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Agenda item [2] (from agenda)

Workplan Task Number / Technical Domain [2]	2018 - 2022 / Task 2.2.1
Working Group	WG1
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Intelligent Measurement of the Character of Aids to Navigation Light

1 SUMMARY

To improve the technical management of aids to navigation, China Maritime Safety Administration has organized and carried out research on the intelligent detection technology of AtoN light character since 2017. The characteristics of AtoN signal light is fully analyzed, then four key problems of measurement of AtoN light character are studied, i.e. remote collection of AtoN light, AtoN light stabilization, removal of the interference of background light, irregular rhythm and period of light. Finally, a complete intelligent detection method has been developed and verified in practice. This document is intended for the provision of guidance to improving the measurement of AtoN light, especially for the on-site measurement.

1.1 Purpose of the document

The purpose of this document is to introduce an intelligent method for on-site or laboratory detection of the AtoN light character.

1.2 Related documents

IALA Recommendation E-200-3 - Marine Signal Lights, Part3 - Measurement

IALA Recommendation E-110 - Rhythmic Characters of Lights on Aids to Navigation

IALA Guideline 1116 - Selection of Rhythmic Characters and Synchronisation of Lights for Aids to Navigation

1Input document number, to be assigned by the Committee Secretary

2Input papers should be assigned to a work task as listed in the Committee work plan which is available in input papers.Leave open if uncertain but consider how the paper is to be processed if not relevant to a work task

2 BACKGROUND

AtoN light is an important aid to navigation to ensure the safe navigation of ships. It provides aids to navigation service for ships with regular signal light. Accuracy and quality of AtoN light are the most basic and important requirements for AtoN lights. Improving the detection method of marine signal light is an important basic work to improve the technical management of AtoN, which is very necessary to promote the quality of AtoN.

At the time when this document is drafted, the published recommendation and guideline of IALA on AtoN light character include IALA Recommendation E-110 - Rhythmic Characters of Lights on Aids to Navigation, IALA Recommendation E-200-3 - Marine Signal Lights, Part3 - Measurement and IALA Guideline 1116 - Selection of Rhythmic Characters and Synchronisation of Lights for Aids to Navigation. E-110 provides suggestions on the rhythmic characters of AtoN light, G1116 provides technical guidance for the selection of rhythmic characters of AtoN light, and E-200-3 mainly advises on the luminous intensity and color measurement methods of AtoN. None of the three documents addresses detection methods for rhythms and periods of the AtoN lights.

However, in the actual operation of AtoN, the measurement of the rhythm and period of the AtoN light heavily relies on human operation. The flash rhythm is observed by naked eyes and the flash period is measured by a stopwatch. This management mode is too extensive, cumbersome operation and low precision. Therefore, it is necessary to deeply study the intelligent measurement technology of AtoN light character, so as to realize the accurate measurement of AtoN light character.

3 DISCUSSION

3.1 Measurement Technology of AtoN Light Character

The rhythm, period and colour of light are the three major elements of AtoN light character. Because of the particularity of the rhythm of AtoN light and the limitations of the measurement technology, especially in the field of the AtoN light, the measurement will be restricted by many factors such as measurement distance, target stability and background light. Therefore, there is no accurate measurement method and instrument before. Based on the in-depth analysis of the characteristics of AtoN lights, this paper fully studies some key technologies, puts forward the solution strategy, integrates the application of light collection technology, beam splitting technology and spectral analysis technology, supplemented by efficient and scientific analysis and calculation, forms a scientific measurement method, and realizes the intelligent measurement of AtoN light character.

3.2 AtoN Signal Light Character

The AtoN signal light character is as follows:

3.2.1 Large Span of Luminous Intensity

Luminous intensity of different types of AtoN varies greatly. For small AtoN, it is less than twenty candela, while that of some large lighthouses can reach up to tens of millions of candela . The luminous intensity of large lighthouses is millions of times that of the small AtoN.

3.2.2 Narrow Beam

The beam of AtoN light is usually designed to be very narrow to obtain a sufficient luminous range for minimum power drain. The beam divergence angle for a lighted buoy is less than 10 degrees at present while that for a lighthouse is more narrow.

3.2.3 Irregular Rhythm of Light

There are many kinds of rhythms of AtoN light, complying with certain provisions. However, among so many rhythms, there is no regularity.

3.3 Key Problems and Solutions of Measurement of AtoN Light Character

3.3.1 Remote Collection of AtoN Light

The measurement distance is not fixed for the complicated and various environment of AtoN. So for AtoN light with small luminous intensity, the signal intensity is not enough in case of a long distance, while for that of large luminous intensity in case of a close distance, the signal may be blocked. Both are hard to be measured accurately. It is necessary for the instrument adaptable to large-span measurement.

