Design and application of core mineral spectrometer

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Core mineral spectrometer is one of the advanced and important tools for core digitalization, altered mineral mapping, ore deposits exploring, and ore-searching in surrounding mine and beneficiation process. In this letter, a new core mineral spectrometer (CMS 350) is designed and developed. The basic principle, structural design, function module, key components, data acquisition, and processing methods of CMS 350 are introduced. In addition, some applications and results of CMS 350 in Zijin Mining are presented to validate the performance of CMS 350.

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Mineralogic logging of drill core is very important for the mining industries, because the spectral characteristics of drill core are the first indicators of mineralization potential[1−3]. The remote sensing and advanced spectroscopic techniques can provide more information on the physico-chemical properties of the surface coverings (including rock shape, type, mineral composition, and chemical characteristics of the rock), and thus are helpful for the identification of latent bedrock, alteration mineral assemblage and surface regolith characteristics, and geological mapping[4]. It has been known that the imaging spectrometers can measure the reflectance of the Earth's surface in hundreds of spectral bands[5,6]. Over the last 20 years, as the result of maturing hardware technology and available specialized software, the use of these data has expanded from only a few expert users primarily for mapping alteration mineralogy[7,8]. Unfortunately, the supporting of the field spectrometer has not kept pace with the development of the imaging sensors and analysis capabilities. Portable spectrometer has been available for a relatively long time outside China, and well-known commercial products, such as ASD FieldSpec, SVC HR1024, etc., have been widely used in varieties of fileds. But in China, only recently have portable high-spectral-resolution field spectrometers become available, such as the portable infrared mineral analyzer (PIMA)[9]. Analytical software has also existed for a long time outside the country, such as Tetracorder developed by USGS, MGM tool developed by Brown University, etc. Besides, the Spectral Geologist, which is the first commercial software for core spectral analysis developed by Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, has been introduced to China. But domestically, few analytical software packages have been developed for qualitative or quantitative analysis of the field data[10,11].

For instance, the Mineral Mapping Technologies Group of CSIRO in Australia has developed a rapid spectroscopic core and chip logging and imaging system since 2002, which is named as HyLogger core scanner[12]. This system uses automated core tray handling, continuous visible and infrared spectroscopy, and digital imaging, to characterise and identify the dominant mineral species on core, chips, and pulps, at spatial resolutions of ∼1 cm (spectral data) and ∼0.1 mm (image data). And it can log up to 1000 m of core per day and several thousand metres of drill chips. Mineralogy is pre-interpreted using specialised identification software trained on a selected suite of minerals showing characteristic absorption features within the measured spectral range[13−15]. There are some applications in drill core using PIMA and HyLogger mineral spectrometer[14,16−18], but on the other hand, the spectral wavelength range of PIMA just covers 1300−2500 nm, and they are much more expensive and inconvenient for use. Above all, in China there are still no such spectrometers, and thus it is very important for the geology industry development to develop a spectrometer in China. This letter describes a core mineral spectrometer (CMS 350) and approach for field spectroscopy using hyperspectral image processing techniques that provide an effective, quantitative measure for core composition, mineral identification and mapping.

The 350−2500 and 8000−12000 nm spectral ranges are usually used for mineral spectrum recognition. The basic principle of core mineral spectrum recognition is that the bend, flexible, and electronic transition of chemical bonds between atoms can absorb energy on some band spectrum ranges, so that the obtained spectrum can be used for distinguishing different altered minerals[19]. According to the spectral characteristics of minerals, the qualitative, quantitative analysis and alteration information extraction can be conducted on minerals in rocks. Thus the geological background, genesis of ore deposits and original rock types can be revealed, and it can provide a data tool for core digitalization, geological studies and geological prospecting. Figure 1 shows the spectrum curves of some typical minerals.

The CMS 350 (Fig. 2) consists of core mobile platform, the instrument bracket, spectrometers, cameras, laser ranging, lighting, control electronics, and control software modules.

