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Intelligent Pavement Damage Monitoring Research in China

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ABSTRACT The development of artificial intelligence technology is of vital significance to the progress of human civilization. Through the development of this aspect in recent years, China has achieved unprecedented gains in equipment and software technology, such as road damage monitoring. However, it is difficult to deal with a large amount of data and real-time data. In addition, China is the third largest country in the world in terms of land area, with well-developed roads and more and more road construction, which increases the workload of road damage monitoring. In order to solve these problems, a research scheme of intelligent pavement damage monitoring is proposed. The main idea of the scheme is to obtain point cloud data by scanning the road surface with unmanned control equipment, carry out Harris, star and sift detection on the pictorial point cloud data, and then judge the damaged area by combining with the characteristic matrix of the damaged data. Through the processing of point cloud data obtained by the existing manned control equipment, it is found that it has a good effect on the monitoring of pavement crack damage. From the actual results obtained, it can be judged that the pavement damage of single crack and multi-crack can be determined. Intelligent development is an application that integrates multiple interdisciplinary subjects. This research can provide some development ideas for intelligent road monitoring, and at the same time, it is hoped to contribute to the development and integration of interdisciplinary subjects.

INDEX TERMS Artificial intelligence, real-time data processing, road damage monitoring, unmanned control equipment, point cloud data, feature matrix, intelligent detection.

I. INTRODUCTION

Road is the infrastructure provided for the convenience of people's travel. It is a public or private facility that people come into contact with the most. It can be divided into cities, villages and so on [11], [22]. The role of highways is to connect cities to villages, city to city, country to country, and other development projects that require improved connectivity. The state divides highways into six levels, namely, the national level, the provincial level, the county and city level, the township level, the village level and the special purpose grades for other special purposes. From the traffic volume can be divided into five grades, respectively for the highway and other one, two, three, four these grades. People have a special definition of highway. Under normal circumstances, the roadbed, road surface on the roadbed, auxiliary signs on both sides of the road, guardrail and other facilities, as well as street lights on both sides of the road, communication power lines and all other components are collectively referred to as the highway. Generally speaking, network is composed of points, lines and planes, where the form of connecting points and lines indicates the mutual connection between objects. All contents contained in the network world are platforms composed of information objects, such as unified combination and connection of point information, line information and surface information, which are transmitted to each node in the network for sharing, and accepted and transmitted among different nodes to make full use of the mutual acceptance of information [3], [12]. Big data refers to a new type of information asset, which requires an efficient computer hardware processing memory and powerful software driver to analyze a large number of data to obtain the correlation between events. In this way, it can observe and make decisions from the side and form a process processing ability, thus increasing the positive growth rate of the research object. Realize the transformation of information assets from intangible to tangible through the maximum utilization of diversified information [1], [23].

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The Internet of things is based on the Internet, and its ultimate purpose is to use information technology means combined with sensor technology to control equipment and daily application facilities through wired network or wireless network, so as to realize the information driven application of serving people anytime and anywhere. It is a classic embodiment of network information modernization [2], [6]. For the current daily life, artificial intelligence is an emerging technology application means. Although it has experienced more than half a century of development in China and abroad, it is still in the development stage in terms of scientific research, application, engineering and innovation. The dominant idea is a kind of technical science that expands the movement mode of human brain to control device judgment, decision-making, operation and other aspects, expands the theory on the basis of practice, and promotes labor liberation by verifying simulation method [8], [24]. The so-called intellectualization [11] is relative to human beings, different stages of the understanding of intellectualization is different. At present, the understanding and application of intelligence is the Internet of things based on the Internet, big data and artificial intelligence, which is generally considered as the idealized processing of certain industries and certain events without relying on human resources. The ultimate goal is to meet and realize the special needs of human beings, which is characterized by starting from the general thinking mode and finally solving problems from the perspective of computers. Intelligent pavement damage monitoring refers to a monitoring technology that acquires, analyzes and judges road surface information through intelligent technical means and finds the damage parts of road surface in an automatic way. The construction of highways has entered the stage of maintenance and self-cultivation since its completion. By 2014, the total mileage of highways in China had reached 4.4639 million kilometers, with 4.3538 million kilometers for highway maintenance, accounting for 97.5% of the total mileage. Therefore, an intelligent pavement monitoring technology is proposed to provide a solution for highway maintenance and maintenance, and at the same time, it is hoped to promote the application of interdisciplinary technology.