The optical telescope based on spectral collection technology can be used for remote collection of AtoN light. In the design and selection of a telescope, high resolution, small aberration, strong light collection ability and portability are required.

3.3.2 Stable Acquisition of AtoN Light

The on-site measurement of AtoN light is usually carried out by boat. The buoy light sways and fluctuates irregularly under the influence of ocean wind and waves, and the ship also inevitably sways and drifts, so it is difficult to have a stable acquisition of AtoN light.

The heart of stable acquisition of AtoN light is to handle sway effectively. The focus adjustment technology can be used for stabilization, and the hydraulic governing platform with this technology is a potent means. By placing the telescope on the hydraulic governing platform, the direction can be adjusted smoothly in the three-dimensional space to counteract the influence of sway and accurately track and acquire the signal.

By the way, it's not easy to timely attract the AtoN light through the telescope directly observing the images of AtoN light to adjust the observation angle. The beam splitting technology can be used here to get a small part of the light collected by the telescope and then use an electronic eyepiece or other ways to display the images of AtoN light on the laptop computer monitor, so as to facilitate the inspectors to adjust the observation angle timely and obtain the AtoN light more efficiently.

3.3.3 Removal of the interference of Background Light

Sunlight, lights on land and all kinds of reflected lights form disorderly background interference to AtoN light, and there is no certain rule to follow. In order to accurately detect AtoN light signal, certain technical means must be adopted to overcome the background interference.

The spectral analysis technology is a useful way to analyze the spectrum of signal lights. It can extract the spectrum of AtoN light according to the specific wavelength of it. Spectrometers are generally used for spectral analysis. In order to reduce the chromatic aberration of optical imaging and improve the sensitivity of the system, a reasonable optical path is required for the spectrometer used. It is critical to pay special attention to the grating constant, diffraction efficiency, wavelength calibration, orders overlap effect correction, CCD detector and other key technical items of the spectrometer.

And then, mathematical models can be used to fit the changing trend of the background light signal and set a certain threshold value, which can accurately distinguish the AtoN light signal and the background signal. The background extraction algorithm can be used to identify the character of most AtoN lights, but for some strong interference background light, the AtoN signal can not be identified accurately. In order to improve the adaptability of the automatic recognition algorithm of AtoN light character, the method of data processing for local signals is adopted, i.e. by selecting a certain range of signals to identify the AtoN light character, in which the background interference is small.

3.3.4 Irregular Rhythm of Light

There are 256 rhythms of AtoN light, complying with certain provisions, but there is no regularity among so many rhythms. It is very hard to identify the rhythm and period of light from a continuous and irregular flashing light sequence and judge their conformity in a timely manner.

For irregular rhythms and periods of AtoN light, a database is established for all of AtoN light characters, the composition character is fully analyzed, sum up the characteristics including the unique characteristics of a few special AtoN lights and the general characteristics of all AtoN lights. Finally, various algorithms can be used in software processing to achieve correct identification. Generally speaking, the processing flow of the algorithm is as follows: firstly, determine the period, secondly, determine the rhythm, and finally, determine the AtoN light character.

3.4 Measurement Method

3.4.1 Measurement System

The measurement system of AtoN light character based on spectral analysis technology is shown in Figure 1.