The mobile platform (Fig. 3) includes the support frame, X/Y movement axes, trays, motor, and drive system. The instrument support frame has stability and load-bearing more than 200 kg, and a corner adjustment device to expediently adjust the level. X/Y movement axes can be realized freely by movement in X/Y direction. Move accuracy should be more than 0.01 mm. The effective moving distance in X and Y axes are 1250 and 900 mm, respectively; a square sliding rail and dust guard are used in the X/Y movement axis, and it can satisfy the needs of different sized core disk. For the tray, because the length of the core plate is not more than 1000 mm usually, and plus the 200 mm length of the calibration auxiliary equipment, the total length of the tray is generally 1200 mm, and the width is not greater than 800 mm. It should be noted that the weight of the core plate and the force bearing point of the X axis need to be considered in the design process, so that the trays can be stabilized and accommodated to be weight requirements of cores. As for the motor and drive system, a stepper motor is usually selected due to its simple driving and cheap price, but the disadvantage of it is that the torque is reduced with speed accelerating, which will affect the accuracy and efficiency during the movement of core mineral. Here, a servo motor is used, and it can overcome the shortcomings of the stepper motor.

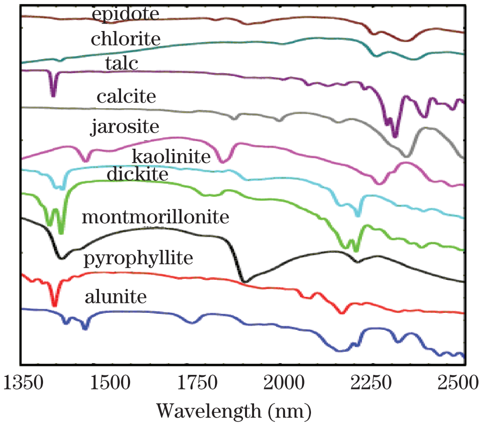

Fig. 1. Spectrum curves of some minerals.

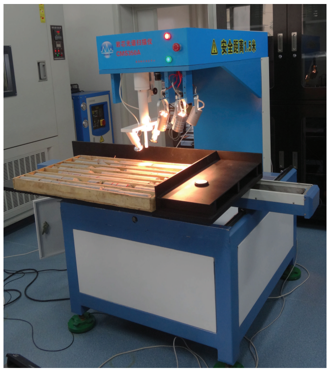

Fig. 2. CMS 350.

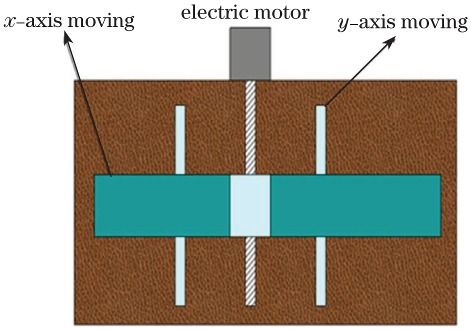

Fig. 3. Core mobile platform.

The instrument bracket is a platform equipped with measuring equipment. There are usually two design methods, one is in stalling the measuring equipment with mobile platform, and the other is the separation design where the instrument bracket is separated from the mobile platform and they will be assembled when used (Fig. 4). The former one has a lower cost and a lighter weight, but the weight of the core plate is too heavy to produce vibration phenomenon, and it will affect the data quality. For the latter one, although the weight and cost are increased, the motion will not produce vibrations because of the separate modular designs, while convenient for handling and transport.

The spectrometer is designed and developed by Nanjing Zhongdi Instrument Co., Ltd, named as CSD350A full spectral feature spectrometer. In this spectrometer three linear CCDs and fiber-optic transmission technique are used. The fiber-optic transmission technique uses three mosaic linear CCD array detectors. The instrument structure is shown in Fig. 5.

The spectrometer is composed of a probe, an optical fiber connector, and three separate spectrometers. Since the spectral wavelength range is 350−2500 nm, the sensor detection performance is divided into three bands splicing, among which the wavelength ranges of spectrometer I, II, and III are 350−900, 900−1700, and 1700−2500 nm, respectively.

