How to Measure Structure Non-Invasively?

- quantification of laser speckle in milk acidification

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Motivation. Many milk products are based on the milk acidification process. Here the protein particles aggregate, and ultimately form a gel matrix. The microstructure of this matrix partly defines the final structure, which is critical for consumer acceptibility.

Light scattering is highly dependent on microstructure, which allows for non-invasive structure measurements. Such measurements are well suited for process control of acidification processes, in order to ensure high, consistent quality.

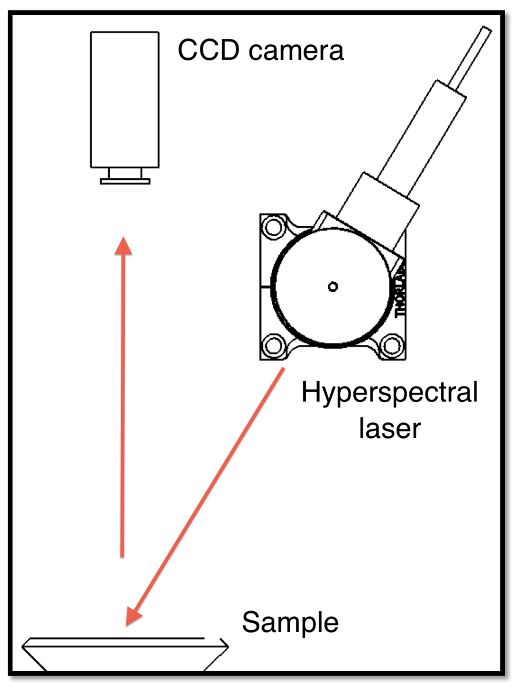
Image Data. The data is images of the diffuse reflectance that occur when laser light is shined into the yogurt. The set-up and data examples are shown in the figure below. The peak intensity (red colour) is the incident point of the light, and scattering and absorption of the light results in diffusion of the light intensity.

Quantification. We believe that the diffuse reflectance images contains a lot of information about the microstructure of the yogurt. Thus a lot of different image features will be investigated. In this study we are looking into quantifying the underlying speckle pattern.

Speckle is the constructive and deconstructive interference of coherent light, due to Brownian motion of the scattering particles. The scale of the speckle pattern holds information about the optical properties, and has been used in medical diagnosis [1].

The **conventional approach** to quantify the speckle size, is to determine the spatial autocorrelation function of the signal, and use the full width at half maximum value (*FWHM*) as an mean speckle size [2]. This measure can be somewhat noisy as it only depends on one point in the autocorrelation function.

