Wear monitoring system of active equipment based on image recognition

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ABSTRACT

The main function of active equipment is to bear weight and provide accurate guidance for the transmission of the whole device. Once the failure of active equipment, the safety and operation stability of the mechanical equipment will be affected. In this paper, a wear detection system based on image recognition technology is developed to solve the wear problem of key parts of dynamic continuously running equipment. Through online video image acquisition, preprocessing, analysis and recognition of wear particles, the wear type and wear severity of key friction pairs of mechanical equipment can be matched and identified, and the equipment fault information and fault development trend can be obtained So as to realize the early warning, diagnosis and maintenance of the key friction pairs of mechanical equipment, so as to prevent and eliminate the failure of active parts affecting the stability and safety of the whole device.

Keywords: OpenCV; image processing; signal-to-noise ratio; average processing; upper computer monitoring

1. BACKGROUND

Wear and tear phenomenon generally appears in production and life, which has caused great economic losses to the national economy. With the development of modern economy and the improvement of people's quality of life, the safety requirements of mechanical equipment are increasingly high, especially some mechanical equipment involving people need to be absolutely reliable, such as aircraft engines, ship generators and trains and other means of transport and nuclear power generators[1]. Damage is the most common and main form of damage to machine parts.

Some scholars have shown that compared with vibration-based machine health monitoring technology, oil condition monitoring provides 10 times more early warning of mechanical failure than vibration monitoring[2]. With the improvement and optimization of sensors and the improvement of on-line monitoring system, the research on on-line monitoring technology of abrasive particles has made new progress. However, the traditional oil monitoring sensors generally monitor the abrasive particle concentration and simple size information, and can hardly identify the geometric characteristics of abrasive particles, and can not detect small abrasive particles. In contrast, sensors based on microscopic image monitoring can provide more morphological characteristics of wear particles, so as to further study the wear process and mechanism[3]. In oil monitoring, almost all abrasive features, including quantity, size, shape, color and surface texture, can be extracted from abrasive images by using image processing algorithm.

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Seventh International Conference on Mechatronics and Intelligent Robotics (ICMIR 2023), edited by Srikanta Patnaik, Tao Shen, Proc. of SPIE Vol. 12779, 1277921 · © 2023 SPIE · 0277-786X · Published under a Creative Commons Attribution CC-BY 3.0 License · doi: 10.1117/12.2690136

Reintjes et al.[4] developed an optical abrasive detector, LASERNET, to determine the type of failure and the severity of wear in helicopter engines and gearboxes. The detector is capable of picking up faulty abrasive particles larger than 50um. The sensor consists of a flow adapter, a CCD imager and a laser illuminator. According to this property of worn particles, the roundness feature can be used to identify bubbles[5]. Objects identified as circles or ovals are treated as bubbles, others are identified as abrasive particles and a series of shape analyses are performed. In 2002, Xiao Hanliang et al.[6] of Wuhan University of Technology developed an online oil monitoring system using inductance measurement and optical fiber technology. In 2009, Li Shaocheng, Zuo Hongfu et al. [7-8] from Nanjing University of Aeronautics and Astronautics developed the abrasive particle monitoring technology using electrostatic induction and microscopic image processing. In 2017, Hao Yanlong et al. proposed a abrasive image analysis method based on image recognition and microfluidics [9], extracted eight abrasive feature parameters [10] by image processing method, obtained more abrasive image information, and identified abrasive particles by grey correlation theory. This analysis method can detect the degree of oil contamination, but the effectiveness of online monitoring and the function of image recognition and analysis need to be improved.

Based on the above content, this paper designs an active equipment wear monitoring system based on image recognition. Through visual image information, the wear situation of different areas is identified, so as to complete the monitoring of active parts and obtain the wear status of active parts[8]. And according to the monitoring results, analysis is carried out to complete the matching of the damage problems of the active parts, to ensure the stability of the overall device operation, and facilitate the maintenance and replacement of the staff.

2. DESIGN SCHEME

The design system in this paper is divided into hardware design and software experiment, and its specific logic block diagram is shown in Fig. 1 below. The hardware part is mainly composed of four modules, which are phase module, flow module, optical field module and flow control module. The control module adopts two modes of execution, namely acquisition state and flushing state. In accordance with relevant strategies, the sample oil is transported to the collection area after receiving action instructions provided by the micro-conveying unit[3]. At the same time, unit volume is calculated according to the working time so as to calculate the concentration. The light field is established before the oil sample enters the collection area, and the sample is exported to the system after collection. The hardware part controls the oil flow in the moving parts at high or low speeds. The video images of abrasive particles are obtained in real time through the electron microscope, and the images with high signal-to-noise ratio are obtained through the coordination of mechanical structures.