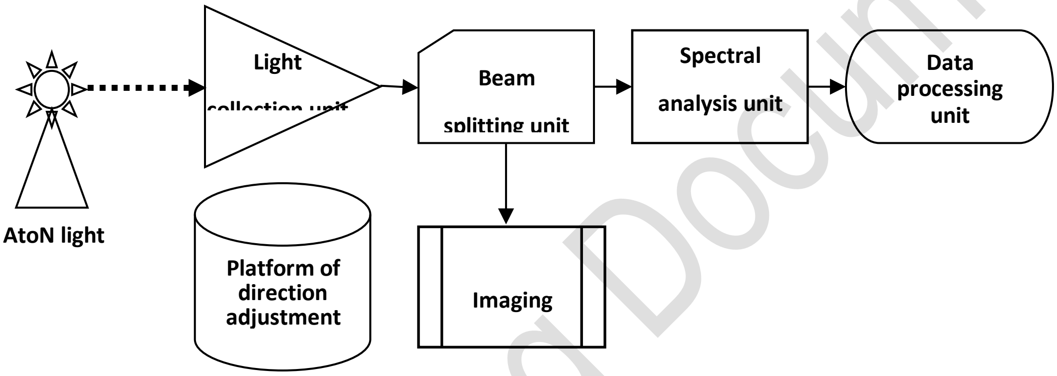


Figure 1 Diagram of AtoN light character measurement system

The whole system mainly consists of a light collection unit, a direction adjustment platform, a beam splitting unit, an imaging unit, a spectral analysis unit and a data processing unit. The AtoN light is collected by the light collection unit, and a small part of it is sent to the imaging unit through the beam splitting unit, and most of the light is sent to the spectral analysis unit for spectral analysis. The spectral analysis unit decomposes the light signal according the wavelength and converts the light signal of all wavelengths to electrical signal. The data processing unit analyzes and calculates the electric signal from the spectral analysis unit, and detects the color, rhythm and period of the light signal. Inspectors observe the detection process through the imaging unit, and control the light collection unit to obtain the light signal in the best way to ensure the accuracy of detection. The direction adjustment platform can be adjusted freely in three-dimensional direction. When detecting a moving target, the direction adjustment platform needs to be started to track the AtoN light.

3.4.2 The Technical Requirements

In order to accomplish the measurement of AtoN light character, the following technical requirements of this measurement system shall be met.

a. Light collection unit

For laboratory detection, the light signal can be collected into the optical fiber only by using the ordinary coupling/convex lens. For field testing, a telescope must be used with an apparent magnification not less than 20X, focal ratio not more than F5.7, and objective aperture not less than 70mm.

b. Beam splitting unit

The beam splitting unit can only separate a small amount of light imaging for observation, so most of the optical signals shall be transmitted to the spectrometer for analysis and detection. It is recommended that the transmission and reflection ratio of the beam splitting unit should not be less than 70/30.

c. Spectral analysis unit

According to the wavelength range of the AtoN light colour, the spectral range of the spectral analysis unit shall not be less than 380-780nm, the spectral resolution shall be higher than 2nm, and the sampling speed shall not be less than 100 frames/second.

d. Sampling frequency

In order to ensure the accurate measurement of AtoN light character, the sampling frequency shall not be less than 100Hz.

e. Measuring time span

In order to completely measure at least two periods of AtoN light and ensure the accurate measurement, the measurement time span shall generally not be less than 90 seconds.

3.5 Validation Result

According to the method described in this paper, the detector of AtoN light character (see appendix for details) has been developed and applied in practical work. It is mainly used for technical measurement of AtoN lights, efficiency evaluation of AtoN lights and project acceptance.The practical application proves that the above method is effective and feasible, and the instrument is stable and reliable. According to this method, the operation is convenient, the interface is friendly, and the accuracy is high. So far, more than 70 AtoNs have been measured, and the measurement accuracy is over 98%. Moreover, the instrument is also suitable for on-site measurement, with strong function and wide application. It has played a very obvious role in boosting the technical management of AtoNs.

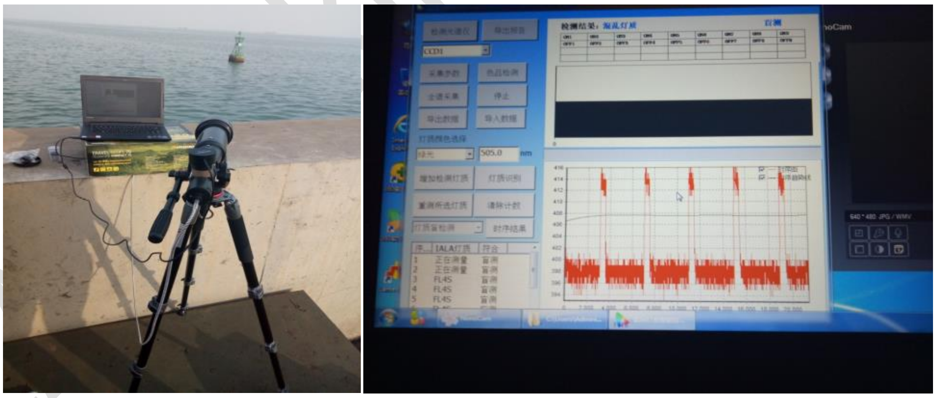


Figure 2 Measurement scenario of No.31 buoy in Yantai Port on the shore

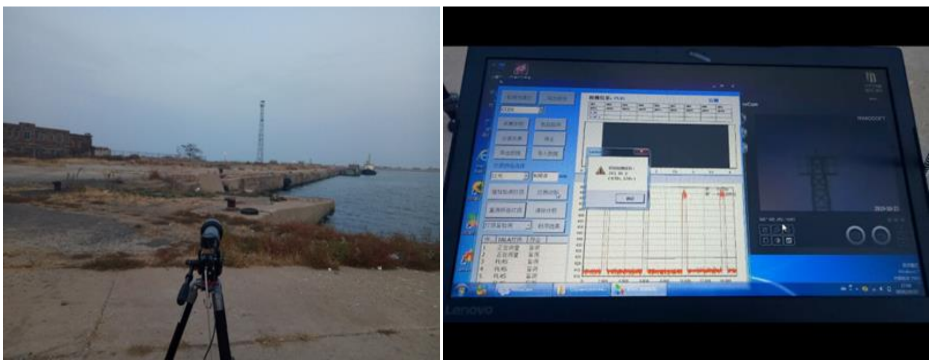


Figure 3 Measurement scenario of north light beacon of east breakwater of Yantai Port on the shore

