

High-sensitive Smartphone-based Raman System based on Cloud Network Architecture

Mr. Faizur Rahman Babul¹, Mrs. Anwar Jahan², Ms. Imrose Basha³

*1,2,3 Assistant Professor,
1,2,3 Department of ECE,
1,2,3 Global Institute of Engineering & Technology, Moinabad, Rangareddy Dist., Telangana State.*

Abstract—

Raman spectroscopy has been increasingly researched this year. Due to the high accuracy, fast speed, and non-destructive detection features of Raman spectroscopy, there are more and more application scenarios. In this paper, a smart phone Raman system is studied. By the optical path design and slit coupling technology, the sensitivity of the device is improved while the size of the spectrometer itself is reduced. In order to improve the detection speed and accuracy, cloud network architecture is proposed. The spectrometer is integrated into the backside of a smart phone and the wireless communication function of the smart phone can be used to realize the connection with the cloud server. The device terminal is only responsible for collecting and uploading data to the cloud. Spectra are identified by the algorithm server. The result and the attributes files are then transmitted to the smart Raman terminal. The algorithm, database, and terminal equipment are separated from each other to facilitate the timely update of algorithms and databases.

Index Terms—Raman spectrometer, sensitivity, recognition algorithm, cloud platform, smart phone.

I. INTRODUCTION

RAMAN spectroscopy is a kind of optical sensing technology capable of acquire characteristic fingerprint spectrum which can be used to identify the composition of analyses. It has the advantages of high accuracy, high speed, and non-invasion. It can provide information on vibrational and rotational information of molecules relating to different chemical bonds or functional groups, providing a powerful tool to identify molecules and even complex chemical structures. Raman spectroscopy has the capability of material identification and component analysis. So, it has been widely used in biomedicine [1-3], safety inspection [4, 5], drug control [6-8], chemical defines [9, 10], medicine administration [11], food safety [12-14], jewellery appraisal [15], archaeology and so forth [16]. Here we present an integrated smart phone Raman spectrum system based on cloud network architecture. The optical collection efficiency is enhanced by using big aperture lens and volume phase holographic transmission grating (VPG, Long March). The volume of the system is decreased, and the sensitivity is enhanced through slit coupling technology. Then, it can be integrated into a smart phone (Cloud Minds) and connected with internet to realize signal detection, transmission and analysis. The advantage of this system is to minimize the computing request and lower the processing request on detection device. Our system has utilized the connection between the device and cloud network to isolate computation from portable Raman device. Deep learning process can be executed on cloud and the final results can be feedback to the smart phone Raman.

The current research of portable Raman mainly focuses on the field application area. The mobility request of security inspections and anti-drug operations cannot be satisfied by laboratory analysis devices, so portable Raman has been widely studied in these fields [17-19]. In addition to the previous application, a portable Raman spectrometer is also used for archaeological research [20] and tumours screening for the first time by Kourkoumelis, N., which fully embody the portability advantage [21]. Although the application range and scenes of portable Raman spectrometers are continuously expanding, the progress on portable Raman spectrometer devices is relatively small.

In 2008, Sowoidnich, K. successfully miniaturized portable Raman optical probe by using 671 nm micro laser module. However, fibre coupling technology was still not used and notebook computers were utilized as a signal processing and analysis unit, resulting in an overall too big volume. Therefore, the miniaturization of Raman system is still on the way [23]. In 2012, Kelly, J. F. proposed the key parameter $F/\#(f/D)$ that needs to be considered in the design of miniaturization Raman system, where f is the focal length and D is the clear aperture. It is found that the light collection efficiency is basically inversely proportional to the square of the $F/\#$. In their research, they used homemade Raman spectrometers to detect common dangerous explosives, RDX and PETN, and obtained fairly good Raman spectra [22]. Tang, M., et al., in 2016, improved the signal collection efficiency of Raman system through optical direct coupling technology. However, the mainstream CT reflection structure was still used in this spectrometer.