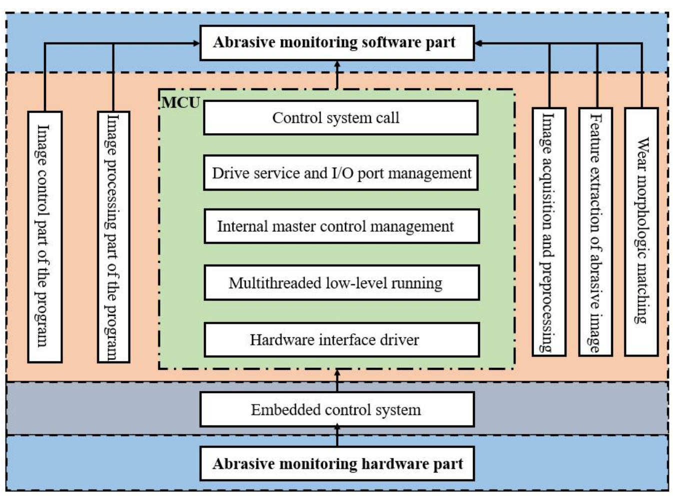

Figure 1. Logical block diagram of system operation

In the software part, the image processing technology and image enhancement technology such as median filtering are used to obtain clear abrasive images of active parts, and the abrasive state is recognized. A cascade classification detector was used to detect and segment the surface features of active parts, and the image data set of abrasive surface features was obtained. This paper also designs different digital image processing algorithms for different visual perception features. By combining the visual perception features with the size and shape of the corresponding abrasive particles, a multi-dimensional abrasive defect identification information database was formed[5-7]. Finally, an algorithm is used to obtain a defect diagnosis model after training by inputting the abrasive defect information database into the neural network and giving a label with or without defect in the output layer. The experimental test set was designed to test the accuracy of the model and displayed in the upper computer.

3. HARDWARE DESIGN

3.1 Control scheme design

The hardware part is mainly used to obtain the morphologic characteristic values of abrasive particles. The design control logic adopts two modes, namely acquisition state and flushing state. In the design, the sample oil is transported to the collection area after receiving the action instruction provided by the micro-conveying unit in accordance with the specified way. Meanwhile, the unit volume is calculated according to the working time so as to calculate the concentration. The light field is established before the oil sample enters the collection area[6]. After the sample is collected, it flows out of the system through the outlet. Fig. 2 below shows the hardware control scheme in the collection state.

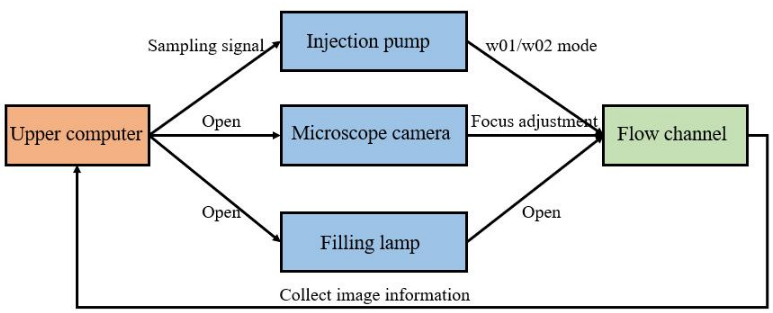

Figure 2. Sampling state flow scheme design

In the flushing state, the upper computer controls the closing of the microscope phase module and the fill light, the serial port sends the flushing signal to the injection pump, and the W01/W02 mode of the injection pump is started to flush the lubricating oil out of the device. The specific design scheme is shown in Fig. 3 below.

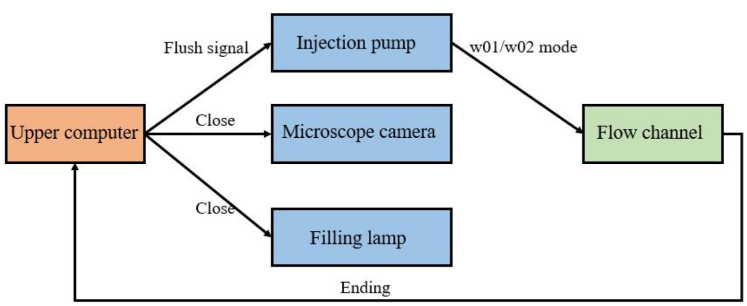

Figure 3. Flushing process design

3.2 Hardware structure design

The hardware structure of fast recognition module consists of image sensor, abrasive runner sensor, optical mobile platform, data input and output. The operating principle of the module is as follows: The lubricating oil can flow at high or low speed under the action of the oil circuit controller. The video image of abrasive particles can be obtained in real time through the electron microscope, and the abrasive particles can be identified through the image recognition method to obtain the equipment wear information contained in the lubricating oil in real time. The identification and evolution rule of the equipment wear state within the running cycle can be output from the wear mechanism level in Fig. 4.