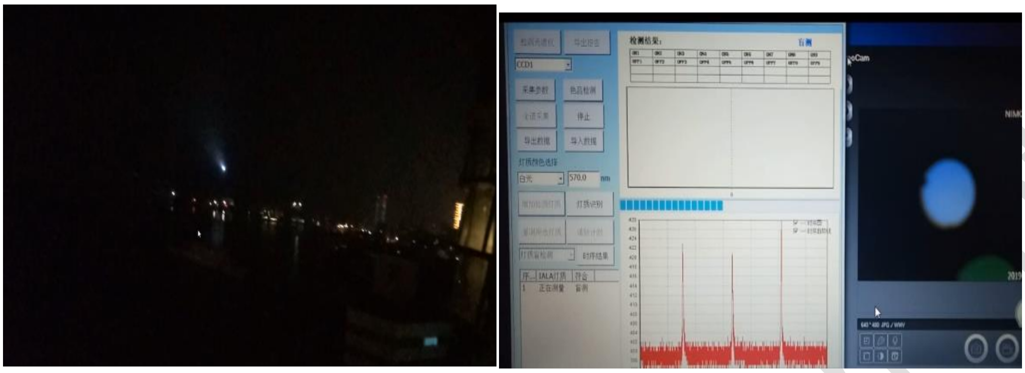


Figure 4 Measurement scenario of Yantai Mountain Lighthouse at night

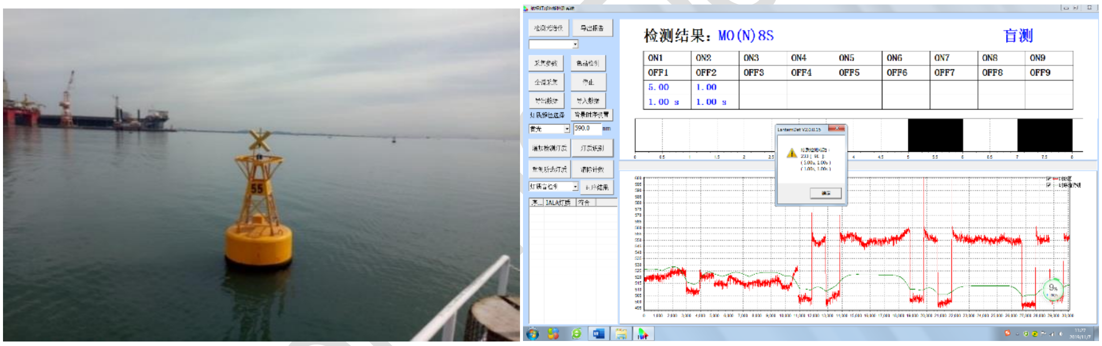


Figure 5 Measurement *scenario of No.55 buoy in Yantai Port by boat*

3.6 Prospect

The intelligent measurement of AtoN light character is an innovative exploration. The achievement based on spectral analysis technology has filled the gap in this field and provides a new technical support to improve the technical management of AtoN. As we are in an age of rapid development of technology, various ways can be tested to solve the technical problems of AtoN light character measurement, such as image processing technology, automatic target tracking technology, etc.. The in-depth study and application of various new technologies will promote the birth of new technologies, which will make AtoN light character measurement more convenient and accurate in the near future.