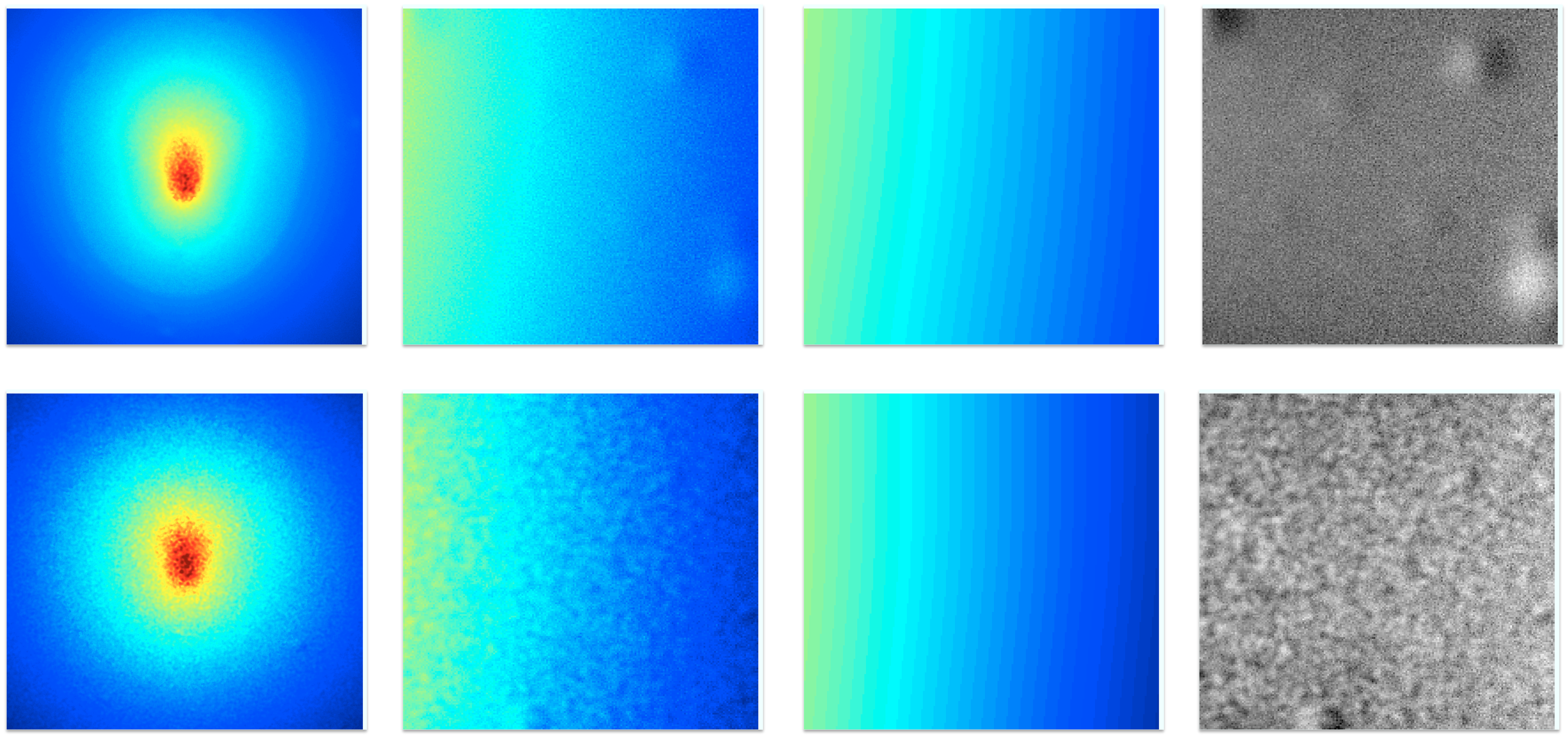
Our approach to estimate the local scale in the speckle pattern is to use a variant of *total variation regularization,* which is often used for denoising. By observing the "velocity" at which a pixel changes intensity (in the iterative scheme), it is possible give a relative estimate of the size of the "uniform" region the pixel is located in [3]. The process is illustrated in the figure below.



Data acquisition set-up.

Whole milk early in a acidification process. The artefacts are air bubbles

Whole milk late in the acidification process.