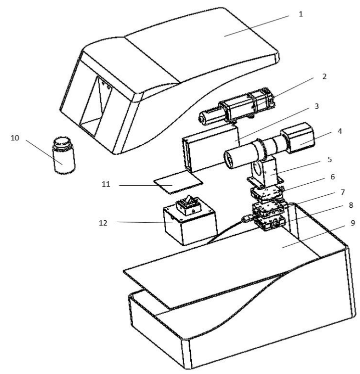

Figure 4. Hardware structure design and assembly details

3.3 Main control selection

The main control module is mainly composed of the main control system and peripheral circuit. The main tasks in this project include data acquisition and processing, serial port control signal reception, system control interrupt program, ensuring the corresponding realization and corresponding requirements of each functional module, and realizing the functional control of the reflected light source and transmitted light source, injection pump, micro camera in the flow module. The main control chip is the core of the main control unit, which is the calculation and logical processing unit of the wear monitoring system. It can receive and process the collected data information in real time. In terms of monitoring and adjustment, the specific functions of the master control system are as follows: the master control system reads and writes the data collected by the microscope camera through the I2C bus, and transmits it to the remote control module through the communication module for image processing. At the same time, after receiving the adjustment signal, it can also generate control signals and transmit them to different injection pumps to ensure the corresponding control of different flow rates. To sum up, the main control module has complex working conditions and a large amount of computation, so the selection of the main control module is of great significance to the real-time and stability of the whole system. According to the communication and control requirements and design indicators of the wear monitoring system of this project, the main control module should have the following characteristics:

1) It has the ability of multiple output signals and can control the operation module at the same time to ensure the stability of the device and operation of the hardware control part.

2) It has enough peripheral ports and communication ports to meet the needs of the injection pump and communication signal reception and signal collection to be processed.

3) With the performance of low power consumption, good real-time performance and strong computing power, the wear monitoring system can ensure faster image acquisition and internal hardware control. Meanwhile, low power consumption can also ensure the endurance of the wear monitoring system.

From the perspective of system resource utilization, STM32F103 can meet the requirements of serial port, timer and other resources needed in this design, and the resource utilization rate is higher. Its control principle is shown in Fig. 5.

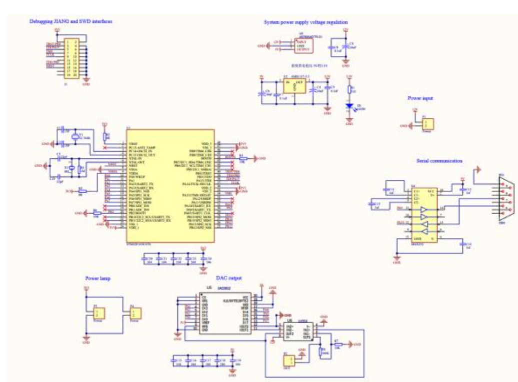

Figure 5. External master line diagram of STM32F103

3.4 External light source

External light source is the front end of the wear monitoring system, and its quality seriously affects the quality of the system's image acquisition. High-quality light source can not only keep the images collected at different times consistent, but also reduce the difficulty of subsequent image processing. The selection of light source mainly considers the type of light source, lighting mode, lighting uniformity and lighting intensity. At present, active device AOI as an external light source mainly include: halogen lamp, high-frequency fluorescent lamp and LED lamp. In order to ensure the accuracy and clarity of images acquired by the system and improve the signal-to-noise ratio of images acquired, LED lights are selected as the system light source in this paper.

3.5 Image acquisition card

The main function of the image acquisition card is to convert the continuous analog video signal of the microcamera into a discrete digital quantity. The acquisition process of abrasive feature image is the process that the image is converted into digital image after sampling, quantization, input and storage to frame memory. Since the transmission of the image signal required in this paper requires a high transmission speed, the general transmission interface can not meet the requirements, it is necessary to use the image acquisition card, considering the bandwidth between the image acquisition card and the image processing system. When using PC, the theoretical bandwidth peak of the image acquisition card using PCI interface is 132MB/S, and the consistency of the sampling frequency and storage frequency of the system should be taken into account when setting the transmission baud rate to prevent the problem of buffer occupation.

3.6 Main body design of sensor detection

The main part of the flow channel of the undisturbed microflow abrasive particle sensor adopts the integrated design. Fig. 6 shows the structural diagram of the runner part. The main part of the runner adopts the integrated design. The upper end cover and the lower end cover realize the fixed connection to the intermediate module. This module is equipped with a new micro-injection pump, which realizes single-channel oil intake and oil pushing. Through the design of RS232 serial communication chip of main control circuit board and the serial communication of upper computer, the abrasive online monitoring software can control the oil flow step size and velocity instruction of micro-injection pump, so as to ensure that the velocity is controllable. The surface texture and flow of abrasive particles in the runner are more clear.