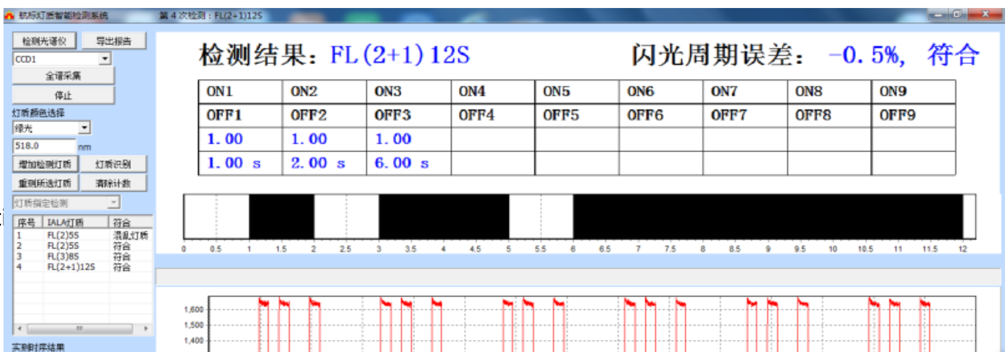
4 REQUEST

The five recommendations about marine signal lights, E-200-1 to E-200-5, haven't covered measurements of rhythm and period of AtoN lights yet, we hope the committee will consider the detection method introduced in this paper. If appropriate, initiate a new task to develop the relevant contents of this input paper as a new part of E-200, i.e. E-200-6, and assign it as a task in the following ENG Committee Task Plan 2022-2026.

APPENDIX

Appendix A Portable Detector of AtoN light character Based on Spectral Analysis Technology

Figure 6 portable detector of AtoN light character



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This portable detector (shown in Figure 6) is developed based on spectral analysis technology. The telescope is manually regulated to collect the light under test and the hydraulic governing platform is controlled manually. The spectrometer analyzes and produces a photoelectric conversion of the signal, and then extract the AtoN signal light information, then computer does the color, rhythm and period of the light calculation, and delivers the final result. The software interface is shown in Figure 7. This detector has been put into use since 2019 and has become a powerful tool for the daily management of AtoN.

The portable detector is mainly composed of light signal collection system, spectral analysis system and data processing system, as shown in Figure 8. The specific working principle is: the light signal from AtoN is collected by the light signal collection system, then coupled to the spectral analysis system through the optical fiber. The spectral analysis system conducts spectral analysis on the collected AtoN signal light, converts it into electrical signal, and finally transmits it to the data processing system for character identification and chromaticity measurement of the AtoN light.

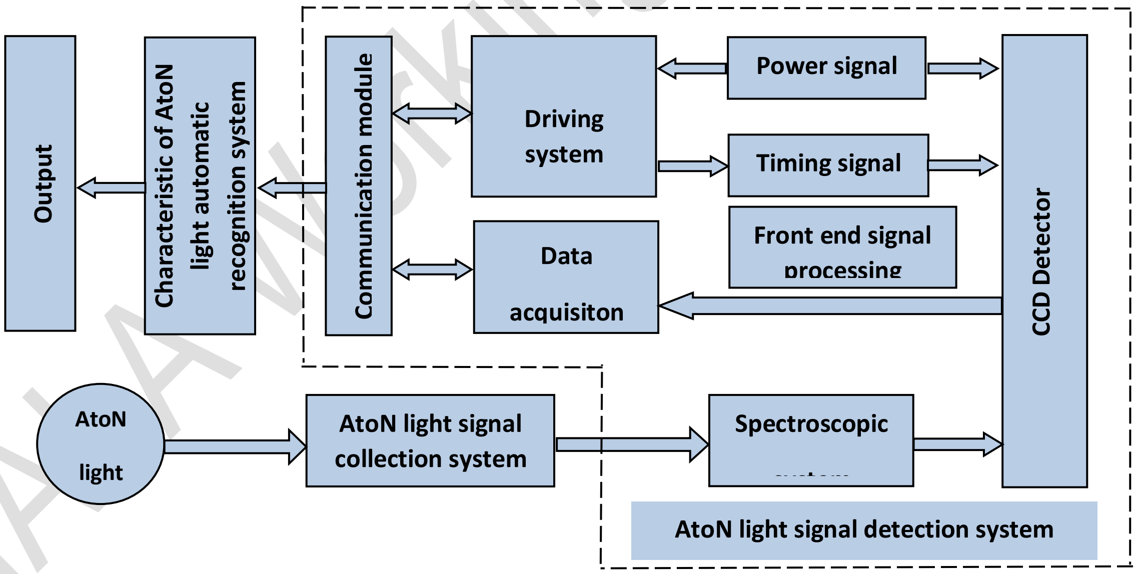


Figure 8 Composition diagram of portable detector of AtoN light character

1 ATON LIGHT SIGNAL COLLECTION SYSTEM

To achieve the remote acquisition of the AtoN light signal, a telescope is used to collect the signal. The design and selection of the telescope is critical to the performance of the detector. If the optical aberration of the telescope is too large, the imaging resolution will become low, and the optical signal transmitted into the optical system will be weakened. Therefore, it is necessary to design or select a telescope system with small optical aberration. Considering the portability and telemetry distance of the detector, Kepler telescope system with simple structure, convenient adjustment and high imaging resolution is selected to collect the AtoN light signal, which can meet the requirements of accurate identification of the AtoN light character. At the same time, a small coupling mirror is designed for close detection of the AtoN light character in the laboratory or in the field.

