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Below the Noise: A Fundamental Method for Enhancing SNR in Low-Concentration Spectroscopic Detection

We present a practical method to improve signal-to-noise ratio (SNR) in Raman spectroscopy for detecting low-concentration analytes in liquid or gas samples. This fundamental approach can be applied to any spectroscopic technique using CCD sensors - Raman, fluorescence, absorption, NIR, etc. Though developed in the Raman context, it is applicable to systems with cooled CCDs and long exposure times.
In such sensors, the main noise sources include dark current, shot noise, readout noise, interference fringes, and pixel-to-pixel quantum efficiency (QE) variation. While cooling suppresses dark current and increased exposure reduces shot noise, fixed-pattern noise - especially fringes and QE variation - still limits the detection threshold. Postprocessing is often insufficient, especially when noise patterns drift with time, making physical nose removal methods necessary.
Our method involves tilting the camera (sensor and focusing optics) around the diffraction grating axis during acquisition, averaging out fringe and QE variation effects. Applied to glucose detection in water, this technique lowered the limit of detection 2-fold compared to static acquisition [1]. This simple mechanical adjustment enhances sensitivity in Raman and other CCD-based spectroscopies.

References

[1] Ata Golparvar, Assim Boukhayma, Timothy Loayza, Antonino Caizzone, Christian Enz, Sandro Carrara, BNSC, 11 (2021) 871-877

Figures

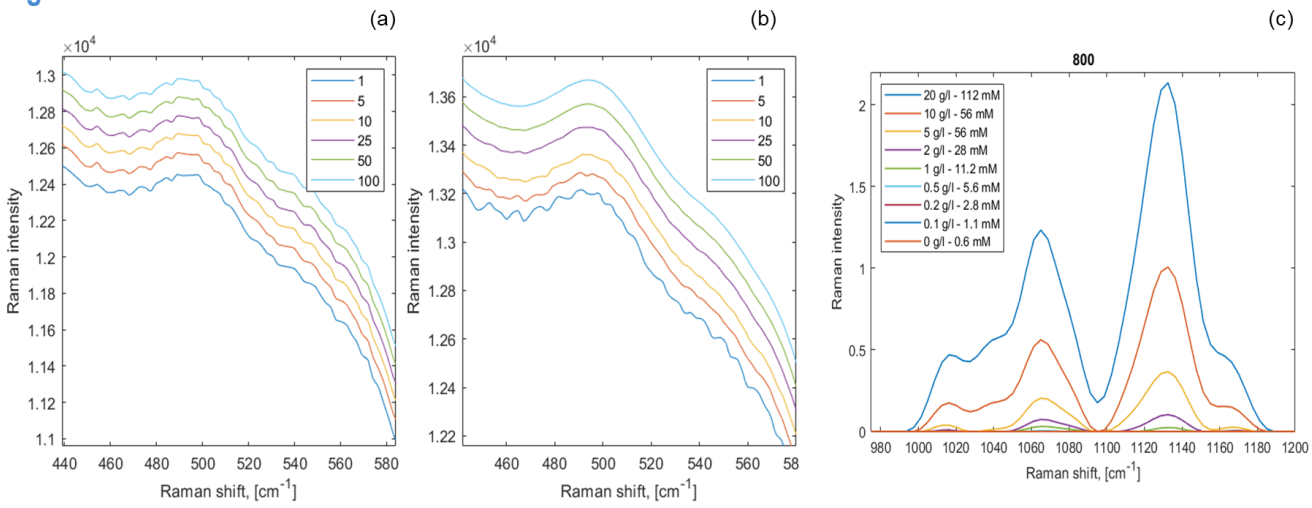

Figure 1: Raman spectra of glucose in aqueous solution measured using a 532 nm laser with 4-second exposure time. (a) Spectrum acquired without camera tilt. (b) Spectra acquired with camera tilt at varying numbers of repetitions (see legend). (c) Characteristic glucose peak observed with camera tilt, enabling visual detection of concentrations below 10 mM.