Glucose concentration detection using a low-cost Raman Spectroscopy Kit

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Abstract. Raman technology offers a cutting-edge approach to measuring glucose solutions, providing precise and non-invasive analysis. By probing the vibrational energy levels of molecular bonds, Raman technology generates a unique spectral fingerprint that allows for the accurate determination of glucose concentrations. This study proposes the use of Raman spectroscopy to identify different glucose concentrations through the detection of Raman fingerprints. As expected, higher concentrations of glucose in the solution conducted to higher peak bands, indicating more glucose molecules interacting with light and consequently increasing the magnitude of inelastic scattering. This non-destructive approach preserves sample integrity and facilitates rapid analysis, making it suitable for various applications in biomedical research, pharmaceutical development, and food science.

1 Introduction

Besides cancer and cardiovascular disease, diabetes has emerged as the third stage of most prevalent chronic diseases, which has become a big issue as far as the health of humanity is concerned [1,2]. By World Health Organization, the diabetes people worldwide are at least 642 million people now and it becomes a great threat to public health (Figure 1). The optical techniques have emerged as the ideal choice, providing accurate and painless means of blood glucose detection, including microwave spectroscopy, optical coherence tomograph, near infrared spectroscopy, and fluorescence techniques. Raman spectroscopy has gathered considerable interest due to its reliable qualitative measurement ability and strong resilience against water interference, establishing itself as a valuable non-invasive method for detecting blood glucose concentrations [3]. This technology precisely offers molecular "fingerprint" by giving distinctive energy emitted because of inelastic interactions between incident photons and molecular vibrations.

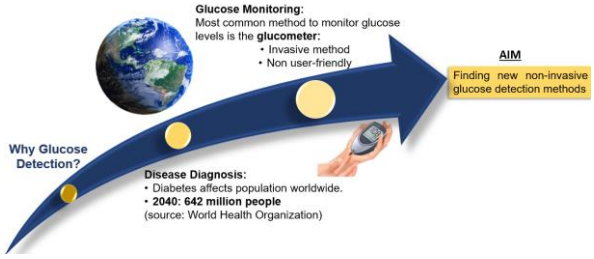

Fig. 1. The importance of glucose monitoring.

1.1 Experimental Setup and Results

Raman Spectroscopy was employed to detect various glucose concentrations by identifying the characteristic Raman fingerprints of glucose.
In controlled laboratory setting, a sequence of glucose aqueous solutions was prepared, spanning glucose mass fractions from 5 wt.% to approximately 50 wt.%. The refractive index (RI) of these solutions were conducted at a consistent room temperature of around 23°C within a controlled environment and were determined using an Abbe refractometer (ATAGO, DR-A1), ranging from 1.3379 RIU to 1.3834 RIU. The experimental setup, illustrated in Figure 2, incorporates the Raman Spectroscopy Kit for cuvette samples from Thorlabs. This Kit represents a significant advancement in modular spectroscopy systems within the field of optics and photonics.

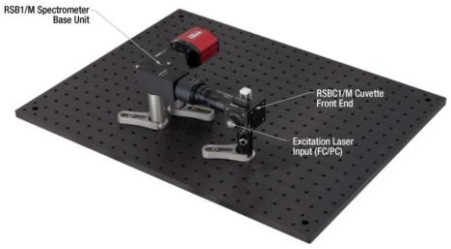

Fig. 2. Raman Spectroscopy Kit used in this work.

Designed for excitation in the visible range (680 nm) to the near-infrared region (785 nm) and detection between 815 nm to 915 nm, the kit offers a spectral resolution better than 10 cm^{-1}. This kit includes a RSB1(/M) spectrometer base unit, a front-end module for collecting

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the scattered Raman signal (RSBC1/M cuvette), and an input for the excitation laser (FC/PC) (Figure 2). Real-time signal processing is carried out on a computer using the Thorlabs OSA Raman Software. Figure 3 illustrates the outcomes of the data analysis conducted on the Raman spectrum. After baseline correction, a 7-point adjacent averaging smoothing technique was employed utilizing OriginLab software. The resulting spectrum shows clearly discernible intensity bands indicative of glucose fingerprints. Particularly noteworthy is the wavenumber at 1125 cm^{-1}, which demonstrated the highest signal-to-noise ratio, closely followed by 1062 cm^{-1}.

