In-line real-time milk composition analysis by tunable laser spectroscopy for dairy farms

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Abstract

In this work we discuss latest advancements of spectroscopic sensing based on tunable laser spectroscopy in the SWIR/MIR spectral region for individual animal-level milk composition monitoring in dairy farms. In-line milk composition monitoring in dairy farms is challenging for a number of reasons - aggressive environment, rapid milk composition dynamics during a single milking cycle, turbulent flow and challenges, associated with the fundamentals of liquid spectroscopy such as large spectral bandwidth requirements, etc. To address these challenges in our work, spectroscopic sensing was performed using BROLIS HerdLine tunable laser-based sensor, operating in the 1.9-2.5 micron wavelength range, with a very fast spectral acquisition rate of ~1000 spectra/s and a capability of sensing milk fat, milk protein and lactose in-flow within the milking line. This spectral region is known for high specificity and sensitivity vs shorter wavelengths, and the choice of the laser allows access to maximum spectral power density possible. Rapid spectral acquisition allows tracking dynamic composition change throughout the individual milking cycle. We deployed 136 sensors across 4 different commercial dairy farms with a total cow number of over 2800 cows. Depending, on the milking infrastructure used in the farm, a single sensor serves from 12 to 60 cows. Cows under investigation were being milked 2-3 times per day. Data was continuously collected for a period of several months and yielded impressive results with regard to Root- Mean-Square-Error-of-Prediction (RMSEP) of 0.2% for milk fat, 0.15% for milk protein and 0.25% for lactose. Such high accuracy provides high confidence for the discussed technology to seek ICAR certification in the very near future. In addition, collected data consisted of all individual animal milkings throughout the monitoring period and was used to build a data model for individual animal and herd-level management not only from the point-of-view of farm economics but also in terms of animal health monitoring. Early insights into the HerdLine health model demonstrate the potential ability to detect health deterioration earlier compared to the standard operating procedures currently in use. We believe, our work demonstrates first larger scale deployment of laser-based MIR spectroscopic sensor technology for dairy farms, with a real ability of real-time high-accuracy individual animal level milk composition analysis

Keywords: spectroscopy, milk composition analysis, in-line sensing, mid-infrared, herd monitoring, laser spectroscopy.

Introduction

Infrared spectroscopy is a well-established and known laboratory technique for analysing composition of different materials and is routinely used as a “gold standard” in a variety of industries - food, petrochemicals, pharma, etc. Typical spectroscopic techniques involve direct absorption spectroscopy, which is most represented by expensive table-top Fourier- transform infrared spectrometers (FTIR), or instruments, based on Raman spectroscopy. Dairy industry is among the industries where FTIR is a standard laboratory tool for milk composition analysis and is routinely used throughout the world, when it comes to the necessity of high accuracy that is necessary for proper herd management and milk quality assessment. Downside of the technique is that it is restricted to the lab use and requires milk sampling – i.e., it is an off-line technique, and most often also off-site. Having a technology that could bring the laboratory accuracy to the farm, would not require sampling, and could analyse milk composition real-time and in-line would be hugely beneficial. In this work, we present a widely wavelength tunable laser based spectroscopic sensor for real-time in-line milk analysis. The laser is designed to work in the 1.9-2.5 micron spectral band, allowing access to 1st overtone and combination ro-vibrational absorption bands of different molecules [1]. In this work we focus on milk fat, milk protein and lactose monitoring in dairy farms.