II. CHINA AND INTERNATIONAL STUDIES

Pavement damage monitoring mainly depends on two aspects: on the one hand, the collection equipment of pavement information; on the other hand, the effective processing of collected information, namely, the identification and judgment of pavement damage information. The determination of pavement damage mainly depends on the analysis of pavement crack monitoring. The location of pavement damage can be determined through crack monitoring, and the degree of pavement damage can be determined according to cracks, which is also an important basis for pavement maintenance. China's domestic and foreign development has gone through three stages: traditional, semi-automatic and automatic. In the 1960s, PASCO developed a road damage detection system based on photographic technology, but it was the GERPHO system developed in France in the 1970s that was put into use. In 1980s, the road surface damage detection system based on video technology appeared. The application of CCD camera took place after the 1990s, and the emergence of related hardware and various algorithms made the computer foundation develop unprecedentedly. In this period, the pavement damage detection system based on high speed digital camera appeared. After 2000, ICC of the United States and INO of Canada developed a pavement damage detection system based on high-speed line-scanning digital camera and laser lighting technology. Subsequently, with the popularization and application of thermal imaging technology in the industry, its effect in pavement damage detection has also been effectively verified. The appearance of 3D laser scanning provides a new research method for pavement damage detection. China began building roads on a large scale in the late 1980s, and since then maintenance has become increasingly heavy. The main algorithms of road surface damage recognition in China include: road surface crack image enhancement algorithm [7], road surface crack image segmentation algorithm [15] and road surface crack automatic recognition algorithm [3]. Other studies have focused on devices to improve the quality of photographs and methods to improve data accuracy, such as laser displacement detection technology for road surface damage. For the monitoring of road roughness, it includes the detection technology of section based on the detection of road longitudinal section, which uses the obtained road longitudinal section to calculate various evaluation indexes, and the response detection technology to establish the correlation between the detection amount and the roughness index IRI. Others include rutting detection technology [9], anti-skid performance detection technology [13] and pavement structure strength detection technology [10], [17]. At present, the automatic detection of pavement is basically realized from the experimental aspect. However, the main problem of pavement damage monitoring is crack identification, which is greatly affected by artificial intelligence technology. With the development of artificial intelligence technology, the intelligent pavement damage monitoring has brought new development opportunities.

III. INTELLIGENT PAVEMENT DAMAGE MONITORING FRAMEWORK

Intelligent pavement damage monitoring mainly relies on the application of artificial intelligence technology in software and hardware, and the mobile platform is unmanned vehicles [4], [5], unmanned aerial vehicles [16] and other equipment. The software includes the driving software to control the motion of the corresponding module device after processing the collected information of the equipment, the central management software to dispatch the field tasks of the monitoring equipment, and the software specifically for damage identification and monitoring. At the same time, it includes auxiliary decision-making functions such as positioning, map annotation, damage assessment, repair method suggestion and highway facilities prediction. Automatic route

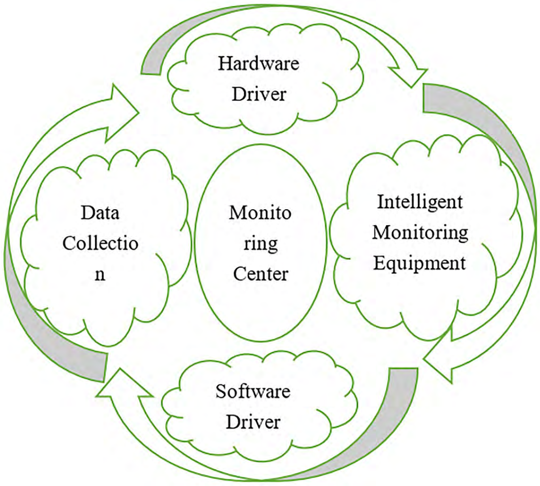

FIGURE 1. Overall framework of pavement monitoring system.

