# Comparison of milk analysis performance between NIR laboratory analyser and miniaturised NIR MEMS sensors

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## Abstract

The dairy farms have a need for on-site milk analysis to determine the fat and protein content of the milk in real-time manner during milking. Near infrared (NIR) spectroscopy has shown promise as an on-farm tool for fat and protein content determination of raw milk. However, for a successful implementation, on-site analysis requires affordable and small NIR sensors for the milk analysis. This study demonstrates the potential of using Micro-Electro-Mechanical-System (MEMS) based NIR sensors for on-farm and at-line measuring the milk fat and protein content and compares the results to golden standard analysis and commercial cooled Photo Diode Array (PDA) NIR sensor.

*Keywords: MEMS, NIR, milk analysis, fat, protein*

## Introduction

The capacity of milk production of dairy farms is not only dependent on farm animal counts, but is also affected by the ability of single milking cows to convert the energy uptake into milk secretion. Over the past 50 years, genetic selection and improved feed and management practices have resulted in an increased milk production per cow lactation. As these modern cows are prone to production-related disorders, they need to be monitored closely to guarantee animal health and welfare. On the other hand, the ability of a farmer to predict the effect of farm animal diet to the milking capacity would benefit from near instant feedback of the milk composition in regards to the fed diet. For example, fat supplements are commonly used in order to increase dietary energy density and improve milk fat output. However, the effect of this diet may depend on factors such as the form of fat being fed and the effect of the overall diet (Lock *et al*., 2013). Thus, monitoring the effect of diet could be advantageous economically. Additionally, due to the increasing size of dairy farms, farmers have less time available for each individual animal to monitor the animal health and the effect of nutrition. New NIR spectroscopy tools could offer useful information on individual cows and help the dairy farmer to optimize the animal management while reducing the workload.

Milk contains valuable information on the metabolic and nutritional status of dairy cows (Friggens *et al.*, 2007). Therefore, regular analysis of the produced milk is an efficient way to monitor cow health and welfare. Nowadays, farms participating in the Dairy Herd Improvement program collect information on the basic milk components of individual cows on a regular basis. However, as samples are analysed in central laboratories off-site, this procedure requires well-organized sample logistics and involves significant analysis costs. Due to the costs and the complexity of the procedure, the collection of samples occurs ones every 4 to 6 weeks, which is an insufficient basis for accurate and up-to-date analysis of individual animal health, secretion cycle and milk quality. This complicates the management of individual cow diets and delays information, which could offer indication on animal health deterioration.

Frequent milk analysis is only feasible, if it is performed on the farm with a minimal investment of labour and resources. Different studies, both in the lab and on the farm, indicate that near infrared (NIR) spectroscopy holds the potential for rapid, non-destructive and on-line analysis of the raw milk composition (Aernouts *et al.*, 2011). Nevertheless, commercial NIR detectors are typically costly and relatively large, not allowing for easy implementation in existing milking systems. In this study, we evaluated the ability of affordable MEMS-based NIR sensors to analyse the NIR transmittance and reflectance of raw milk collected from farm and predict the fat and protein concentrations from these spectra.