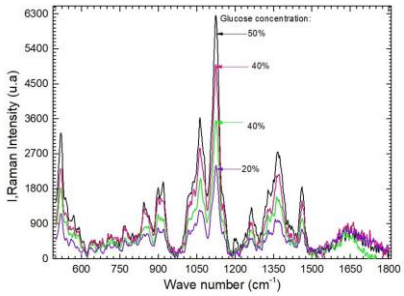

Fig. 3. Raman spectra measurements for different glucose solutions.

The spectral deconvolution techniques were employed to resolve corresponding peaks, enhancing the accuracy of glucose concentration determination. The analysis revealed a strong correlation between the intensity of specific Raman bands and glucose concentration levels, emphasizing the kit efficacy in precise analyte quantification.

Additionally, comparative studies with traditional glucose monitoring methods showcased the kit superiority in terms of sensitivity and specificity, demonstrating its potential clinical application in diabetes management and biomedical research.

In Figure 4, the spectral intensity response to varying glucose concentrations in aqueous solutions is depicted for two different bands. The 1602 cm^{-1} Raman signature, named the Raman spectroscopic signature of life, is a Raman marker band for cellular metabolic activity, and the 1125 cm^{-1} band, a characteristic Raman band of glucose.

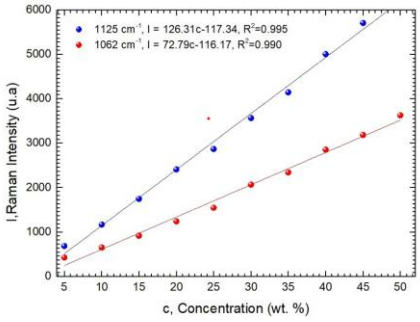

Fig. 4. Raman intensity response to varying glucose concentrations.

Both fingerprint regions display a clear linear relationship between Raman intensity and glucose concentration. As expected, higher glucose concentrations yield more prominent peak bands, attributed to enhanced interaction with light, thereby resulting in an amplified magnitude of inelastic scattering. This observation emphasizes the sensitivity of the spectroscopic system to changes in glucose concentration and highlights its potential for precise quantification in diverse analytical contexts.

If one intends to employ it as a sensor element, two peaks taken from the fingerprints should be subtracted. Using the bands from Figure 4 (1125 cm^{-1} and 1062 cm^{-1}), the sensor for detecting glucose concentration as a function of intensity is obtained (Figure 5). Then, the glucose intensity sensor demonstrates a linear response that is independent of fluctuations in the source.

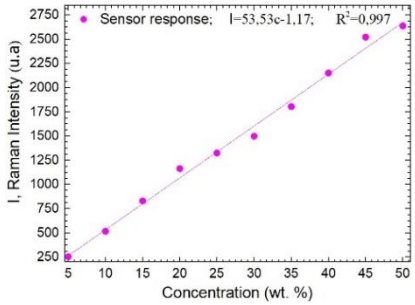

Fig. 5. Sensor response to glucose variations.

2. CONCLUSIONS

The analysis of this work showcases the Raman Spectroscopy Kit performance in identifying glucose fingerprints and quantifying glucose concentrations. Through advanced data processing techniques and spectral analysis, strong correlations between Raman intensity and glucose levels were established, underscoring the kit precision and sensitivity. These findings not only demonstrate its advantage over traditional monitoring methods but also highlight its potential for clinical applications in diabetes management and biomedical research, since it is a non-destructive approach preserves sample integrity and allows for rapid analysis, rendering it suitable for a wide array of applications.

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References

1. X. Min, R. Liu, B. Fu, K. Xu, Appl. Spectrosc 71:2076–2082, (2017).
2. N. Li, H. Zang, H. Sun, X. Jiao, K. Wang, T. C. Liu, Y. Meng, Molecules, 24(8):1500, (2019).
3. S. Song, Q. Wang, X. Zou, Z. Li, Z. Ma, D. Jiang, Y. Fu, Q. Liu, Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 303, 123176, (2023).