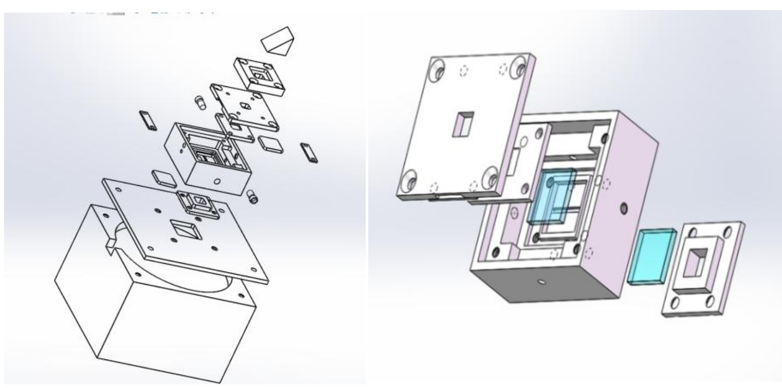

Figure 6. Assembly drawing of main part of sensor runner

Module assembly is shown in Fig. 7. The components of the runner from top to bottom are successively the upper end cover, two reflector lamp fixing plates, internal fixing plates, upper slide, runner module, lower slide and lower end cover. The overall size of the runner is set to 45*50*20mm. The lower end cover is provided with rectangular slot holes to facilitate the transmittance of light at the bottom. After many tests can be finally obtained, made the width of 1.5mm runner size. An optical adjusting frame is arranged below the runner. Figure 7 below shows the XYZ triaxial optical adjustment frame, the height of which is between 75 and 85mm.

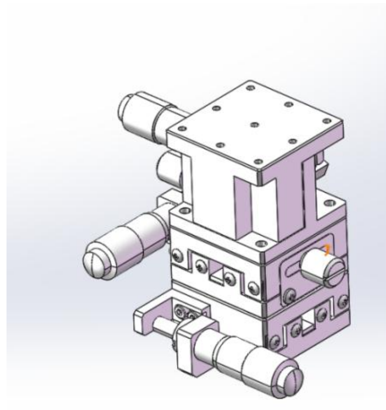

Figure 7. Optical axle frame

Since the imaging target exists in the oil pipeline, the imaging system is different from the traditional imaging mode. Starting with the analysis of the optical system under the influence of multiple refractive indexes of oil and optical glass, the complete reflection of isosceles right Angle prism is used to realize the horizontal positioning installation of the micro-camera, and the optical structure analysis of the depth of field under the macro condition, the construction of the abrasive multi-light source imaging acquisition environment is completed. The prism receives the region observed by the channel at the middle of the bottom right Angle. Through its total reflection, the flow channel observable area appears at the center of the right Angle plane of the microscopic camera lens, and the camera lens is fine-adjusted by the movement of XY axis and inclination Angle, and the matching positioning of the two contour centers is realized in the software. At the same time, the lens mounting bracket is designed, and the sides are fixed by m3 top wire. These are shown in Fig. 8 and Fig. 9.

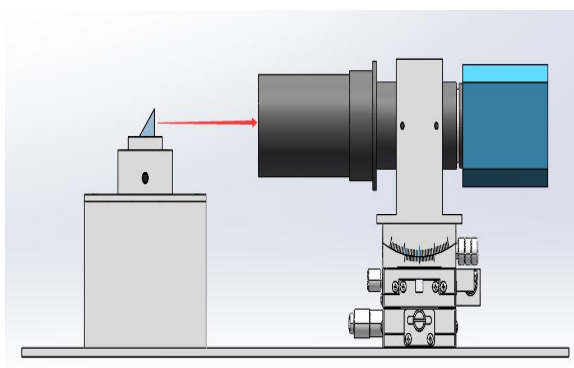

Figure 8. Camera lens matching positioning diagram

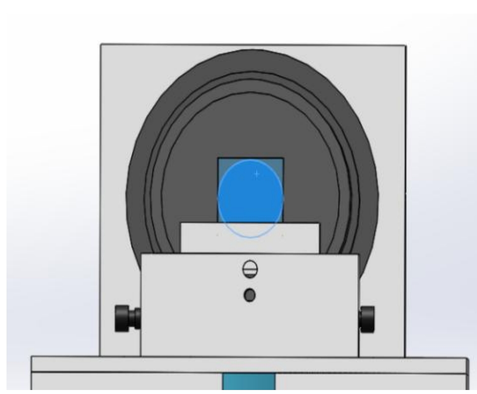

Figure 9. Lens mounting bracket

4. SOFTWARE PART AND EXPERIMENTAL VERIFICATION

4.1 Image processing scheme

Image analysis mode realizes the digital processing operation function of the image, including binarization, square equalization, Gaussian filtering, median filtering, contour recognition five kinds of image processing processes, as shown in the figure. The basic purpose is to obtain the abrasive information contained in the image, including the equivalent diameter of the largest abrasive particle, the equivalent diameter of the smallest abrasive particle and the percentage of large size abrasive particles in the total number of abrasive particles in the image.