2 SPECTRAL ANALYSYS SYSTEM

One of the key item of this system is to design a reasonable optical path, reducing the chromatic aberration of optical imaging and improving the sensitivity of the system. The system is based on the cross asymmetric Czerny Turner structure, which is composed of incident fiber, a slit, collimating lens, plane grating, an image-forming mirror, a filter for eliminating second-order diffraction spectrum and linear CCD detector.

The output light of the fiber irradiates on the collimating lens through the incident slit, and is reflected to form a parallel light through the collimating lens. The parallel light is then dispersed by the grating according to the wavelength. Finally, the parallel light is focused on the CCD pixels through the image-forming mirror, and the photoelectric conversion of the signal is realized.

2.1 Selection of Grating

The grating, as a dispersive element, not only determines the working band of the spectroscopic system of the detector, but also directly affects the spectral resolution of the detector. It is necessary to choose the appropriate grating constant based on the working band of the detector and the spectral resolution required.

2.2 Calibration of Wavelength

This detector is based on spectral analysis technology. It not only needs to carry out efficient dispersion and imaging of incident light, but also needs to clarify the wavelength corresponding to the signal. So wavelength calibration is a necessary work for this system.

2.3 Correction of Orders Overlap Effects

Spectral lines of different spectral orders will overlap. The overlap of spectral order will lead to the position where no spectral line should appear, the second-order spectrum of other spectral lines appear, affecting the judgment of the wavelength of the AtoN light colour.

The order overlapping effect is an inherent feature of diffraction gratings. Although the diffraction efficiency is mainly concentrated in order 0 and +1, for the high-brightness blue-violet light in the marine environment, the higher-order diffraction light cannot be ignored, and the overlapping of multi-order diffraction spectrum of the grating will occur. The solution is to limit the short-wave signal into the optical system. In this portable detector, a long-pass optical filter is placed in the front of the spectrometer to solve the orders overlap effects.

2.4 Selection of Detector

For spectral analysis, the size of unit pixel of detector (CCD) is an important parameter. If the width of the CCD pixel is too large, it may cause the CCD to be under sampled, i.e., although the optical system has a high resolution, there is no way to express it through the detector. The smaller the pixel width is, the better the spectral resolution can be guaranteed. However, too small the pixel width will lead to the decrease of the sensitivity of CCD. Therefore, both the sensitivity and the resolution of the optical detection system should be considered when selecting CCD.

3 DATA PROCESSING SYSTEM

This detector establishes the internal database for AtoN light character , containing more than 200 kinds of AtoN light characters. A scientific automatic recognition algorithm of AtoN light character was designed by using several algorithms, including grouping alignment, tolerance mechanism and timing sequence rejection. The overall flow of the automatic recognition algorithm of AtoN light character is shown in Figure 9.