## Methods and materials

The aim of his study was to evaluate the ability of affordable MEMS sensors on the analysis of milk ingredients. The spectral information content of milk was recorded using automated sampling device with integrated NIR MEMS sensors. The performance of the sensors was evaluated in predicting the milk fat, protein content and lactose level of individual raw milk samples. The samples were collected from the dairy research farm of the Natural Resources Institute of Finland (Luke) in Maaninka. The herd consisted of 100 cows, both primi- and multiparous, in different stages of lactation. The cows were housed in a free stall with slatted floor and cubicles and fed a total mixed ration based on grass silage supplemented with variable amounts of barley grain, oats, molassed sugar beet pulp, rapeseed meal and mineral premix. The cows were milked 2 times a day (6 AM – 8 AM and 3 PM – 5 PM) in a 2-times-8 herringbone milking parlour (SAC, Denmark). In this trial, milk samples were collected during two morning and one evening milking sessions of two successive days. One litre of milk representative for the whole milking was collected for each cow according to the ICAR standards (ICAR, 2017a). Right after collection, the milk was stirred gently and two representative samples of 50 ml were taken. 1 ml preservative (bronopol) was added to the samples to ensure conservation. The preservative does not interfere with NIR analysis results although the same calibration cannot be utilised with pure milk and preservative infused milk. Samples were stored at 4°C and analysed 3-4 days after sample collection. First sample set was analysed at Valio central laboratory at Seinäjoki for fat and crude protein content according to ISO 9622 (ISO, 2013). The second sample set was analysed with the milk analyser prototype at VTT Research facilities at Oulu. Before this analysis, the samples were heated from 4°C to 39°C with heated bath and stirred gently during the heating to ensure homogeneity. In total, 252 different raw milk samples were analysed. The milk analyser prototype developed by VTT contained four MEMS sensors of three different wavelength ranges from Spectral Engines Oy (Finland): NIRONE 1.4 with 1.1 – 1.4 µm, NIRONE 2.0 with 1.7 – 2.0 µm and NIRONE 2.5 with 2.2 – 2.5 µm wavelength range in transmission, and NIRONE 2.0 with 1.7 – 2.0 µm in reflection mode. The NIR MEMS sensors use Fabry-Perot Interferometers for wavelength scanning, which enables compact sensor packaging and fast signal collection (Rissanen *et al.*, 2017). However, the sensors are prone to drift as they do not have cooled detectors. The system used a custom built powerful light source and hybrid metal glass cuvettes to achieve sufficient signal to noise ratio. The spectral information of milk was recorded with MEMS sensors integrated into a prototype device with milk sample handling and temperature control shown in Figure 1.

The recorded spectral data with normalised background is presented in Figure 2 for the four MEMS NIR sensors: NIRONE 1.4, 2.0 and 2.5 in transmission geometry and NIRONE 2.0 in reflection mode. The best signal to noise ratio was achieved with NIRONE 2.0 sensors. The NIRONE 2.5 showed high signal to noise ratio, which could be improved with shorter transmission path length if lower SNR would be preferred. In this study, the optical path length in milk sample was 1 mm. This can be achieved with the custom hybrid-glass cuvette. Shorter optical path would require a new type of cuvette solution and might have challenges with bubble free detection.

*Figure 1. Sample handling with temperature control, integrated MEMS sensor modules (NIRONE, Spectral Engines), custom light source and cuvette and two optical geometries for transmission and reflectance measurements.*

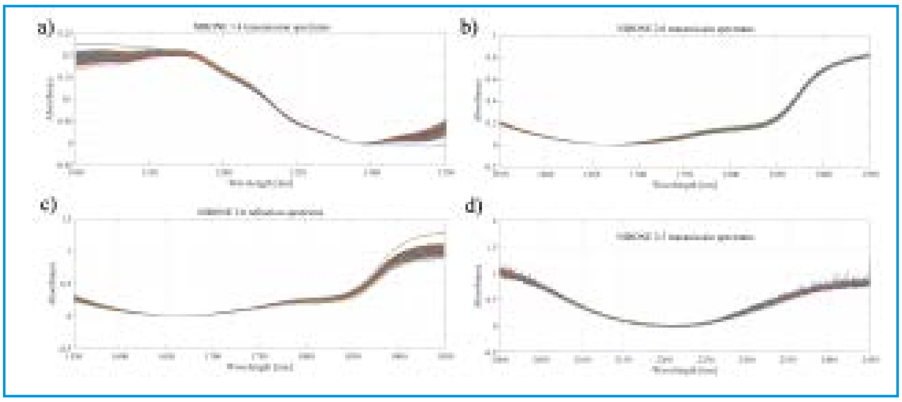


*Figure 2. Absorbance spectra recorded from raw milk samples of 84 cows from 3 milking sessions: two morning milking and one evening milking.*

The absorbance spectra were analysed with PLS calibration as shown in Figure 3 for fat, protein and lactose levels. The validation of the calibration gave most promising results for NIRONE 2.0 in transmission and reflectance geometry.

The NIR MEMS sensor results were compared to Tec5 spectrometer (InGaAs-PDA, drift ~2%) data using Valio laboratory NIR analysis as reference for fat, protein and lactose level. Prediction error data of sensors was compared to ICAR recommendations for on-farm analysers as shown in Table 1.