4.2 Image preprocessing

This part mainly analyzes the preprocessing of abrasive sampling image, including the following three kinds of image preprocessing processes:

1) Template automatic threshold binarization: image Ostu automatic threshold binarization is carried out, and segmentation results are obtained according to empirical formula. Ostu threshold method is an automatic threshold determination method based on the maximum variance between classes. This method is simple and fast.

2) Template smoothing method denoising: image smoothing, select the median filtering method, denoising while maintaining the image edge;

3) Contrast enhancement: Use gray transform method to manually adjust brightness, contrast and y correction until the best processed image is obtained. For abrasive images obtained under the same environmental conditions, the parameters do not need to be adjusted for online detection.

In this paper, the experimental results are compared and analyzed. Then the gray-level threshold is segmented for the gray-level image to facilitate the morphological recognition of the gray-level.

Image binarization is to set the gray value of pixels on the image to 0 or 255, that is, to present the whole image with obvious visual effects of only black and white. Binarization is a necessary part of contour recognition. The granular image after binarization is shown in Fig. 10.

Figure 10. Image of abrasive particles treated by binarization

Square equalization is to adjust the brightness and shade of the image to facilitate more accurate binarization of the image, as shown in Fig. 11. Square equalization is to enhance the contrast of the image, so that the gray level of the equalized image covers a wider gray range, making the contrast more obvious and enhancing the accuracy of image recognition.

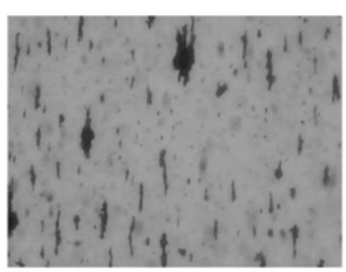

Figure 11. straight square equilibrium

In the process of weighted average of the whole image by Gaussian filtering, the value of each pixel is obtained by weighted average of its own and other pixel values in the neighborhood. Under the concept of image processing, the frequency domain processing and time domain processing of the image are linked together, which can be used as a low pass filter to filter out the low frequency energy and play the role of image smoothing. Gaussian filtering is a linear smoothing filter, which is suitable for eliminating Gaussian noise. The processing results are shown in Fig. 12. Median filtering can overcome the image detail blurring caused by common linear filters such as box filter and mean filter, so as to eliminate the noise of the abrasive image and improve the recognition accuracy of the abrasive image.

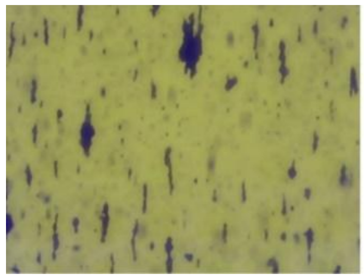

Figure 12. Median filtering results

4.3 Image segmentation and recognition

1) Image segmentation

The principle of contour recognition is processed by findContours function in OpenCv. The contour contour of abrasive particles can be marked with red lines by drawContours function. The contour recognition processing result is shown in Fig. 13.

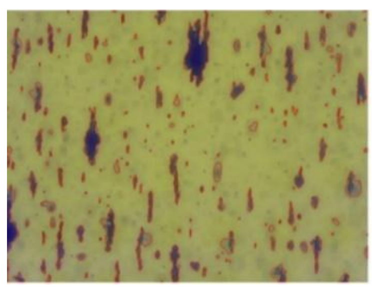

Figure 13. Contour recognition results

Then, the image is preprocessed. Firstly, the fuzzy image is restored. Before the fuzzy image restoration, the collected color image is converted to gray image for convenience. The median filter is used to denoise the image, each abrasive particle is numbered, and it is synthesised into a video. Part of the video screenshots are shown below. During the shooting process, due to the influence of the light source, the highlighted part of the surface becomes white when the abrasive particle is binarized, and it will be regarded as other particles when it is identified. Closed operation, hole filling and other methods to restore the damaged abrasive particles, as shown in Fig. 14.

