

# Viscosity Analysis of Liquid Food Using Hyperspectral Imaging

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**Summary:** This study suggests the use of the third overtone region (675–965 nm) with an NIR hyperspectral camera as a first step toward a non-contact, mobile approach for estimating viscosity in liquid foods—a critical quality parameter. Key spectral features (such as normalized peak intensity, area ratios, FWHM, and peak position) were extracted from selected channel regions and input into a K-Nearest Neighbor (KNN) regression model ( $k=3$ ), achieving high predictive accuracy (MAE = 0.141 Pa·s, MSE = 0.927 Pa·s<sup>2</sup>, R<sup>2</sup> = 0.95) and accurately predicting sample viscosity across variations. These findings lay the groundwork for a compact, multi-spectral AMS-based device, supporting in-field quality control and food safety.

**Keywords:** Viscosity Prediction, Non-Invasive Measurement, KNN Regressor, Hyperspectral Imaging (HSI), Spectral Band Selection

## Background, Motivation and Objective

Viscosity is a key quality parameter in liquid foods, impacting texture, consistency, and production processes [1]. Near-Infrared (NIR) spectroscopy, especially in the third overtone region, offers a promising non-contact alternative for real-time viscosity estimation by capturing the key absorption peaks relevant to molecular interactions linked to viscosity [2][3]. Besides, hyperspectral imaging (HSI) combined with machine learning has shown potential for quality control in food applications, enabling non-invasive prediction of physical properties and chemical composition [4][5]. This study suggests the use of the third overtone region in the NIR range (675–965 nm) for non-contact viscosity estimation in liquid foods. A K-Nearest Neighbor (KNN) regression model enables a preliminary investigation into a non-invasive alternative to traditional viscometers, focusing on key spectral features.

## Methodology

We used a hyperspectral sensor (MV1-D2048x1088-HS02-96-G2-10, Photonfocus) [6] with an IMEC snapshot mosaic CMV2K-SSM5x5-NIR sensor, capturing 25 NIR channels (675–975 nm) at 2048×1088-pixel resolution. Samples (olive oil, water, honey, and milk) in glass containers were illuminated with two 50 W halogen lamps positioned at a 45-degree angle, 20 cm from the camera, to ensure consistent conditions. These samples were chosen to cover a range of viscosities and compositions, ensuring initial feasibility before expanding to a larger dataset. Calibration was conducted with reference white and dark images to correct for environmental and sensor-related inconsistencies. Regions of Interest (ROIs) were extracted from each sample's images, resulting in a data

matrix (192660, 25). Reflectance values were normalized and converted to absorbance using Lambert-Beer's Law as shown in Eq. (1):

$$A = \log_{10} \left( \frac{1}{R_{\text{reflectance}}} \right) \quad (1)$$

where  $A$  is the absorbance and  $R_{\text{reflectance}} = \frac{I_{\text{reflected}}}{I_{\text{incident}}}$  is the reflectance ratio.

For visualization, data preprocessing included Gaussian filtering for noise reduction and cubic spline interpolation for spectral smoothing. Spectral region selection targeted features associated with molecular interactions relevant to viscosity, specifically the normalized peak intensity ratio, normalized area ratio, Full Width at Half Maximum (FWHM), and peak position. A K-Nearest Neighbors (KNN) regression model ( $k=3$ ) was used for simplicity and accuracy, trained on water, milk(H-milch 0.3% Fett), olive oil and honey (Wild Honey) samples.

## Results and Discussion

The absorbance spectrum (Figure 1) reveals distinct peaks that correspond to molecular interactions impacting viscosity.

Water's peaks observed arise from O-H stretching overtones, enhanced by water's polarity and hydrogen bonding. Its low viscosity (0.001 Pa·s) is due to small molecular size and relatively weak intermolecular forces.

Milk shares these peaks (765 nm and 802 nm), modulated by interactions with proteins and fats. Reduced peak intensity reflects disrupted hydrogen bonding, while its higher viscosity (0.002 Pa·s) is due to colloidal suspensions increasing intermolecular friction.

Oil shows broad peak at channel8 (778 nm), associated with C-H stretching in hydrocarbons.

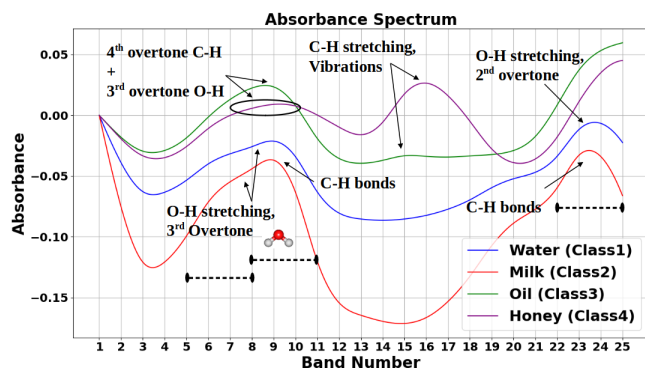


Fig. 1: Absorbance Spectrum and Channel Selection

Its higher viscosity (0.1 Pa·s) stems from large nonpolar molecules and van der Waals interactions, with minimal hydrogen bonding.