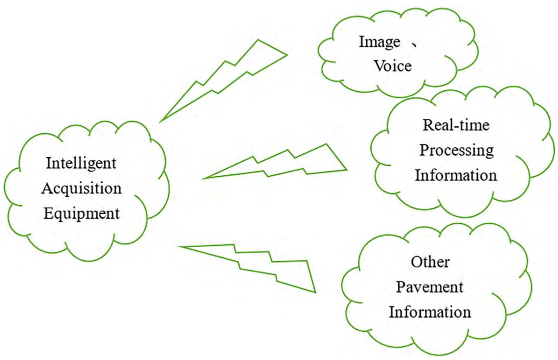

FIGURE 2. Function diagram of equipment acquisition information.

planning, monitoring program formulation, positioning and patrol inspection are carried out through the instruction issued by the monitoring center. The overall framework of the system is shown in figure 1 below.

When the equipment is in operation, it can send back the image, voice and other information collected in the field in real time according to requirements, as well as the marked damage location information. It is convenient for maintenance personnel to confirm and repair the damaged road surface. Meanwhile, real-time information of other road real-time information can be transmitted back as required. The device information function is shown in Figure 2 below.

IV. ROAD DAMAGE LOCATION MONITORING

When a laser beam irradiates the object surface, the reflected laser will carry information such as orientation and distance. After obtaining the spatial coordinates of each sampling point on the object surface, a set of points is obtained, which is called "point cloud". The main data used here is the image data obtained after the rendering of laser point cloud data [19]. Only the pixel information of the image is used, and then the location of the pavement crack is determined after the gray processing of the image, corner detection, feature detection and feature screening.

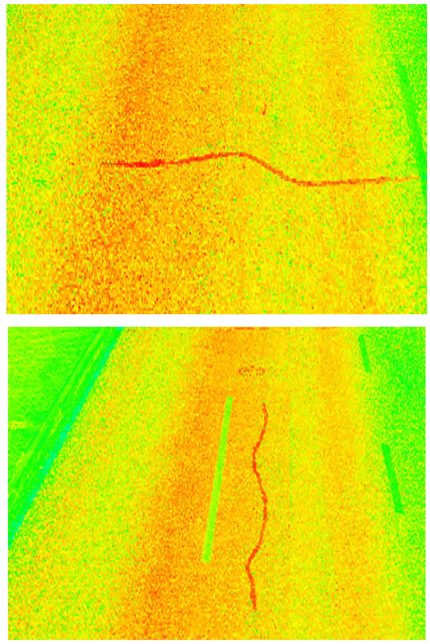

FIGURE 3. Pavement damage monitoring.

FIGURE 4. Monitoring data graying.

A. IMAGE GRAY PROCESSING

For the color and brightness processing of the rendered image format point cloud data, there are three general conversion formulas:

$$\text{Gray}(i,j) = [R(i,j) + G(i,j) + B(i,j)]/3 \tag{1}$$

$$\text{Gray}(i,j) = 0.299 * R(i,j) + 0.587 * G(i,j) + 0.144 * B(i,j) \tag{2}$$

$$\text{Gray}(i,j) = G(i,j) \tag{3}$$

Gray is the result of converting the grayscale. R, G and B are red, green and blue channels. The picture containing a crack and the grayed result are shown in figure 3 and figure 4 below.