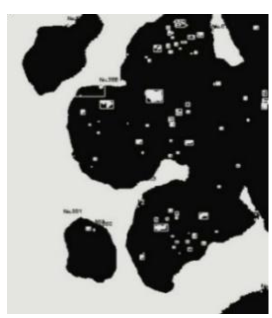

Figure 14. Screenshot of particle number

The same structural element is used to conduct corrosion operation and then expansion operation on the target image, which is called open operation. On the contrary, the same structural element is used for the target image to perform expansion operation first, and then corrosion operation, which is called closed operation. The open operation is usually used to smooth the edges of objects, break the narrow neck and remove the slender protrusions and independent points. Closed operations are also used to smooth edges, but unlike open operations, closed operations are often used to close narrow depressions and slender channels, eliminate holes, and fill in tiny cracks between contours. Assuming that A is the target image, B is the structural element, x represents the corrosion operation, and the field represents the expansion operation, then the calculation processes of the open and closed operations are shown in Eq. (1) and Eq. (2) respectively.

$$OPNE(A, B) = (A \times B) + B \tag{1}$$

$$CLOSE(A, B) = (A + B) \times B \tag{2}$$

In conclusion, among the four basic operations, only the open operation can eliminate fine noise points in the image while smoothing the edges. In addition, the known non-wear interference area size is generally less than 3 pixels. Therefore, this paper selects the open operation with structure element as 3X3 square to process the image after threshold segmentation, and the results are shown in Fig. 15.

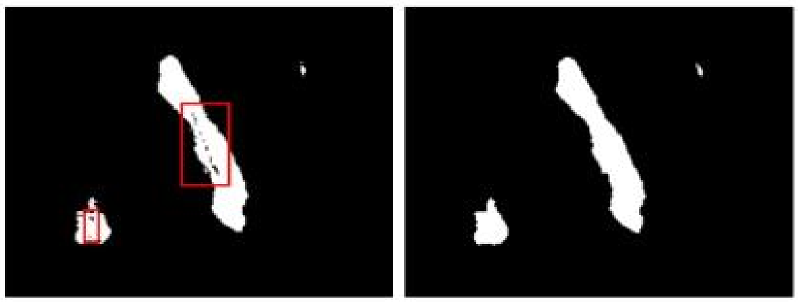

Figure 15. Morphologic treatment of abrasive particles

2) Image morphological matching

The cv2.findcontours function is used to discover the contour and extract features such as counting, length-diameter ratio, area and equivalent diameter. The axial ratio of length and length of abrasive particles is a characteristic parameter used to judge the contour of abrasive particles, and the calculation is shown in Eq. (3). Generally speaking, the ratio of cutting abrasive particles is larger than that of other types, which is used to judge the contour of cutting abrasive particles and spherical abrasive particles. At present, the method of drawing a rectangular frame of abrasive particles on the image is adopted. The rectangular frame is connected with abrasive particles externally, that is, the length and width of the rectangular frame can be regarded as the long and short axis of abrasive particles.

$$\mathrm{AR} = \frac{\mathrm{a}}{\mathrm{b}} \tag{3}$$

Among them:

Major axis length $a = (4/\pi)1/4^{3/8}/I\zeta^{1/8}$

Short axis length $\mathrm{b} = (4/\pi)1/4I\zeta^{3/8}/I\eta^{1/8}$

The abrasive analysis process is displayed in the processing process display area. After the video processing is completed, the total number of abrasive particles will be made into histograms according to ISO4406 and NAS1638 standards, and the number of abrasive particles will be marked on the histograms and displayed in the pollution level display area.

4.4 Design of upper computer

There are many data analysis schemes in PyQt running language, which greatly reduces the time of developing data analysis module and satisfies the design requirements of upper computer in this paper. PyQt program development follows the model - view - control three-layer model, its characteristics are shown in Fig. 16.

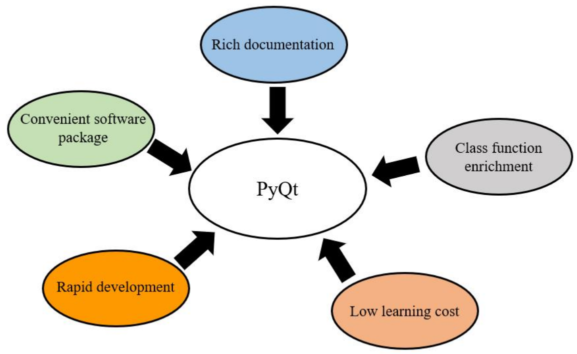

Figure 16. PyQt program development characteristics

The main interface is divided into four parts: menu bar, button bar, video display area and result display area. The setting section of the menu bar includes two parts: pump and sample. Click them respectively to display the setting box of the injection pump as shown in Figure 18 and the setting box of the sample as shown in Fig. 17.