Although the parameter $F/\#$ before the slit is small, the $F/\#$ of the spectrometer is restricted by the reflective optical structure, which results in a decreasing of coupling efficiency. The focal length (101 mm) need to be increased to improve the resolution of the system to correct aberrations. Then, the entire system is still large and the optical part alone already reaches 227.3mm * 180.5mm * 46mm [24]. In 2017, Jehlicka, J. et al. compared the available eight Raman spectrometers and found that the size of Raman spectrometers on the market is still too large. The smallest First Defender RM (Thermo Scientific) weighs 0.8Kg, and others are more than 1.5Kg. The outdoor application scenarios place higher demands on the portable instrument and weight and size. In order to expand the application of Raman, it is urgent to fabricate a hand-held

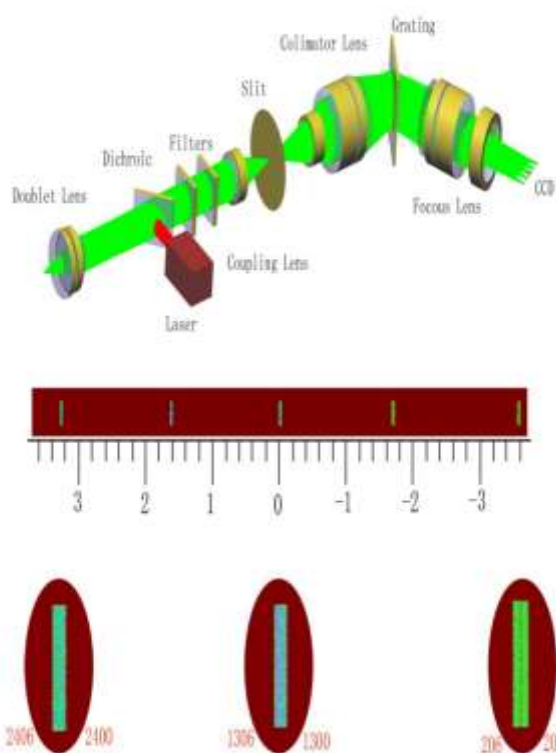


Fig. 1. Schematic illustration of optical system and simulation analysis

Raman spectrometer with small size, light weight and high sensitivity [25]. The Raman spectroscopy system contains three parts: Raman probe, laser device, and spectrometer. In order to improve the optical collection efficiency and further improve the sensitivity of the system, it is necessary to upgrade the optical element

selection, structure layout, and optimize optical performance. At present, optical fibre is the most popular element to realize the optical connection between Raman probes, lasers and spectrometers on the market. Although this coupling method is simple and flexible, it greatly reduces the optical collection efficiency of the system, which is approximately 1/5 of direct coupling system [22]. So the optical fibre limits the ability of the Raman spectrometer.

In this paper, we apply the slit space coupling technique together with the fixed focal length lens in the Raman system, combined with the VPG, reducing the system volume, optimizing the aberration of the optical system, and improving the resolution and sensitivity of optical system. The cloud network architecture is built by using the current wireless communication function of smart phones to meet the on-site rapid detection requirements for complex environments. The time required for the detection of substances is reduced by both sensitive optical system and cloud algorithm.

II. OPTICAL SYSTEM DESIGN

The semiconductor laser emits a near-infrared laser with wavelength of 785 nm, which is reflected by the dichroic mirror to the double-glued achromatic focusing objective lens. The laser signal is focused on the measured sample via the objective lens. The tested sample can be solid powder or liquid. The samples absorb the laser energy and generate Raman signal. The Raman signal is coming back through reversible light path.

