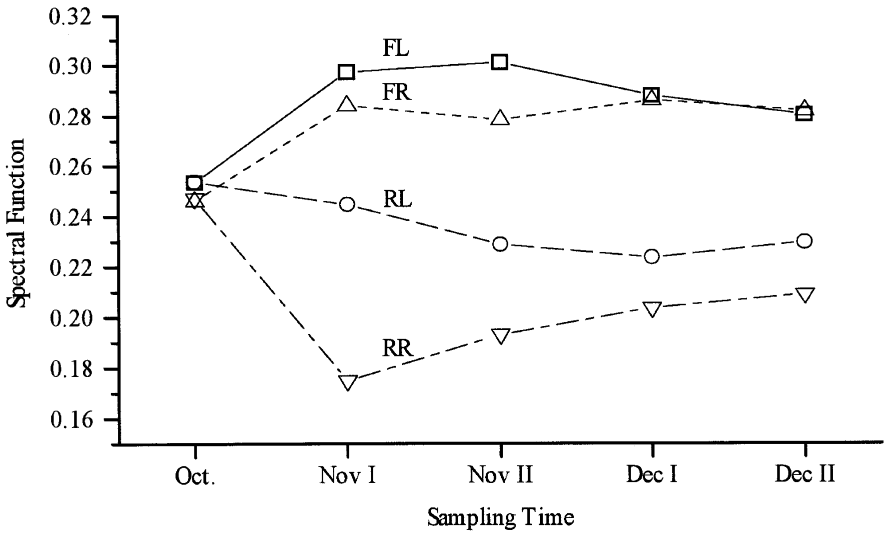


Figure 5. Spectral functions of cow no. 686 for three consecutive months (bulk milk).

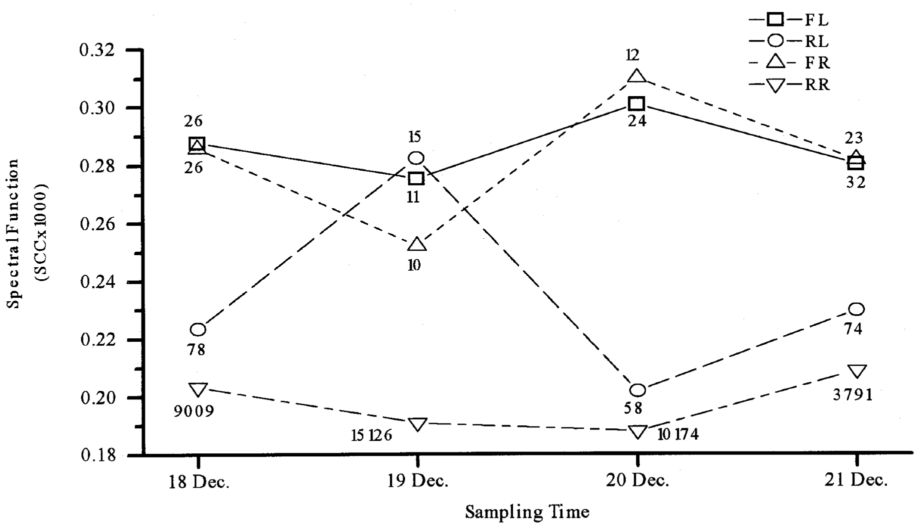


Figure 6. Spectral functions of cow no. 686 for four consecutive days (quarters foremilk).

The core of such an approach is the fact that the milk is from the same cow. It has been demonstrated that the milk spectra of different cows are different, by nature.

Fundamental research is needed to explain all the changes with the spectra and the spectral function when mastitis occurs. It will help to replace the *SCC* measurement on milk samples with qualitative in-line quarter milk analysis in the process of milking. NIR monitoring of different objects on a dairy farm, similar to the mastitis diagnosis described above, could be applied for very precise control and management on an individual basis.

Conclusions

NIR spectroscopy could be a new technology for animal monitoring on a dairy farm where individual spectra for each cow are taken and analyzed in real time and at different stages of lactation. For example, NIR spectroscopy is quite successful for early mastitis diagnosis when the quarter milk spectra of the cow are compared and observed in real time. The advantage of the NIR method for mastitis diagnosis over other methods is its sensitivity, repeatability and simplicity. The use of NIR measuring technology for monitoring and an AI approach, for interference and decision making, will enable more individual in-line cow data to be acquired and processed for better management on a dairy farm.