The probe consists of a light source and the optical fiber connectors, using two 12 W halogen illumination lights for focusing on the core. The focal spot diameter is 10 mm. In order to reduce the astigmatism light which affects the quality of the data, the reflected light inlet is designed less than 8 mm, and as close as possible to the irradiated core focal spot. The structure of the probe is shown in Fig. 6.

The light source uses tungsten halogen. Light hits on the core surface after convergence. Uneven surface of the core generates diffuse reflectance, then the diffuse light enters into the fiber tip and is transmitted to the spectrometer by the optical fiber.

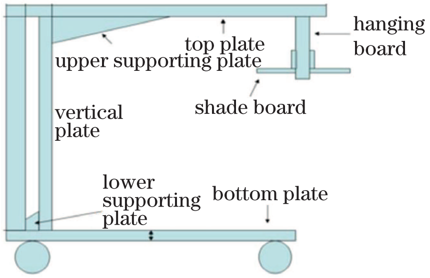

Fig. 4. Instrument bracket.

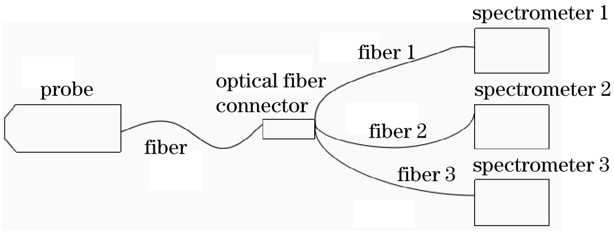

Fig. 5. Instrument structure.

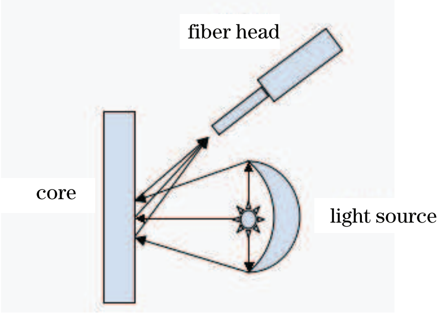

Fig. 6. Probe structure.

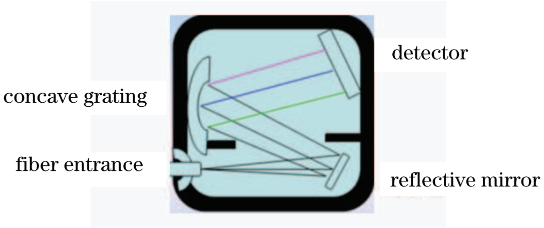

Fig. 7. Spectrometer structure.

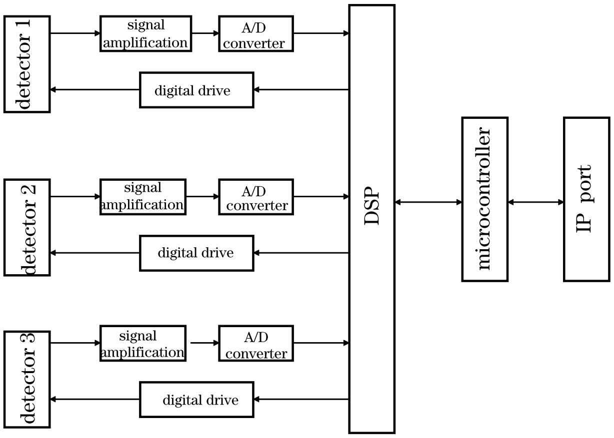

Fig. 8. Spectrometer control.

The fiber uses quartz fiber to reduce the energy loss in the transmission process of shortwave infrared. The fiber consists of 32 bars of 0.2 mm in diameter, and the connecting portion is in combination with the probe. The spectrometer connection portion is divided into three ways, and each has 12 bars. All of the fibers are combined into one row, making up a 0.2 mm slit and enter into the spectrometer respectively.