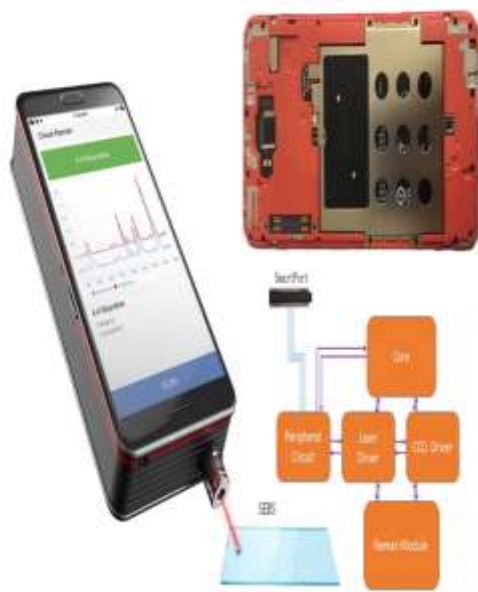


Fig 2. Raman system integrated in smartphone

The collimated light enters the collection optical path through dichroic mirror and is filtered by two filters (Smock) to block the 785 nm scatter and Rayleigh scatter signals (optical density is 7 for 785 nm laser light, and the transmissivity for light which wavelengths longer than 789 nm is greater than 95%). The purified Raman signal is coupled into the slit through a doubleglued coupling lens to achieve spatial filtering of the focal plane. After passing through the slit, the Raman signal enters the spectrometer and passes through the first fixed focal length lens to achieve collimation of the Raman light signal. The collimated Raman light is diffracted by a VPG and each diffraction light has a different diffraction angle. The camera lens collects the diffracted light so that the light is finally focused on the line array charge coupled device (CCD) (Hamamatsu S11510) to perform the spectroscopic detection of the Raman signal. In an ideal single-wavelength state, the detected CCD image is the slit on the focal plane, so the slit spatial filtering can be employed to improve the spectral resolution. In this optical system, the lens F/2.0 (custom made) is used to replace the collimating mirror F/4.0 in the spectrometer of the market, which facilitates the optimization of aberrations, thereby reducing the parameter F/# and

improving the light collection efficiency of the system. In addition, the VPG replaces the original plane holographic reflection grating, increasing the spectral diffraction efficiency from an average of 40% to an average of 75%, and further improve the sensitivity of the Raman system. Furthermore, slit space coupling technology is employed for connecting lasers, Raman probes and spectrometers, which reduces the system volume and increases the optical collection efficiency of the system. The total cost is less than \$10,000.

We optimize the light path through Code. Only the angle of the grating, imaging lens, and the detector with the distance from the imaging lens to the detector is set as optimization variables for optical system optimization. After optimization, the result is imported into Light Tools for optical simulation analysis. It can be seen from the simulation chart that 200 cm⁻¹ and 206 cm⁻¹, 1300 cm⁻¹ and 1306 cm⁻¹, and 2400 cm⁻¹ and 2406 cm⁻¹ can be completely distinguished from the simulation diagram, and the spectral resolution is better than 6 cm⁻¹ according to the Rayleigh criterion.

III. SYSTEM INTEGRATION AND DATA PROCESSING

The optical part is integrated on the back of the smart phone and connected to the smart phone through the Airport to communicate with the Raman system. When Raman spectrum acquisition is performed, the smart phone APP issues an acquisition command and transmits it to the Raman system via the Airport. The Raman processor triggers the emission of laser light. At the same time, the CCD is synchronized to synchronize signal acquisition. The data is transmitted to the smart phone via Smart Port when the acquisition is completed. The spectral data processing flow is shown in Figure 2. The collected spectral signal is Original Signal; the signal spectrum with high signal-to-noise ratio is obtained through the background signal and noise deduction; then the Baseline is obtained by Penalty weighted least square method. The baseline is relatively smooth, including the external environment light and the fluorescence signal of the sample; the baseline is subtracted from the spectral signal to obtain a pure Raman spectrum; then the pure Raman spectral signal is calibrated by wavelength correction and radiation correction to obtain a normalized standard Raman spectrum; finally, the identification algorithm is used for spectrum matching to achieve accurate material identification.

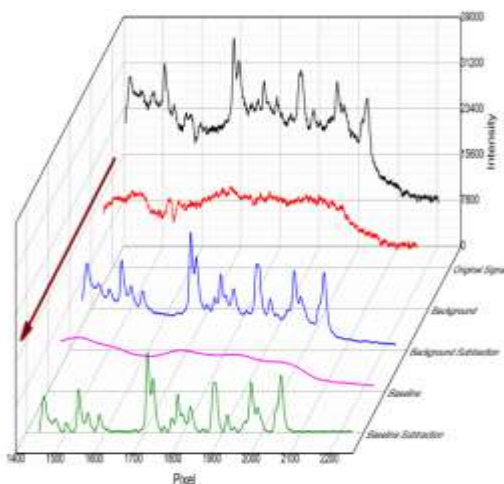


Fig.3. Raman spectrum preprocessing

IV. CLOUD NETWORK ARCHITECTURE AND EXPERIMENTS

We have utilizes smart phones to connect to the cloud to achieve rapid detection of substances (Figure 4). Our smart phone Raman system only collect Raman signal via Raman optical module and send signal to cloud network architecture. Signals can be uploaded via WIFI/Bluetooth/4G. The uploaded signal and background are received by the input of cloud server.