References

1. H.M.J. Udo and B.O. Brouwer, *Comput. and Electr. in Agricult.* 335 (1993).
2. W. Rossing, S. Devir, P.H. Hogewerf, A.H. Ipema, C.C. Ketelaar-de Lauwere and J. Metz-Stefanovska, “Robotic Milking: State of the Art” in *Proc. of the 3rd Intern. Dairy Housing Conf.*, Florida, US. ASAE publications, pp. 92–101 (1994).
3. S. Devir, J.A. Renkema, R.B.M. Huirne and A.H. Ipema, *J. Dairy Sci.* **76,** 3607 (1993).
4. P.C. Williams and K.H. Norris, *Near Infrared Technology in the Agricultural and Food Industries.* American Association of Cereal Chemists, Inc., St Paul, MN (1988).
5. J.S. Shenk and M.O. Westerhaus, *Analysis of Agriculture and Food Products by Near Infrared Reflectance Spectroscopy*. NIRSystems Inc. Silver Spring, MD (1994).
6. M. Iwamoto *et al.*, *Nippon Shokuhin Kogyo Gakkaishi* **33,** 848 (1986).
7. I. Murray, M. Morrin, R.M. Paterson and J. Rooke, “Rumen Organic Matter Degradation Kinetics from Near Infrared Reflectance Spectra” in *Proc. of the 6th Int. Conf. on Near Infrared Spectroscopy,* Lorne, Australia. Australian Chemical Society (1994).
8. K.F. Smith, P.C. Flinn and R.J. Simpson, “Using NIR to Aid the Breeding of more Nutritious Pasture Plants”, in *Proc. of the 6th Int. Conf. on Near Infrared Spectroscopy,* Lorne, Australia. Australian Chemical Society (1994).
9. F.E. Barton, II, and W.R. Windham, *J. Assoc. of Anal. Chem.* **71,** 1162 (1988).
10. J.L. De Boever, G. Huyghebaert, Ch. Boucque and G. de Groote, “Prediction of Fat and Protein Content in Individual Cow Milk by NIR Spectroscopy—Preliminary Results” in *Proc. 3rd Intern. NIRS Conf.* Brussels, Belgium, p. 279 (1990).
11. R. Tsenkova, K. Iordanov and J. Shinde, “Near Infrared Spectroscopy for Evaluating Milk Quallity”, in *Proceedings of Prospects for Automatic Milking*. Pudoc Sc. Publ., Wageningen, pp. 185–192 (1992).
12. Z. Schmilovitch, E. Malts and M. Austerweil, “Fresh Raw Milk Composition Analysis by NIR Spectroscopy”, in *Proc. of the Int. Conf. on Prospects for Automatic Milking*. Pudoc Soc. Publ., Wageningen, Netherlands (1992).
13. K.H. Norris, R.F. Barens, J.E. Moore and J.S. Shenk, *J. Anim. Sci.* **43,** 889 (1976).
14. S.M. Abrams, “Sampling”, in *Near Infrared Reflectance Spectroscopy: Analysis of Forage Quality,* Ed by G.C. Marten, J.S. Shenk and F.E. Barton, II. Agric. Handbook No. 643. USDA-ARS, US Government Printing Office, Washington, DC, p. 22 (1989).
15. R.N. Tsenkova, K.I. Iordanov, K. Itoh, J. Shinde and J. Nishibu, “Near Infrared Spectroscopy of Individual Cow Milk as a Means for Automated Monitoring of Udder Health and Milk

Quality", in *Proc. of the 3rd Int. Dairy Housing Conf,* Ed by R. Bucklin. ASAE, Michigan, pp. 82–91 (1994).

16. R. Tsenkova, " A Comparative Analysis of some Applications of Infrared Spectroscopy for Determining of Milk Quality During Milking", in *Proc. of the 6th World Conf. on Animal Production,* Helsinki (1988).
17. Y. Harada and M. Nakataki, "Possibilities for NIR Determination and Qualitative Assessment of Animal Compost", in *Proc. of the 89th Annual Meeting of Japanese Society of Zootechnical Science*, Niigata, Japan, Abstracts, p. 84 (1994).
18. D.H. Clark, D.P. Marcinkowski and R.C. Lamb, "Estrus Detection with Near Infrared Transmittance Spectroscopy", in *Proc. of the 2nd International NIRS Conference,* Tsukuba, Japan, pp. 119–124 (1989).
19. D. Barbano, "Impact of Mastitis on Dairy Product Quality and Yield: Research Update", in *Proc. 28th Ann. Mtg*. Natl. Mastitis Counc. Inc, Tampa, Florida, pp. 44 (1989).