The spectrometer uses concave flat field grating for light splitting and CCD linear array detector for reception. The structure of the spectrometer is shown in Fig. 7.

As shown in Fig. 7, the diffuse light reflected by the core passes through the fiber and enters into the fiber entrance. Then the light goes into concave grating for splitting after reflected by the mirror. After splitting, the single spectrum is received by the detector. Concave grating has different parameters according to the different bands, but the overall structure has not changed.

The spectrometer control consists of detector driver, signal amplification, A/D converter, DSP control, and microcontroller, among which the DSP controls the three-way detector drive and signal acquisition. The acquired data are transmitted into microcontroller, which is connected with the computer via IP port and executes related command. The structure of the spectrometer is shown in Fig. 8.

The parameters of the spectrometer are as follows: spectral range: 350−2500 nm; spectral resolution: full spectrum is better than 7 nm; spectral wavelength repeatability: better than 1 nm; spectral measurement speed: less than 20 times/s; SNR: better than 2500: 1; power dissipation: 20 W, built-in lithium battery; instrument weight: less than 3.5 kg.

The SNR measurement method is: measuring the dark-current of the spectrometer and the whiteboard by regarding the whiteboard as the object and measuring its reflectivity. Calculating the mean square deviation of reflectivity, the result is the SNR.

We use the industrial type camera and develop control software by ourselves. The camera has 1600×1200 pixels, hard trigger function, and 500 mm of the lens focal length, and can take 30 frames per second. It generally requires a resolution of the measured core in 0.1×0.1 (mm). Due to the amount of data photographs, jpg format is used for storage, while pixels resolution does not need to be high for application.

The lighting system is divided into two parts with one being the spectrometer lighting. This lighting requires high stability, but texture waves and drift are very small. In addition, the power is supplied by switching power and the high stability of the regulator circuit voltage, the halogen light also needs the power. The other part is the camera lighting, typically using the LED light. But the experiments have shown that the LED light has some effects on the spectral value, so we choose halogen light here. For the halogen lighting system, the light is nonuniform, and the halogen light should not be focused. The independent halogen lamp can be selected and mounted in lampshade with the frosted glass so that the light that shines on the core are uniform.

Electronics control unit includes six modules, as shown in Fig. 9, which has a separate spectrometer and the camera's internal electronics; the data is read through an IP port, and the other controls are programmed by the microcontroller for the target control, and then the core scan action can be driven and the relevant parameters can be obtained.

Software control unit is programmed strictly in accordance with the modules as shown in Fig. 10. All the modules are combined together to achieve a complete measurement procedure.

This instrument is the first successfully developed core spectrum of practical scanner in China. It has been applied in Zijin Mining, Fujian, and more than 25,000 m cores are scanned. We will take drill DZK1202 (Zijin Mining provided) as the example to validate the performance of our proposed instrument. Figure 11 illustrates the spectral curve of alunite, and Fig. 12 is the image of core.

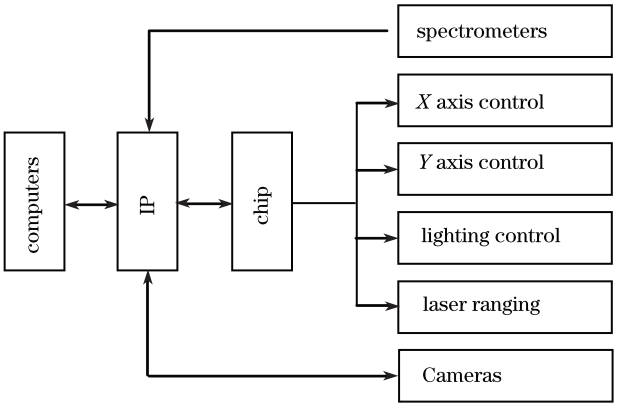

Fig. 9. Electronics control unit.