B. HARRIS ANGLE DETECTION

Moravec first proposed the concept in 1977. Moravec principle was proposed in 1981. In 1988, Harris C and Stephens M proposed Harris corner detection algorithm based on these views [18]. The principle of Harris corner detection algorithm is to find the direction grayscale variance of the image target pixel points, that is, the gradient values in the horizontal and vertical directions of the image. And the matrix M associated with the function and the two eigenvalues of M. Then the pixel is detected by local non-maximum suppression, and the corner is determined by this process. Is defined as:

$$E_{u,v}(x, y) = \sum\nolimits_{u,v} w_{u,v}[I(x+u, y+v) - I(x, y)]^2 \tag{4}$$

The formula $I(x+u, y+v)$ is expanded by Taylor series, which can be converted into:

$$E_{u,v}(x, y) = \sum\nolimits_{u,v} w_{u,v} I^2(x, y)(I_x^2 u^2 + 2I_x I_y uv + I_y^2 v^2) \tag{5}$$

This is expressed as a matrix:

$$E_{u,v}(x, y) = [u \quad v] \sum\nolimits_{u,v} w_{u,v} I^2(x, y) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix} \tag{6}$$

That is:

$$\begin{bmatrix} \mathrm{u} \\ v \end{bmatrix} M [u \quad v] = [u \quad v] \sum\nolimits_{u,v} w_{u,v} \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix} \tag{7}$$

Available:

$$M \cong \sum\nolimits_{\mathrm{u},v} w_{u,v} \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \tag{8}$$

Is:

$$M = G(\sigma) * \begin{bmatrix} I_{\mathrm{x}}^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \tag{9}$$

The response function of the Angle point of the pixel point Harris is:

$$CRF(x, y) = \det(M) - k(tr(M))^2 \tag{10}$$

In the formula, $I(x+u, y+v)$ and $I(x, y)$ represent the gray value of pixel $x+u, y+v$ and pixel (x, y), respectively. $w_{u,v}$ is Gaussian function, and I_x and I_{y} are partial derivatives of pixel gray in horizontal and vertical directions. k is a constant term, and its value range is $0.04 \sim 0.06$. $\det(M)$ and $tr(M)$ is the determinant and trace of matrix M, respectively. When $\boldsymbol{k}$ is 0.04, the detection results of Harris Angle is shown in Figure 5.

We can see from the figure that although corner points can be detected, there is too much noise interference. Because there are too many noise feature points, we try to do feature detection first, and then do feature screening.

C. STAR FEATURE DETECTION

The STAR feature is a local speckle feature, which uses a two-layer filter to approximate the Laplace transform of gauss. It has good stability and high computational efficiency. The extracted feature points can maintain good significance, stability and repeatability even when the perspective changes.

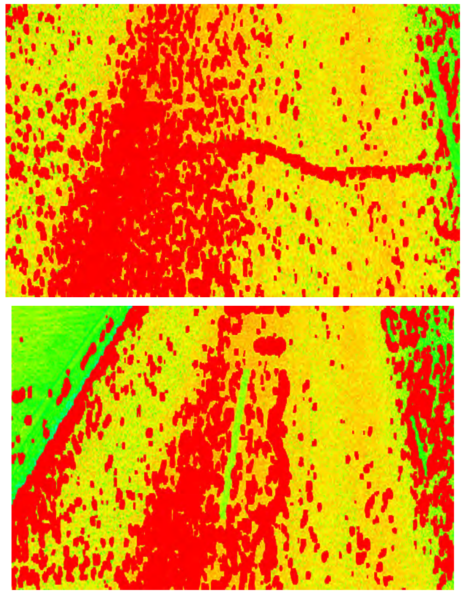

FIGURE 5. Corner detection.

