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

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| Background

[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. The ability of a farmer to predict the effect of farm animal diet to the milking capacity requires information on the animal behaviour as well as on the near instant feedback of the milk composition in regards to the fed diet. The conventional method for information on milk composition at farms is sending samples to central laboratories for comprehensive analysis. However, many farms would consider alternative on-site analysis if cost-effective and reliable options would be available. In this study, we have evaluated the ability of affordable Micro Electro Mechanical System (MEMS) based NIR sensors on the analysis of milk ingredients including fat, protein and lactose.

| Methods

The studied NIR MEMS sensors use Fabry-Perot Interferometers for wavelength scanning. This enables compact sensor packaging, fast signal collection and affordable sensor module price. However, the sensors are prone to drift (~7%) as they do not have cooled detectors. The spectral information of milk was recorded using four NIR MEMS sensors integrated into a prototype device with milk sample handling and temperature control shown in Figure 1. The NIR MEMS sensors had three wavelength ranges in transmission 1.1 - 1.4 µm, 1.7 – 2.0 µm & 2.2 – 2.5 µm and one wavelength range 1.7 – 2.0 µm in reflection. The system used a customized powerful light source and hybrid metal glass cuvettes to achieve sufficient signal to noise ratio.

| Data Analytics

The data was analysed with PLS calibration using 98 cows for calibration and 68 for validation as shown in Figure 2. The MEMS sensor results were compared to Tec5 spectrometer (Si-PDA, drift ~2%) data using Valio laboratory analysis as reference information. Prediction error data was compared to ICAR recommendations for on-farm analyser as presented in Table 1.

- NIRONE 2.2 - 2.5 µm wavelength range achieved best MEMS sensor results (transmission mode) → Protein and lactose prediction error were inside the ICAR limit
- Fat prediction was higher than ICAR limit, but the performance seemed better than AFI Milk sensor performance
- Tec5 cooled spectrometer reached lowest prediction error for protein and lactose, but was worse for fat prediction → Could be related to the low maximum of the Tec5 wavelength (960 - 1690 nm)

Figure 1. Milk Analyser prototype

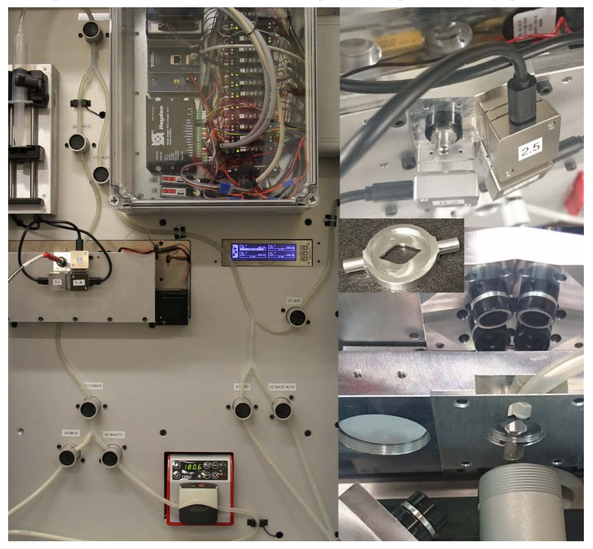
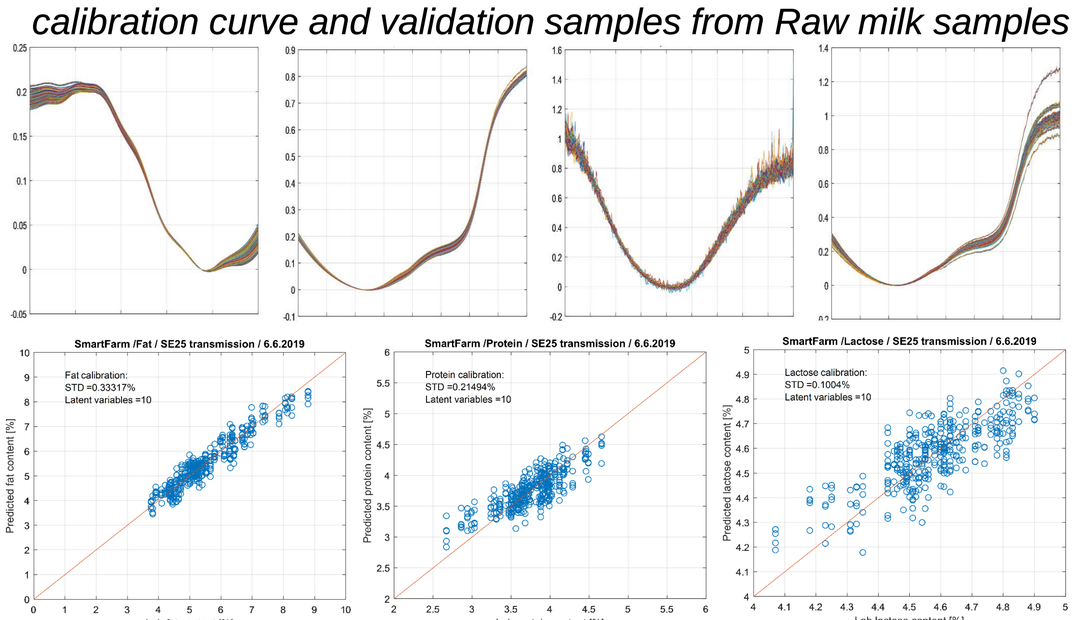


Table 1. Comparison of prediction errors of MEMS sensors, Tec5 cooled spectrometer, AFI Milk and ICAR standards

Sensor/ Standard	FAT [w/w %]	PROTEIN [w/w %]	LACTOSE [w/w %]
NIRONE 1.4 T	0.45	0.28	0.11
NIRONE 2.0 T	0.39	0.22	0.11
NIRONE 2.5 T	0.33	0.21	0.10
NIRONE 2.0 R	0.39	0.22	0.13
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

Figure 2. Absorbance spectra and PLS model showing calibration curve and validation samples from Raw milk samples



| Conclusion

Milk analyser prototype was developed for on-farm milk ingredient analysis with MEMS NIR sensors. Custom build optical prototype with optimised measurement geometry and powerful light source enabled MEMS NIR sensor performance, which can meet ICAR recommendations for on-farm analysis.

[1] Kaniyamattam, K., and A. De Vries. "Agreement between milk fat, protein, and lactose observations collected from the Dairy Herd Improvement Association (DHIA) and a real-time milk analyzer." Journal of dairy science 97.5 (2014): 2896-2908

[2] https://www.icar.org/wp-content/uploads/2015/08/Section-11-Extract.pdf

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