**AUTO-FOCUSING METHOD FOR RAMAN SPECTROSCOPY** Y. H. Liu[1], Z. C. Ling[1*] and C. Q. Liu[1], [1]Shandong Key Laboratory of Optical Astronomy and Solar-Terrestrial Environment, School of Space Science and Physics, Institute of Space Sciences, Shandong University, Weihai, Shandong, 264209, China (zcling@sdu.edu.cn).

**Introduction:** Raman spectroscopy has been proved to be an efficient method for mineral identification [1,2], but there are still many problems to be solved [3]. In the on-going planetary exploration missions, it is becoming more and more critical to make payloads more intelligent with the intent to simplify explorations procedures and acquire data with better SNR. This work proposed a method which was aimed to realize automatic focusing in Raman spectroscopy based on Raman intensity. In addition, miniaturization of Raman spectrometer was also realized, which improved the usability of Raman spectrometer.

There are two critical components in this automatic focusing method, including Focus Evaluation Function (FEF) and Extreme Search Algorithm (ESA), which will be briefly described in this abstract.

*Focusing Evaluation Function (FEF)* The FEF has an extreme value when the focal plane coincides with the surface of the sample to be measured. In other words, the FEF extreme value point should corresponds exactly to the focus. In this article, several FEFs based on spectral signals are compared. And finally, the full spectra integration was applied as the FEF.

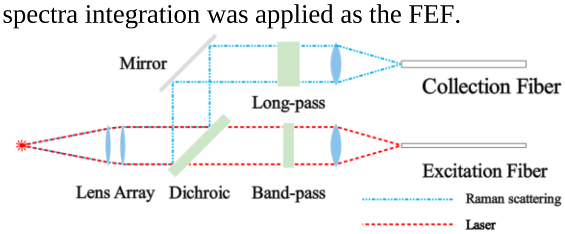


Fig. 1 Structure diagram of the auto-focusing probe.

The FEF will change when the distance between samples and the focal plane of the lens array varies. In particular, the extremum FEF value can be acquired when samples are exactly in the focal plane. Therefore, the quality of the focusing evaluation function will directly affect the precision and efficiency of the auto-focusing procedure. We purposed several FEFs, including the maximum peak intensity of raw spectrum, partial or full spectra integration of raw spectrum, the maximum peak intensity of spectrum with baseline subtracted, partial or full spectra integration of spectrum with baseline subtracted. The curve of the ideal FEF changing with the focusing position. And it should be as monotonous as possible on both sides of the extreme value and be able to reach the extreme value at the optimal focusing position. Which means it should meet the following characteristics:

a. Unbiasedness: The extreme value of the FEFs should occur when the lens array is accurately focused on the surface of the testing samples, that is, the estimated value obtained through the auto-focusing procedure is consistent with the true value of the focus.

b. Unimodal: the curve of the FEFs changing with the focal length should have only a single extreme point and should increase/decrease monotonically on both sides of the extreme point.

c. Efficiency: with the intent to improve the efficiency of the method, the calculation amount of the FEFs in focusing procedure should be as few as possible. In addition, fast calculation methods should be utilized, such as addition and subtraction, rather than complex operations such as gradient calculation.

d. Universality: FEFs should be capable of focusing evaluation tasks of different samples.

e. Robustness: the FEFs should be able to suppress the influence of accidental factors such as cosmic rays.

Furthermore, the FEFs is best characterized by steepness near the extreme point (i.e., the focal point). This will make the FEFs highly sensitive to the extreme point being the focus.

According to the features above, by comparing kinds of spectrum-based FEFs, it can be found that there is little increment of computation between full spectra integration and the maximum peak intensity of spectrum. However, the former has higher robustness than the latter in suppressing the random noise caused by single or a few pixel anomalies.

In the procedure of the sample position from defocus to focus, the full spectra integration gradually increases and approaches until the focus position reaches the extremum. After passing the focusing position, the focal length of the lens array keeps varying, and in the procedure from focusing to defocusing, the integration of the full spectra decreases, which meets the requirements of unimodal. Therefore, the integration of full spectra performs well as a FEF in this spectrum-based auto-focusing method.