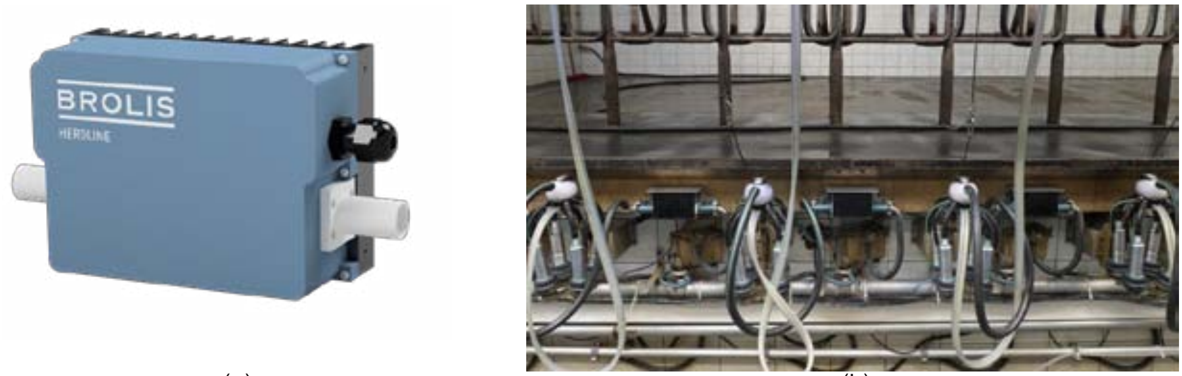
HerdLine dairy farm study

Spectroscopic sensing hardware and farm installation

This work utilizes BROLIS HerdLine sensor (Figure 1a), which is based on a patented swept- wavelength laser technology, with internal wavelength and output power locking within every spectral sweep [2, 3]. The laser houses BROLIS in-house GaSb laser chip and GaSb photodetector chip for signal collection. GaSb-based gain-chip is designed to have gain- bandwidth of in excess of 300 nm and continuous wave output power of multiple mW. The laser is strictly single mode, with a linewidth of sub MHz range. The laser line is then rapidly swept across the gain-bandwidth at a speed of 1000 spectra per second, with a resolution of 1 nm. This enables the possibility of tracking the composition dynamics within every individual milking. The sensor has a flow through tube, which connects directly to the milking line, and laser is scanning the milk flow through the tube in transmission mode. As the light passes the milk flow, it is collected by a GaSb photodetector with a cut-off wavelength of around 2.7 microns. Collected signals are converted into absorbance, and further processed to deconvolute individual concentrations of target analytes. Depending on the milking parlour, a single sensor can serve from 12 to 60 cows. The cleaning of the milk tube is performed at the same time as the milking line is washed and is designed to withstand both high temperature and high/low pH agents. Figure 1b illustrates a real-life dairy farm installation of HerdLine sensors. Powering, reading and controlling the sensors is performed via a single power-over- ethernet (PoE) cable, which connects to the local farm server. The data from the local farm server is then further streamed to the cloud infrastructure, where it is aggregated and converted into data that is streamed back to the farmer via the HerdLine software. Complete hardware set that was deployed at different farms consisted of HerdLine sensors, mounting racks, cabling and a local server.

Sensor performance in the dairy farms

This study is based on 136 HerdLine sensors, deployed in 4 dairy farms in Lithuania and another European location with around 2800 dairy cows in total. Cows under investigation were milked 2-3 times a day. Reference sampling was performed in two different ways. In 3 farms, reference sampling was performed manually by collecting small volumes of milk in short time intervals during a milking cycling, to average for the intrinsic composition dynamics of the milking cycle. Collected samples were then sent to a governmental laboratory UAB “Pieno tyrimai” for certified testing. As it will be evident from the results- manual sampling for control measurements yield excess



(a) (b)

Figure 1. (a) BROLIS HerdLine sensor. The white hose adapters of the milk tube connect to the milking line. Black electrical connector is for the PoE cable. (b) Real-life farm installation into a parallel milking parlour with 40 milking points serving up to 1000 cows.

error in averaging composition levels, particularly for milk fat concentration. In another location, the milk of the entire milking cycle was collected in a collection tank and then the sample was taken from that tank as a representative average sample and analyzed in the EUROFINS laboratory. In this location the sensors collected data for milk fat and protein only and not for lactose. Sensors collected data in the farms from over 6 months to 3 months of each dairy cow. Figure 2 shows sensor performance in a farm, where control samples were collected manually. Data represents 8 days of operation. RMSEP for fats is 0.37%, proteins 0.18% and lactose 0.28%. Note that all this data corresponds to an in-line, in-flow measurement. Figure 3 shows data for fats and proteins in site 2, where control samples were taken from the collection tank. The data also corresponds to 8 days of operation for proper comparison. RMSEP obtained for fats and proteins is notably better – 0.2% and 0.1 % respectively. We attribute this to the fact that using manual control sampling technique is prone error as it as it has direct influence on the averaging of the concentrations of the constituents of the entire milking cycle. Fat concentration changes dynamically during the milking cycle as shown in Figure 4, as measured by the HerdLine sensor. HerdLine's rapid spectral capture ability allows to see the intrinsic dynamics and perform proper averaging, yielding a high-accuracy in-line in-flow measurement.

Possibility of monitoring individual cow's milk composition allows aggregating data and constructing data trends over extended periods of time. Such trends are valuable for both individual animal and herd status monitoring, when it comes to health, nutrition, or precision selection. Figure 5 shows a 6-month data trend of an individual animal. Data demonstrates that accurate concentration measurements of milk composition allow detecting onset of acidosis/ketosis much earlier compared to activity tracker technologies. For example, the sensor depicted in Figure 5 indicated acidosis risk immediately after installation for animal No. 60257 as seen by the fat-to-protein ratio, which was not indicated by any other alternative technology. Furthermore, after