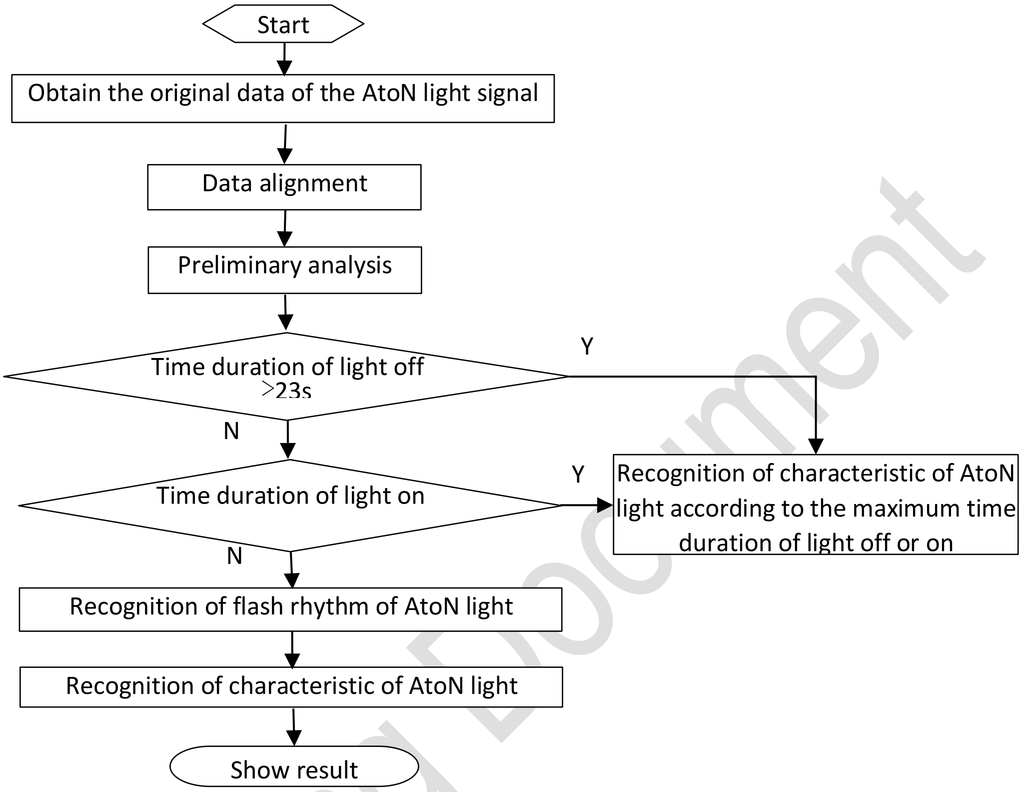
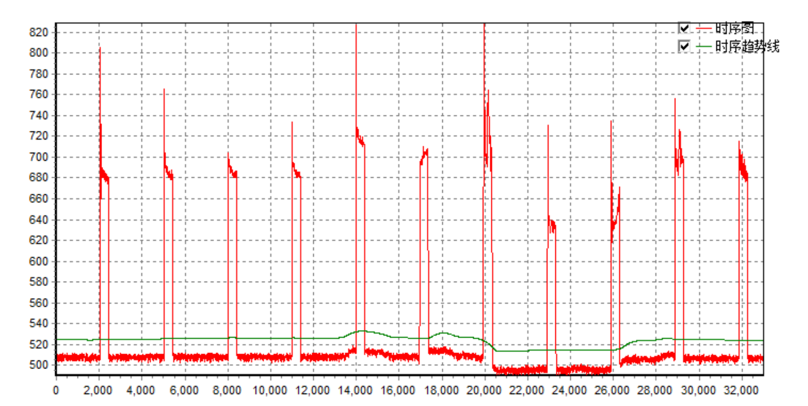


Figure 9 The flow chart of the automatic recognition algorithm of AtoN light character

In addition, it is necessary to design an algorithm to eliminate the effects of background light such as sunlight in the daytime, reflected light from sea level and other objects. Fig. 10 and Fig. 11 show AtoN light signal collected with small and large background interference respectively. By simulating the changing trend of the background light signal and setting a certain threshold value, the AtoN light signal and the background signal can be distinguished accurately. The specific algorithm: the ratio method is used to approximate the background data, and then the exfoliation peak method is used to approximate to extract the background data, which was fitted by five times curve fitting. Then, according to the set proportion, a certain proportion is added on the basis of background as reference data. The signal larger than the reference data is considered as high level, while the signal lower than the reference data is considered as low level, and then the timing sequence identification is carried out. Fig. 12 and Fig. 13 respectively show the unstable AtoN light signals and its character identification results.