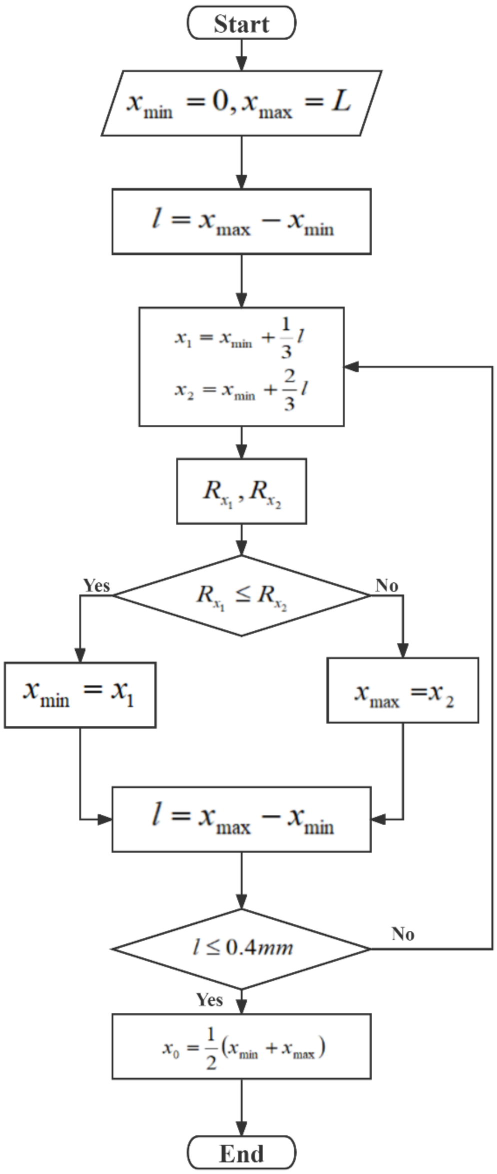


Fig. 2 Flow chart of trichotomy search

*Extremum Search Algorithm (ESA)* ESA is the other key component to find the best focusing position efficiently. By applying the characteristic that the extreme point of FEF curve corresponds precisely to the focusing position, ESA works out the best position by quickly finding the extreme point of FEF. Under the circumstances that the performance of FEFs is similar, a better ESA can significantly improve the focusing efficiency. In order to meet the requirements, the ESA selected should apply to a dual function with less computation, fast operation speed, and high accuracy. Several algorithms are widely utilized including traversal method, Fibonacci search (also named as the golden section search method), function approximation method, and mountain climbing method.

Trichotomy search method continuously shortens the extreme point range to approach the extreme point of FEF according to the judgment conditions, and finally achieve the preset accuracy to realize the focusing function. Therefore, trichotomy search can get a focusing result with very high precision when accuracy of FEF and focal length adjustment is high enough,. The trichotomy search algorithm is shown as Fig. 2.

a. The extreme point range is set to the entire adjustable interval of step motor which drives the lens array.

b. Length of the extreme point range is written as L.

c. Acquisition of spectrum at trisection point. Afterwards, two trines ($0 < x_1 < x_2 < L$) in the extreme point range can be calculated, and then the Raman spectrum of these two trines were acquired. FEFs can be calculated based on the spectrum of two trines, marked as $FEF_1$ and $FEF_2$.

d. Comparison of FEFs. If FEF is positively correlated with the focus degree, as utilized in this paper, then the trisection point which has a lesser FEF is taken as the new endpoint. Latter extreme point range length is two thirds of the former one.

e. Repeat step b. to d. until the range length is less than a predetermined threshold.

f. Finally, the midpoint of the extreme point range is taken as the focal point.

**Conclusion:** In this paper, a spectrum-based automatic focusing method is designed and a Raman system based on this method is realized and welly functioned. And afterwards, the system was integrated and miniaturized to build a Raman probe prototype for non-ideal conditions like field study and security check.

However, there are still some shortcomings in this research, such as short adjustable range (limited by the focal length of lenses which consists the lens array to adjust the focal length) and cannot be applied to transparent or translucent materials. These deficiencies will be further supplemented and improved in the future.

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**References:** [1] B. Xue et al. (2019) *Journal of Deep Space Exploration, 6(05):*503-512. [2] Z.C. Ling et al. (2013) *Geological Journal of China Universities*, 632-633. [3] W.G. Kong. (2011) *Shandong University, PhD dissertation.*