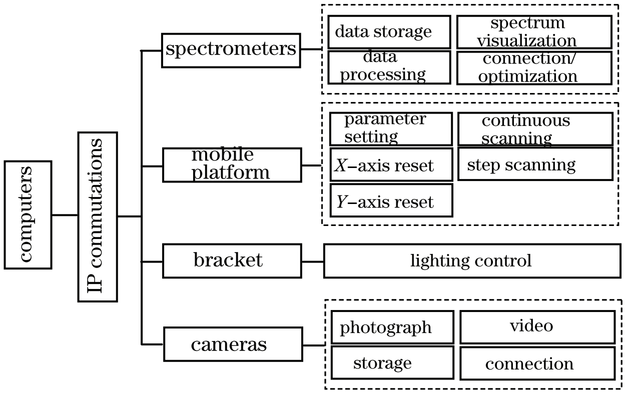

Fig. 10. Software control unit.

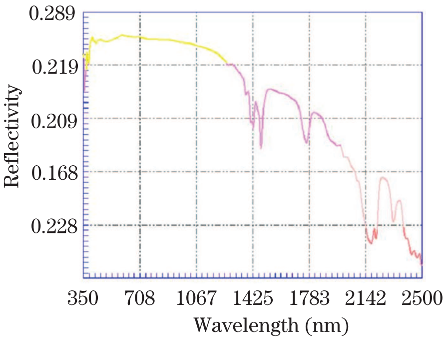

Fig. 11. Spectral curve of alunite.

Fig. 12. Image of core.

DZK1202 drilling mineral maps of Zijin Mining are shown in Fig. 13, from which we can see that the distribution of kaolinite, pyrophyllite, muscovite, and dickite are consistent with the actual investigation. Figure 14 shows the extraction parameter results of alunite.

Alunite parameter information extracting selects 1760 nm absorption peak as the characteristic peak. Removing the envelope line to calculate the absorption peak height, the ratio of absorption peak height to 1910 nm adsorbed water peak, the wavelength position of the absorption peak, the FWHM, and the symmetry of the absorption peak, then you can obtain those parameters in Fig. 14.

Three-dimensional mapping results of the alteration minerals are shown in Fig. 15 by extracting the absorption peak position in 1480 nm of alunite and calculating the wavelength shifting parameter. From the results we can conclude that the gold ore is changed regularly with the spectral parameters of alunite which has close relations with copper mineralization in Purple Mountain, and when near the volcanic, the 1480 nm absorption peak of alunite will moves to long wavelengths.

According to Ref. [20], the changes in these parameters reflect that the chemical composition of alunite varies with crystallization and gradual environmental changes. It will be intrusions on the hydrothermal center and the location of intrusive body; it is useful for the deep exploration, and the final model will be further improved with more scanned core data.

After years of exploratory research, this instrument has achieved its target in core digitalization and core

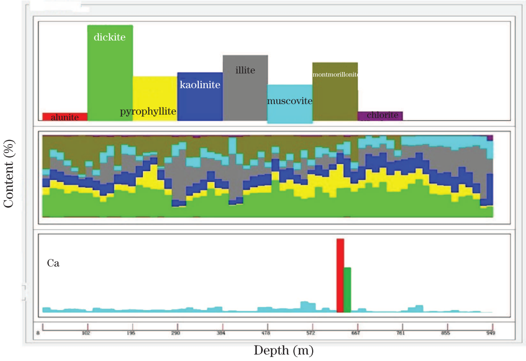

Fig. 13. Minerals statistics.

Fig. 14. Parameter results of alunite.