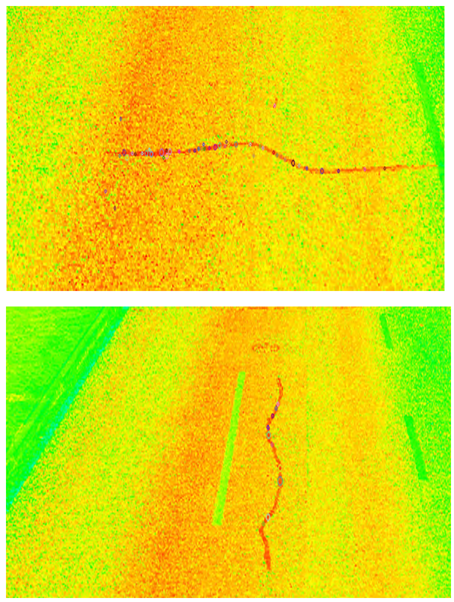

FIGURE 6. Detection of STAR feature points.

We can see that most of the feature points are concentrated on the crack. The feature detection diagram is shown in figure 6 below.

D. SIFT FEATURE DETECTION

The basic idea of SIFT is feature scale operation of image. In the process of use, it needs to go through five steps: scale space extreme value detection, accurate positioning of key points, key point direction allocation, feature descriptor generation and feature matching. The scale space function can be obtained by the following formula:

$$L(x, y, \sigma) = G(x, y, \sigma) * I(x, y) \tag{11}$$

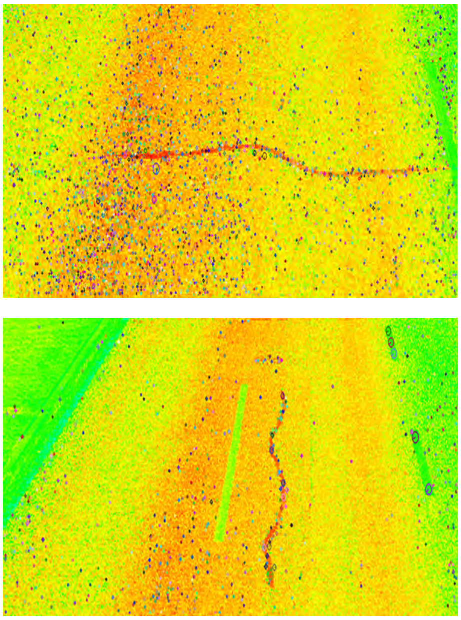

FIGURE 7. SIFT feature detection.

The DOG extreme value detected after rapid calculation is as follows:The extreme value detected after quick calculation is as follows:

$$D(x, y, \sigma) = [G(x, y, k\sigma) - G(x, y, \sigma)] * I(x, y) \quad (12)$$

Get:

$$D(x, y, \sigma) = L(x, y, k\sigma) - L(x, y, \sigma) \quad (13)$$

The scaling space function of DOG key points is expanded as follows:

$$D(x) = D + \frac{\partial D^T}{\partial x}x + \frac{1}{2}x^T\frac{\partial^2 D}{\partial x^2}x \quad (14)$$

$$\hat{x} = -\frac{\partial^2 D^{-1}}{\partial x^2}\frac{\partial D}{\partial x} \quad (15)$$

Thus, when $D(x) = 0$ and $x = (x, y, \sigma)^T$, deviation of the key points as follows: Formula (15)

In general, the expression meaning of σ is scale factor. In general, (x, y) is used to represent the specific position of pixels. Value factor coefficient $\boldsymbol{k}$ is expressed as the scale factor coefficient, usually set to $2^{1/s}$. Where $\boldsymbol{S}$ represents the number of layers when multiple σ is taken.