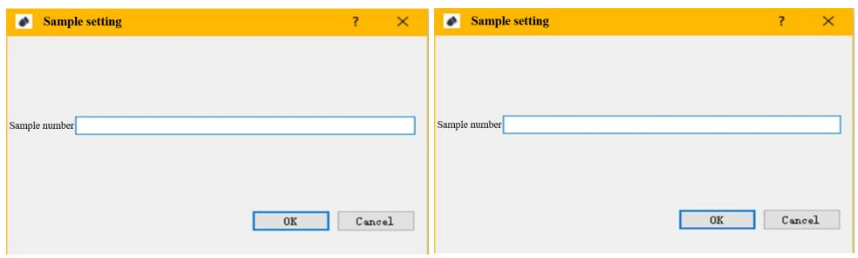

Figure 17. Setting box

The button bar contains four buttons: start detection, data query, runner flushing and emergency stop. Video display is divided into two parts: data collection display area and processing process display area. The result display area includes four parts: pollution level display area, wear particle display area, data display area and wear type display area.

After the main interface is opened, the video recording in the acquisition area is enabled by default. After the user clicks the Start detection button, both the pump and the progress bar will respond. The pump will suck oil for 1600 steps at the set flow rate (the process takes about 14 minutes at the flow rate of 1), and then push oil for 300 steps at the set flow rate. The software will generate the video at 30 frames per second and save it to a selected folder. As shown in Fig. 18.

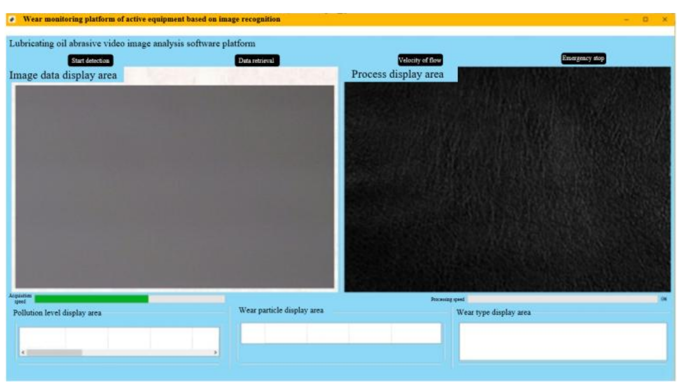

Figure 18. Collection process

After the video is generated, the processing interface will automatically find the storage path of the video and decompose it. The abrasive analysis process will be displayed in the display area of the processing process. The processing adopts the per-frame processing method, the single frame is preprocessed, the abrasive counts and marks.

After the video processing is completed, the total number of abrasive particles will be made into histograms according to ISO4406 and NAS1638 standards respectively. The number of abrasive particles will be marked on the histograms and displayed in the pollution level display area. ISO4406 will distinguish 5um and 15um particles, NAS1638 will distinguish 5-15, 15-25, 25-50, 50-100, more than 100 five intervals.

The category results of wear particles will be made into a histogram, and the same number of marks will be displayed in the wear particles display area. There are three types of long particles, round particles and oval particles. At the same time, the software will automatically save the result picture to the database. Select the data to be queried from the list, click the query button below, and the chart data will be automatically pulled out and displayed in the database interface, as shown in Fig. 19.

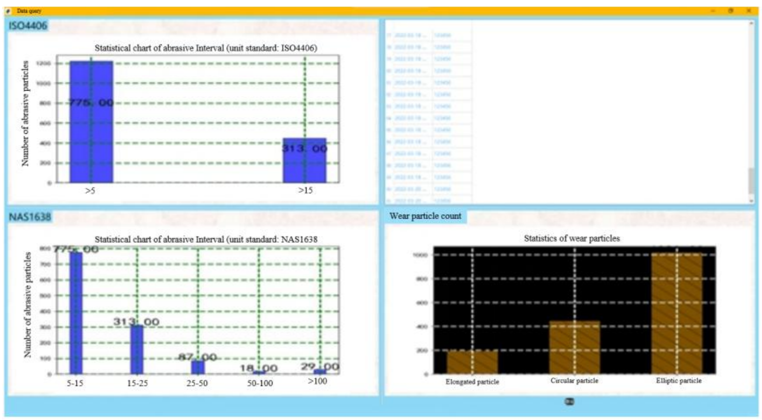

Figure 19. Database interface

4.5 Experimental verification

In order to verify that the wear monitoring system of active equipment based on image recognition developed in this paper can monitor the key parts of active equipment in real time, the identification module is used to carry out online oil monitoring experiments. In the experiment, SAIC TG3 is used as the experimental oil, TG3 is injected into the pipeline and the flow rate is set "001". Click the start detection button, and the pump and progress bar respond. The pump sucks 1600 steps of oil at the set flow rate, and then pushes 300 steps of oil at the set flow rate. The software generates video at 30 frames per second and saves it to a specific folder. After the video is generated, the processing process interface automatically finds the video storage path and decomposes it. The abrasive analysis process is displayed in the processing process display area, and the abrasive particles are counted and marked. After the video processing was completed, the total number of abrasive particles was made into histograms according to ISO4406 and NAS1638 standards, and the number of particles was marked on the histograms and displayed in the pollution level display area, as shown in Fig. 20 and Fig. 21.