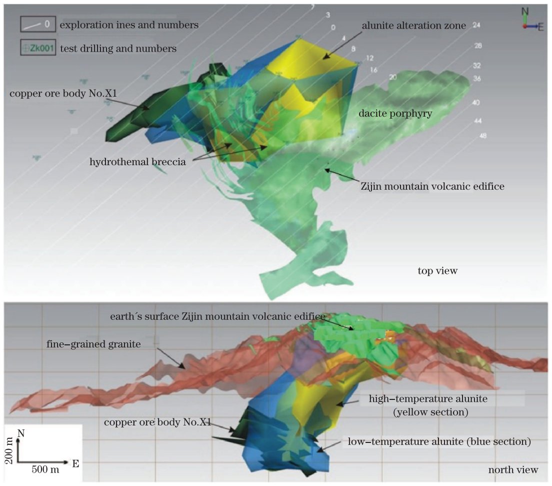

Fig. 15. Spatial distribution schematic of alunite for gold and copper ore in Zijin mountain (provided by Zijin Mining)

minerals information extraction. It provides an important means of measurements and completely changes the traditional core catalog methods for core digital, geological studies, genesis research, mining perimeter prospecting, and mining process optimization. The application and experimental results in Zijin Mining have proved the reliability and data quality of the instrument, and will promote more applications for this instrument.

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References

1. J. A. Bolger, Appl. Spectrosc. **54,** 181 (2000).
2. X. Hou and B. T. Jones, *Encyclopedia of Analytical Chemistry* (John Wiley and Sons, New York, 2000).
3. R. N. Clark, *Manual of Remote Sensing* (John Wiley and Sons, New York, 1999).
4. F. D. van der Meer, H. M. A. van der Werff, F. J. A. van Ruitenbeek, C. A. Hecker, W. H. Bakker, M. F. Noomen, M. van der Meijde, E. J. M. Carranza, J. B. de Smeth, and T. Woldai, Int. J. Appl. Earth Obs. **14,** 112 (2012).
5. A. F. H. Goetz, Remote Sens. Environ. **113,** S5 (2009).
6. E. J. Milton, M. E. Schaepman, K. Anderson, M. Kneubühler, and N. Fox, Remote Sens. Environ. **113,** S92 (2009).
7. Q. Tong, Y. Xue, and L. Zhang, IEEE J. Sel. Top. Appl. **7,** 70 (2013).
8. F. A. Kruse, Int. J. Remote Sens. **17,** 1623 (1996).
9. Commonwealth Scientific and Industrial Research Organisation, “Portable Infrared Mineral Analyser (PIMA)”, http://www.ga.gov.au/about-us/our-facilities/laboratories/inorganic -chemistry.html (February 13, 2014).
10. S. He, X. Yao, C. Jiang, J. Liu, Y. Liu, and L. Chen, Chin. Opt. Lett. **1,** 145 (2003).
11. Y. Lv, Z. Sun, and Y. Zhao, Chin. Opt. Lett. **10,** 062801 (2012).
12. Commonwealth Scientific and Industrial Research Organisation, “HyLogger”, http://www.csiro.au/en/Organisation-Structure/Flagships/Minerals-Down-Under-Flagship/Exploration/hylogging-systems/HyLogging-instrumentation.aspx (February 13, 2014).
13. L. Elizabeth, C. Wendy, S. Pete, and K. Tyler, Geoth. Res. T. **36,** 1281 (2012).
14. M. Speta, B. Rivard, J. Feng, M. Lipsett, and M. Gingras, in *Proceedings of IEEE International Geoscience and Remote Sensing Symposium (IGARSS)* 2184 (2013).
15. M. Tappert, B. Rivard, D. Giles, R. Tappert, and A. Mauger, Econ. Geol. **106,** 289 (2011).
16. M. E. Schaepman, S. L. Ustin, A. J. Plaza, T. H. Painter, J. Verrelst, and S. Liang, Remote Sens. Environ. **113,** S123 (2009).
17. B. Gao, M. J. Montes, C. O. Davis, and A. F. H. Goetz, Remote Sens. Environ. **113,** S17 (2009).
18. W. Calvin, A. Lamb, and C. Kratt, Geoth. Res. T. **34,** 761 (2010).
19. F. Gan and R. Wang, *Foundation and Technical Methods of Extraction of Remote Sensing Rock Information Application* (in Chinese) (Geological Publishing House, Beijing, 2004).
20. Z. Chang and Z. Yang, Econ. Geol. **107,** 1479 (2012).