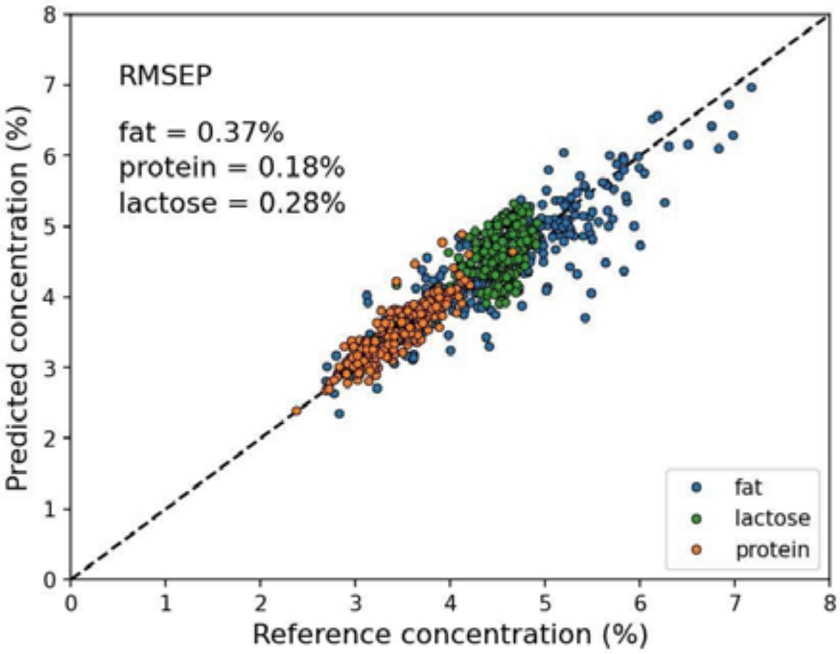


Figure 2. HerdLine sensor performance in site 1 with manual control sampling technique used. Data is plotted for all 24 sensors.

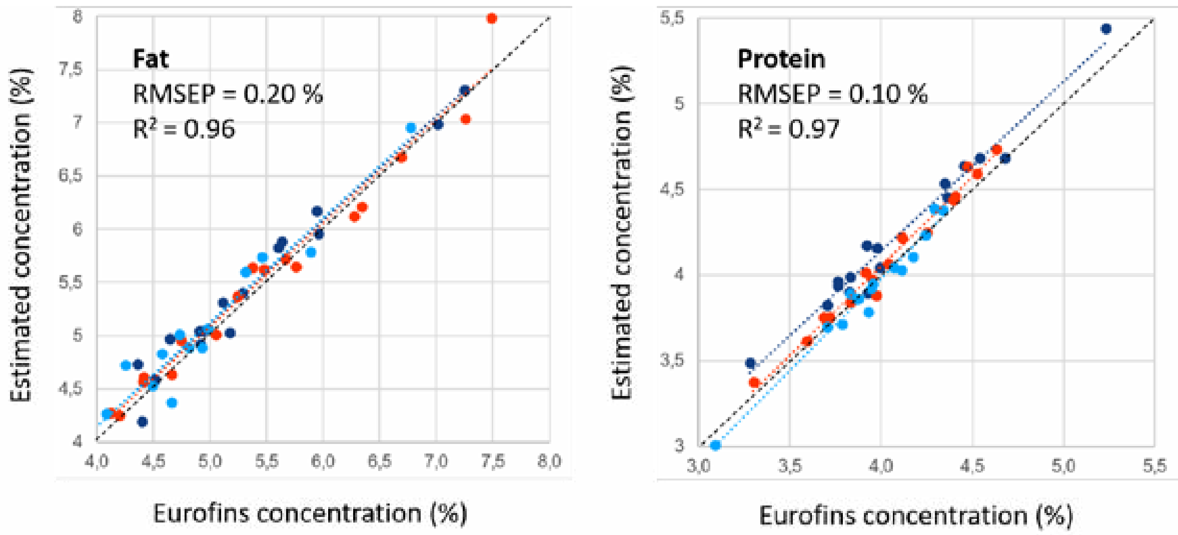


Figure 3. HerdLine sensor performance in site 4, where control samples were taken from the collection tank and analyzed in Eurofins laboratory.