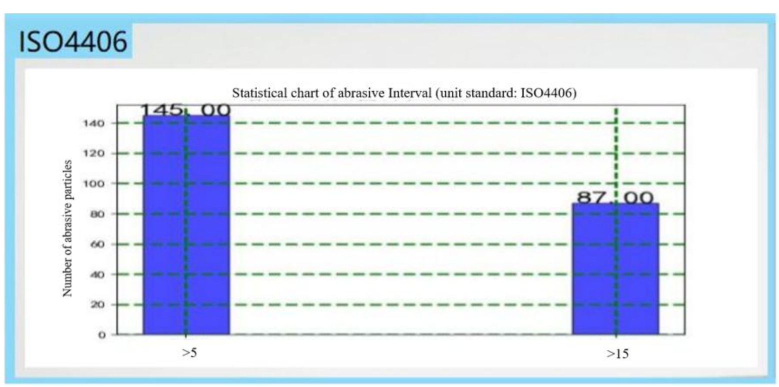

Figure 20. ISO4406 data

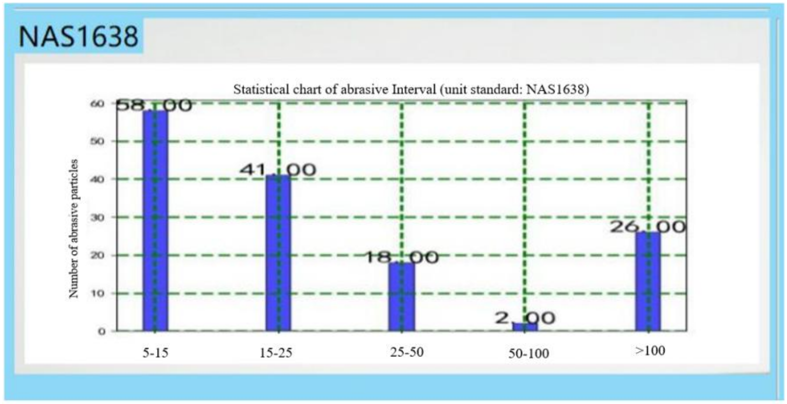

Figure 21. NAS1638 standard data

The category results of wear particles are made into a histogram, and the number of marks is also displayed in the wear particles display area. The data is displayed above the histogram and the number of particles is listed in the table shown in Fig. 22.

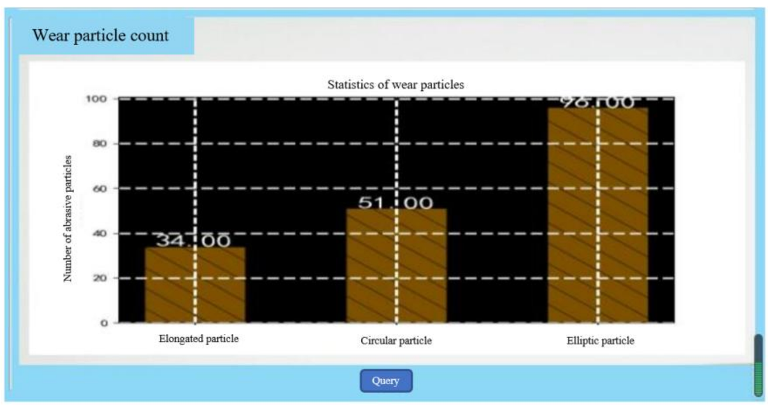

Figure 22. Columnar diagram of worn particles

5. CONCLUSIONS

Aiming at the problem that the wear of active parts has a serious impact on the device, this paper designs an active equipment wear monitoring system based on image recognition. Through image acquisition and processing of the wear particles of lubricating oil, the system can obtain the wear results of high signal-to-noise ratio. Then, the design algorithm and image recognition technology are used to obtain the wear features of the active parts, so as to obtain the current wear conditions of the active parts of the device. The system designed in this paper further standardizes and strengthens the ability of equipment self-diagnosis, prediction and maintenance support. At the same time, the monitoring system also reduces the link of equipment support, optimizes the support system and resources, and achieves the purpose of accurate, mobile, fast and economic support, which has a good application prospect.

ACKNOWLEDGMENT

This Paper was supported by National University Student Innovation and Entrepreneurship Training Program Project Grant(Project Number: S202210497081).

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