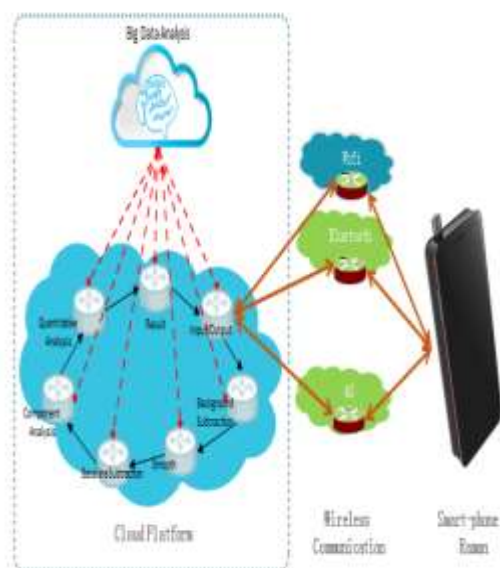


Fig 4. Smart-phone based Raman material identification system based on cloud network architecture

Then the signal spectrum without background interference is obtained after the background signal subtracted. The signal spectrum is smoothed and the baseline is fitted, and the baseline is subtracted to obtain a pure Raman spectrum. The cloud spectrum database contains the spectrum of common chemicals and the same substance contains multiple spectral data, each with a different resolution and spectral range, for adapting to different spectral devices. Finally, the matching algorithm is used to identify the Raman spectrum. The cloud network architecture implements the isolation of the Raman module and the analysis module, realizing interconnection through wireless network, reducing the hardware requirements. The cloud recognition algorithm applies the deep learning method, which based on Tensor Flow, has the advantages of high speed and high accuracy and then improves the performance of the entire system.



Fig 5. Results of the recognition of pure substances and mixtures by the Smart-phone based Raman system

In this paper, smart-phone based Raman was used for the material identification of alcohol, acetone, and their mixtures (Figure 5). The integration time is set to be automatic. The control program judges the integration time by the current spectral signal to noise ratio (SNR) and stops the acquisition when the SNR reaches a certain level. When the power is 300 mow, the optical automatic collecting time of the three substances is respectively 0.58 s, 0.32 s and 0.43 s, the algorithm analysis time is 0.3 s, and the wireless upload and download time is less than 0.5 s. Then the total detection time is less than 2 seconds. The red curve is the Raman spectrum in the database and the blue curve is the Raman measurements from the proposed system The parameters of the mobile phone spectrometer are: laser power 0-500 mow linearly adjustable, size in 3D 169 mm*65 mm*27 mm, weight 380 g, spectral range 200-1800 cm⁻¹, spectral resolution 9-11 cm⁻¹, battery power 5800 mA. It shows obvious advantages in terms of volume weight, architecture, algorithm, detection speed wireless network and geographic information system. The detailed information can be checked in Table 1. Portable Raman System Performance Comparison.

V. CONCLUSION

Here we aim to reduce the size of the Raman system and increase the sensitivity of Raman system. The optical efficiency and spectral resolution of Raman optical system are improved by using the fixed focal length lens and the VPG. The sensitivity of the system is further increased with slit direct coupling technology, which connects the laser device, Raman probe and spectrometer directly. The size of the Raman system is reduced, making it possible to be integrated in a smart phone. The smart phone Raman are connected with the cloud network

TABLE I
PORTABLE RAMAN SYSTEM PERFORMANCE COMPARISON

Parameters	Other Portable Raman on The Market	The Proposed Smart-phone Raman
Volume and weight	bulky	thickness 27mm, weight 380g
Architecture	Stand-alone architecture, almost no communication capability	Cloud detection architecture, excellent user experience, more intelligent application scenarios can be derived
Algorithm	Local algorithm, low efficiency and accuracy	Cloud deep learning algorithm + local traditional algorithm with high accuracy and speed
Database	Local database, difficult to update, inconvenient for centralized management of equipment	Cloud large databases, types can be continuously expanded; user-built libraries can be synchronized by the cloud. Local database guarantees detection without internet
Mixture identification	accuracy is low, and proportional analysis cannot be done.	The recognition accuracy of the mixture is high, and the ratio of the mixture can be identified with accuracy of 5%.
Detection speed	Detection and analysis time of 6-30s	Detection and analysis time of 1-3s
Wireless network	WIFI or Bluetooth	WIFI, Bluetooth and 4G
Geographic Information System	None	GPS

Architecture. It deploying databases and algorithms to cloud servers, and interconnecting smart Raman terminals through wireless networks. The processing capabilities of smart-phone Raman spectrometer is enhanced, which frees Raman terminals from processing occupation, facilitates the real-time updating of the database and analysis algorithms. The proposed cloud network architecture combined with the smart phone Raman system make on-site material identification and big data analysis possible.

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