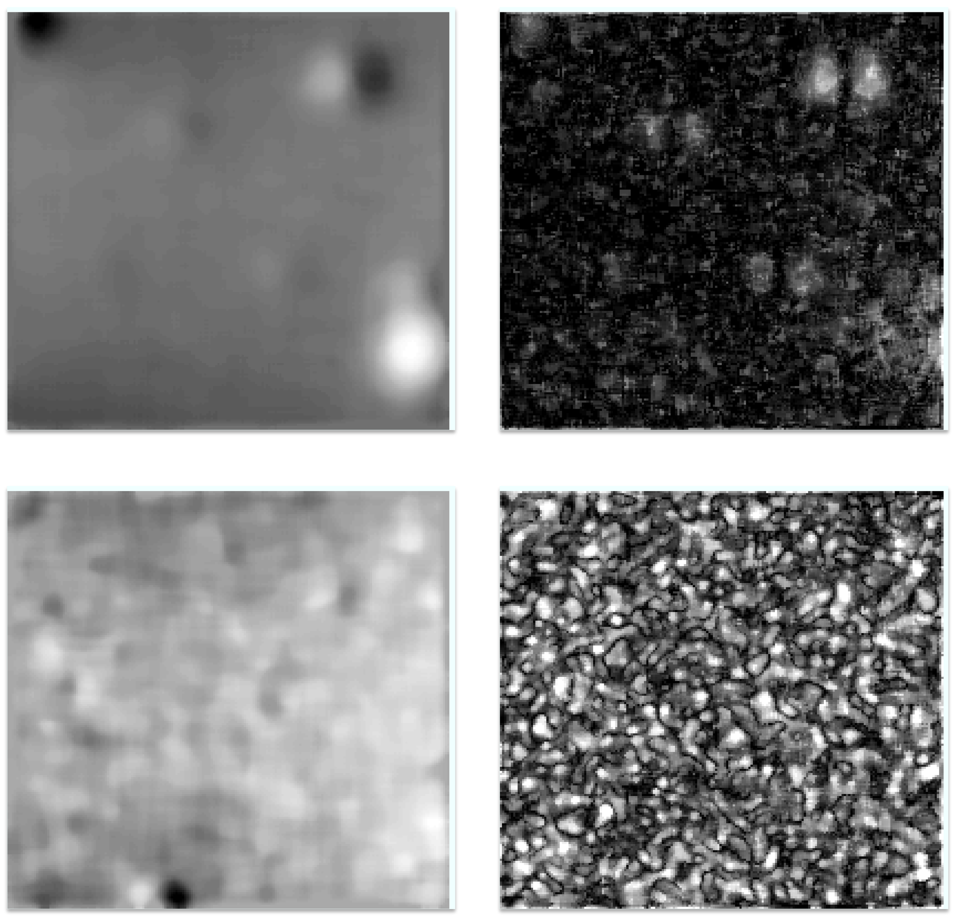


Diffuse reflectance image.

Zoomed view of the diffuse reflectance image.

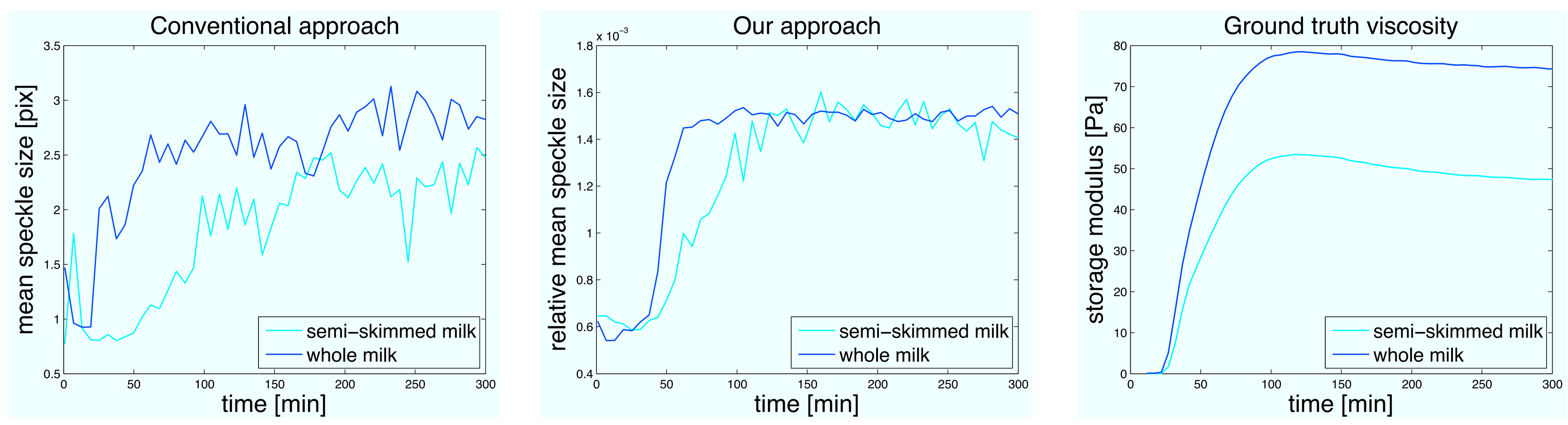
The diffusion field is estimated by a thin plate spline (TPS).

The speckle pattern is isolated by removing the diffusion field using the TPS.



Speckle pattern after total variation regularization.

Local scale derived from velocity of pixel intensity changes.



The time development for two different milk acidification processes is shown. The mean speckle size is reported using both the conventional- and our local scale approach. Ground truth viscosity measurements are also reported.

Conclusion and future work. The results of using a local scale measure of the speckle pattern are encouraging and shows strong correlation between the development of the viscosity and the local speckle scale measurement.

Compared to the conventional quantification scheme for the average speckle size, the proposed method seems to give a more robust signal, which is important for process control applications.

However, measures of the speckle size does not seem to be able to generalize to different acidification processes.

In the future, larger experiments will be conducted, and more features will be investigated alongside speckle size. For process control it will be important to select features that are both robust and sensitive.

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References.

[1] Y. Piederrière et. Al "Scattering Through Fluids", Optics Express Vol. 12, No. 1, 2004

[2] J.W. Goodman "Statistical Properties of Laser Speckle Patterns, Springer-Verlag Berlin 1984.

[3] T. Brox "A TV Flow Based Local Scale Measure for Texture Discrimination", 8th European Conference on Computer Vision, May 2004

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