Tec5 InGaAs sensor reached best prediction results for fat, protein and lactose. Protein and lactose prediction errors were near or reached the ICAR limit. Although fat reached

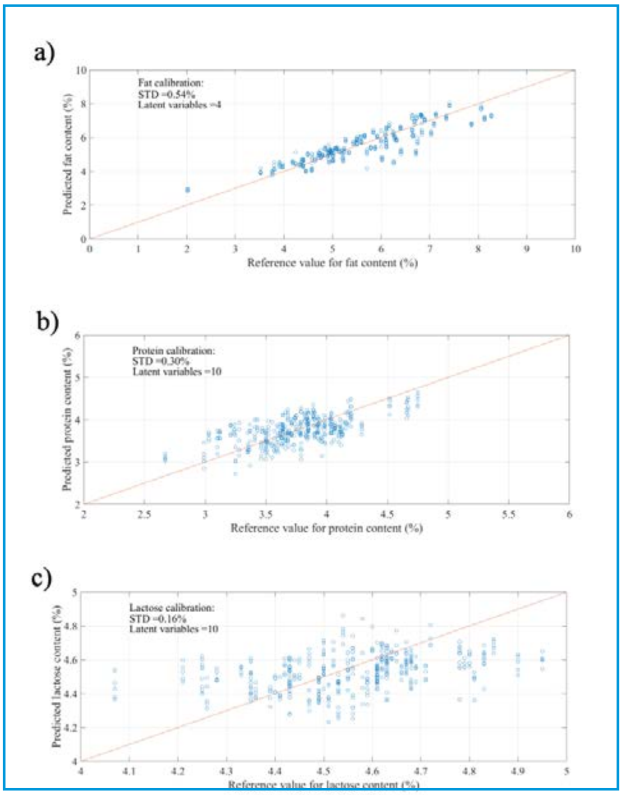


*Figure 3. PLS models for raw milk absorbance spectra showing calibration curve and validation samples for a) NIRONE 2.0 transmission mode, b) NIRONE 2.0 reflectance mode and c) NIRONE 2.0 transmission mode.*

*Table 1. Comparison of prediction errors of MEMS sensors, Tec5 cooled spectrometer, AFI Milk and ICAR standards. The prediction error and calibration curves shown in Figure 3 are marked with bold font.*

| Sensor/Standard | Fat [w/w %] | Protein [w/w %] | Lactose [w/w %] |
|---|---|---|---|
| NIRONE 1.4 Transmission | 0.58 | 0.34 | 0.17 |
| NIRONE 2.0 Transmission | **0.54** | 0.34 | **0.16** |
| NIRONE 2.5 Transmission | 0.54 | 0.35 | 0.17 |
| NIRONE 2.0 Reflectance | 0.56 | **0.30** | 0.19 |
| Tec5 cooled InGaAs | 0.51 | 0.13 | 0.07 |
| AFI Milk on-line analyser [1] | 0.62 | 0.24 | 0.28 |
| ICAR on-farm analyser standard [2] | 0.25 | 0.25 | 0.25 |
| ICAR laboratory analyser standard | 0.10 | 0.10 | 0.10 |

a lower prediction error than achieved with AFI Milk analyser study, the comparison of lactose, protein and fat prediction indicates that fat prediction could have reached a lower level than it did. Thus, there is a suspicion that a sampling error might have affected the fat levels between reference and measurement samples. Similarly, MEMS sensor results show quite high fat prediction. The prediction result is similar to AFI Milk analyser result. Although, the protein prediction showed higher values than AFI Milk, the lactose prediction was quite similar. As a summary we can state that the performance of the MEMS NIR sensors did not reach the level that could be achieved with cooled InGaAs sensors without future instrument development. The performance of the MEMS NIR sensors should be further optimised by adjusting the light source alignment, sensor ambient temperature and by adding more averaging into the measurement routine. The development of affordable milk sensors utilising MEMS sensors could be the route to affordable on-farm analyser, as the price range of Tec5 is ~ 10 times higher than the price for MEMS NIR sensors.

## Conclusions

MEMS sensors are small and cost-effective option for on-farm and on-line monitoring of the milk quality. However, the drift of the sensors limits their performance. Although the studied NIRONE sensors can reach similar level as the AFI Milk analyser in short raw milk trial, the long-term function and stability of the sensors requires further studies. In future more advanced sensor implementation should enable more accurate analysis with lower prediction errors. The implementation of affordable MEMS sensors into milking equipment could allow for high-frequent and rapid analysis of the milk quality on farm. This would enable converting the obtained time-series of milk quality parameters into valuable information for on-farm monitoring the health of individual cows.

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