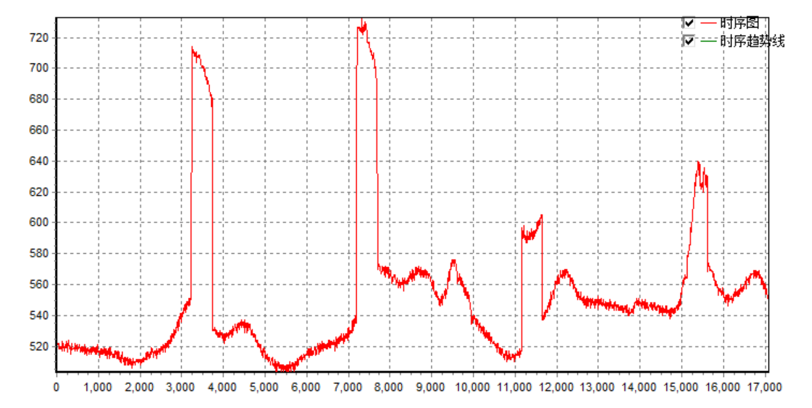


Figure 11 AtoN light signal collected with large background interference

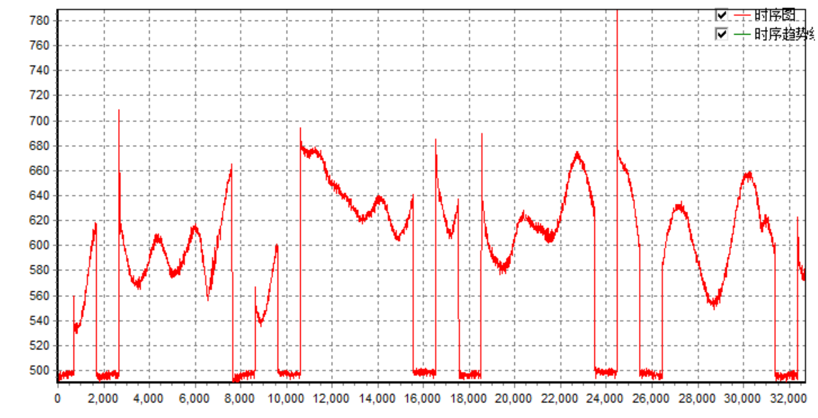


Figure 12 Collection of unstable AtoN light signal interference

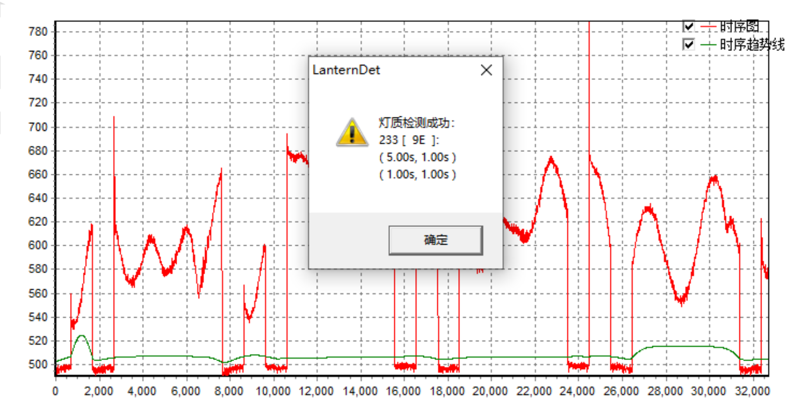


Figure 13 The result of recognition with background extraction algorithm

The background extraction algorithm can be used to identify the character of most AtoN lights, but the signal in Figure 14 can not be identified accurately. In order to improve the adaptability of the automatic recognition algorithm of AtoN light character, the method of data processing for local signals is adopted, i.e. by selecting a certain range of signals to identify the AtoN light character. Figure 15 shows the identification results of the local signals in Figure 14 .

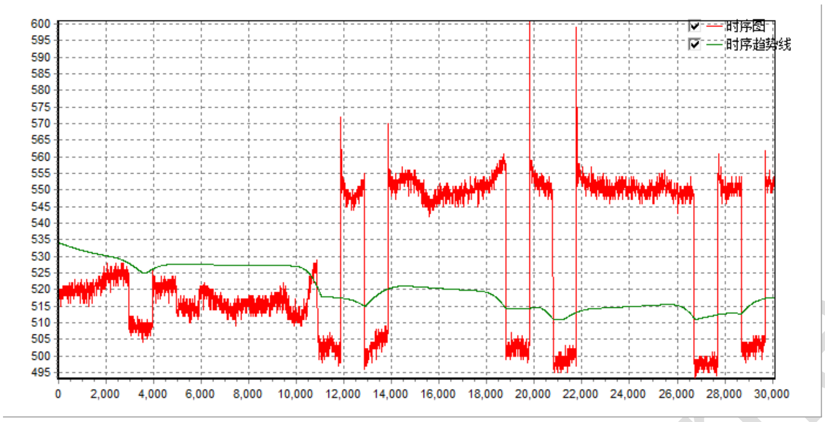


Figure 14 The AtoN signal which cannot be accurately identified

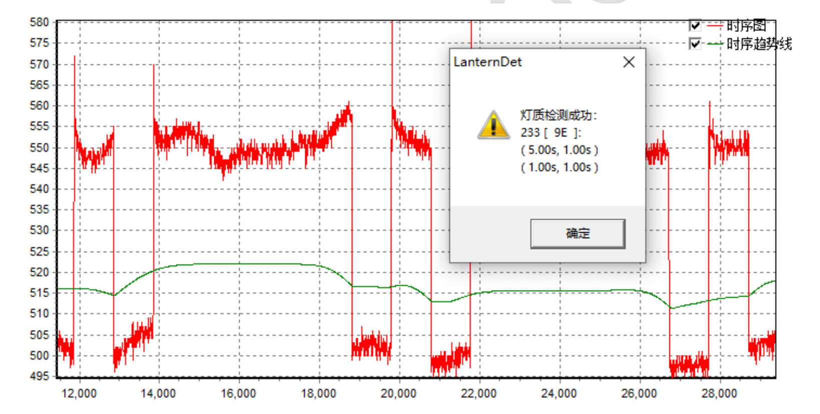


Figure 15 The result of AtoN light character recognition using local signals