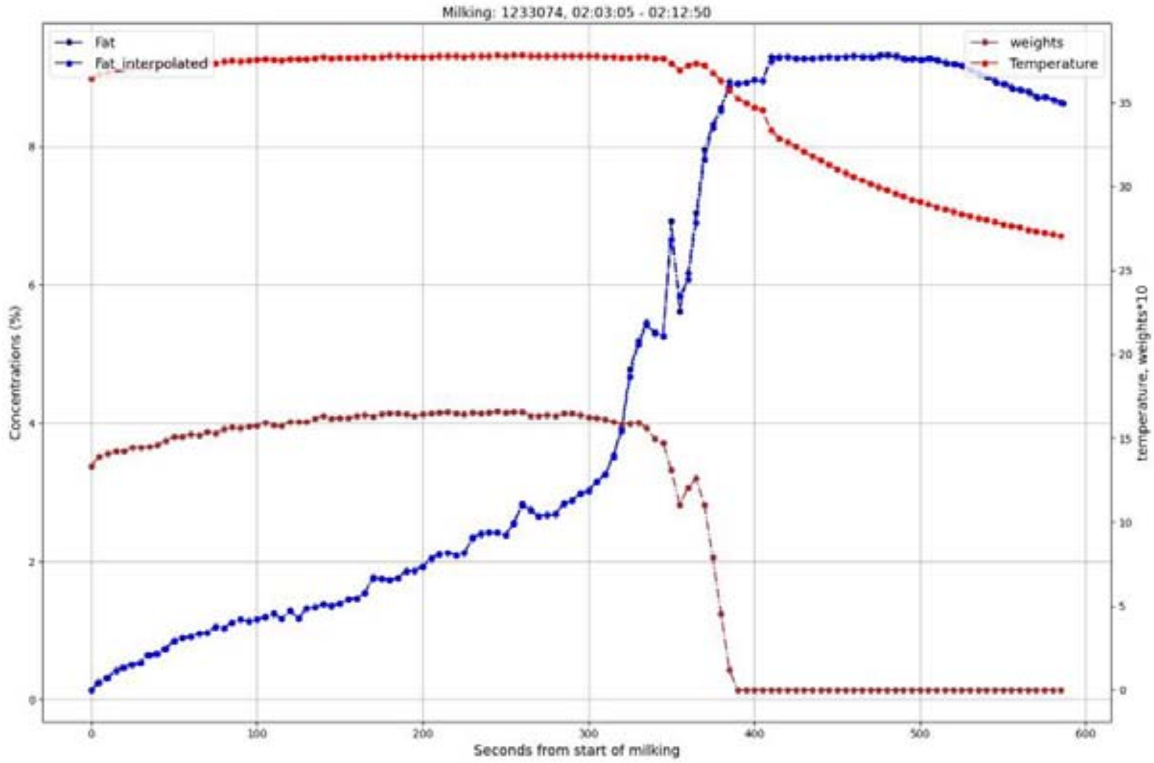


Figure 4. Fat concentration dynamics within single milking cycle as measured with a HerdLine sensor.

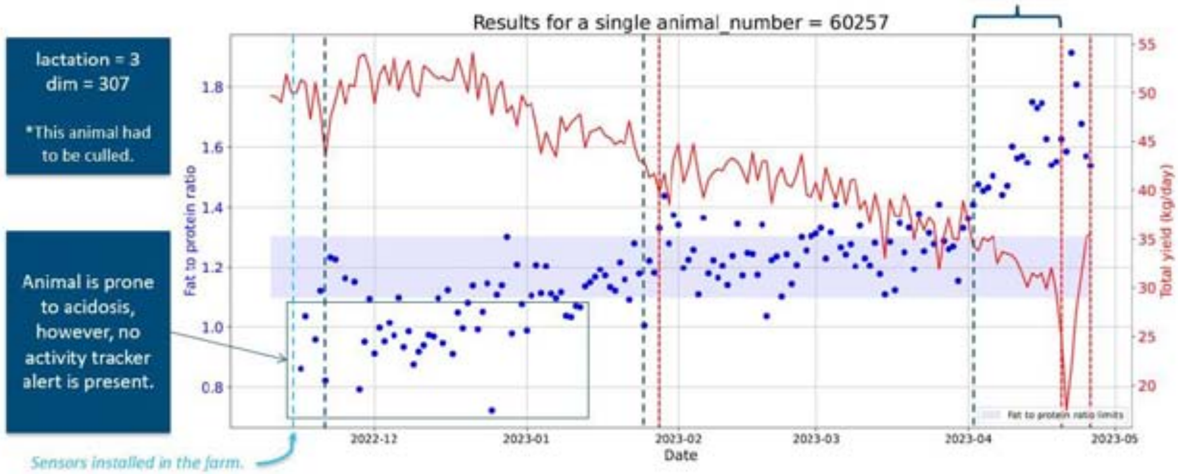


Figure 5. Fat concentration dynamics within single milking cycle as measured with a HerdLine sensor.

5 months, the cow went to ketosis state, as indicated by an increased fat-to-protein ratio. Activity tracker sent a warning only 17 days later, when the milk yield was already down by 50%. This is a powerful illustration of how precision in-line sensing technology can help dairy farmers manage the herd health in-time. In a similar manner, data trends from individual animals within the same farm can be aggregated to provide a trend for the entire herd.

References

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[3.] **US 11**,177, 630 B2.