Honey's spectrum combines water, sugars, and organic acids. Broad bands arise from overlapping water and carbohydrate C-H stretching vibrations. Its high viscosity is due to strong hydrogen bonding between sugars and water, forming a dense molecular network.

Based on spectral analysis, channels 4–7, 7–10, 13–18 and 21–24 were selected as regions of interest, capturing O-H and C-H absorption bands sensitive to hydrogen bonding. Key peak properties intensity, area, and Full Width at Half Maximum (FWHM) were extracted to quantify intermolecular forces related to viscosity. dataset (192660, 20), created with three container volumes and balanced pixels per class, trained a K-Nearest Neighbors regressor,  $n\_neighbors=3$ ,  $weights='distance'$ ,  $algorithm='auto'$ , and  $leaf\_size=20$ . An 80/20 data split yielded an  $R^2$ (Regression metric) of 0.95, Mean Absolute Error (MAE) of 0.141 Pa·s, and Mean Squared Error (MSE) of  $0.927 (Pa.s)^2$ , supporting effective viscosity prediction based on selected channels.

Figure 2 shows the model's accuracy in predicting viscosities for water (0.001 Pa·s), milk (0.002 Pa·s), oil (0.1 Pa·s), and honey (around 10 Pa·s). Minimal variance within each category demonstrates its robustness. Testing with varied container volumes and repeated measurements addressed uncertainties and enhanced real-world generalizability.

## Conclusion

This study establishes a foundation for a portable, embedded device using the AMS AS7265x chipset, demonstrating the potential of NIR spectroscopy in the third overtone range for non-contact viscosity estimation in liquid foods. Initial experiments with a hyperspectral camera (675–965 nm) identified specific absorption peaks linked to viscosity-related molecular interactions. The AS7265x chipset, with its 18 channels spanning 410–940 nm, aligns closely with these peaks, making it well-suited for capturing critical molecular details. Future work will focus

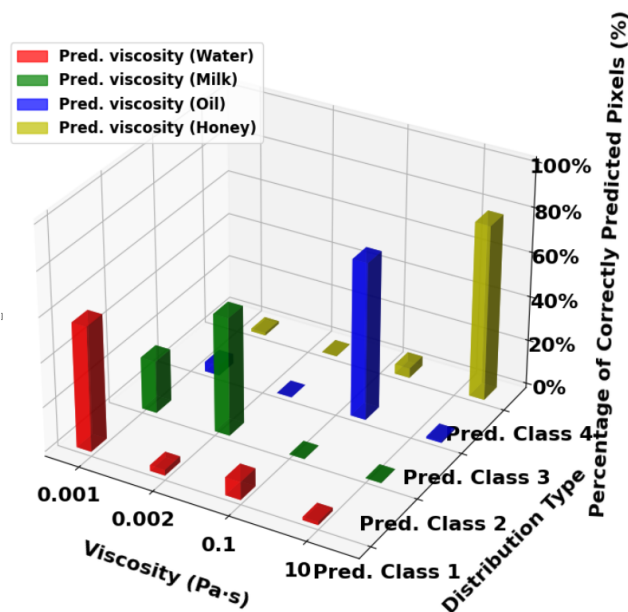


Fig. 2: Distribution of Predicted Pixels Across Viscosity Categories

on validating the chipset's performance across diverse samples, improving unknown sample detection, incorporating contactless temperature measurements with corrective adjustments, and expanding the dataset by including more samples, along with rotated measurements and additional containers, to enhance statistical robustness and invariance.

## References

- [1] R. Rodrigues, "The viscometer and its role in the food and beverage industry," 2024. Accessed: 2024-11-03.
- [2] A. Badr Eldin, *Near Infra Red Spectroscopy*. 07 2011.
- [3] D. Macleod, "The frequency of vibration of molecules in liquids and its relation to viscosity," *Proceedings of the Physical Society*, vol. 50, no. 5, p. 788, 1938.
- [4] J. Hwang, K.-O. Choi, S. Jeong, and S. Lee, "Machine learning identification of edible vegetable oils from fatty acid compositions and hyperspectral images," *Current Research in Food Science*, vol. 8, p. 100742, 2024.
- [5] M. Aqeel, A. Sohaib, M. Iqbal, H. U. Rehman, and F. Rustam, "Hyperspectral identification of oil adulteration using machine learning techniques," *Current Research in Food Science*, vol. 8, p. 100773, 2024.
- [6] Photonfocus, "Photonfocus." Accessed: 2024-11-03.