The targets that SIFT can achieve include extremum detection, feature point location, feature point direction allocation and feature factor generation. The SIFT feature [20] is the local feature of the image. Compared with STAR, there is an additional color gradient, indicating the color change. SIFT feature detection can be used to rotate and scale the image and change the brightness value of the image, so that it can maintain invariance to a certain extent. This feature has some positive effects on image segmentation and grayscale change. In addition, when the Angle of view changes and radiation transformation occurs, the noise can be unaffected to a certain extent and maintain a certain stability. At the same time, it has

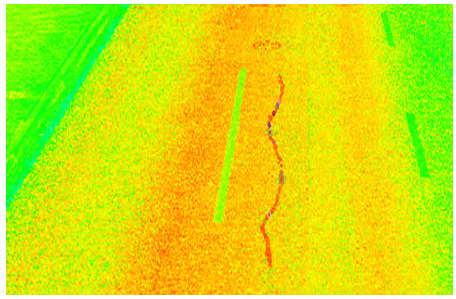

FIGURE 8. Final feature detection results.

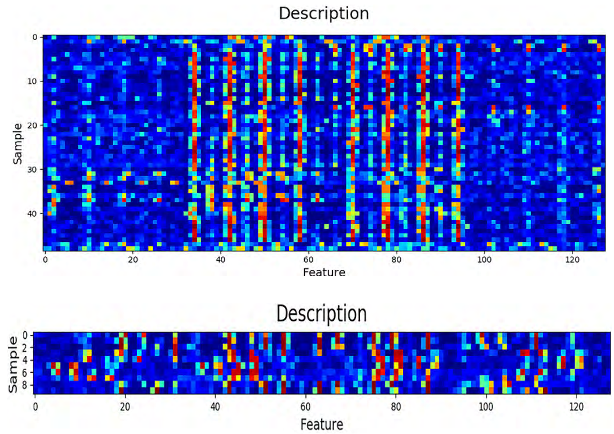

FIGURE 9. (a) Description of feature point matrix. (b) Description of feature point matrix.

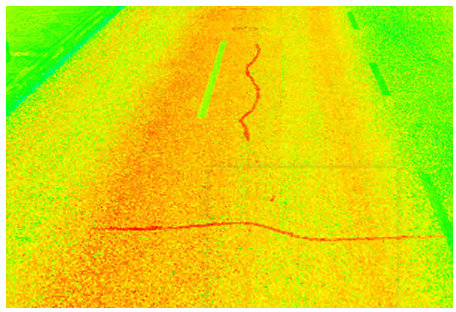

FIGURE 10. Original fracture drawings.

FIGURE 11. Gray scale of fractures.

the characteristics of uniqueness, multiplicity, high speed and extensibility. The direction of feature point detection and the maximum color change according to the feature is shown in figure 7 below.

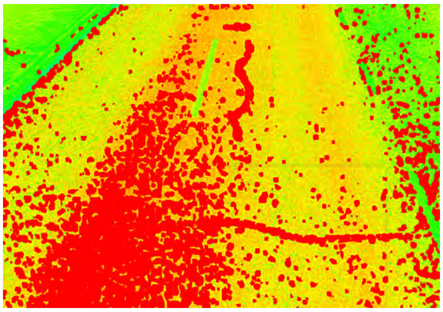

FIGURE 12. Joint angle diagram.

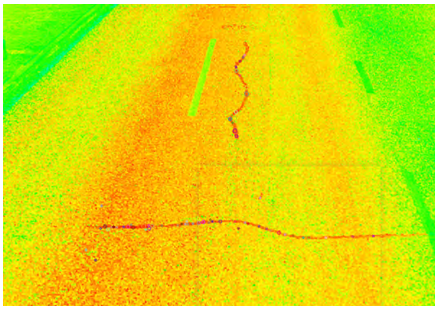

FIGURE 13. STAR detection diagram.

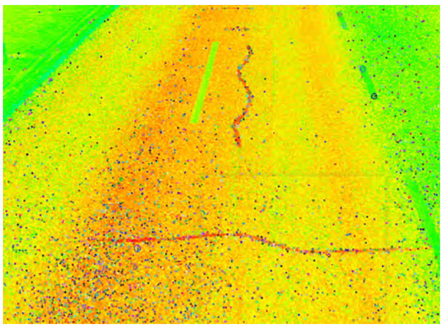

FIGURE 14. SIFT detection diagram.

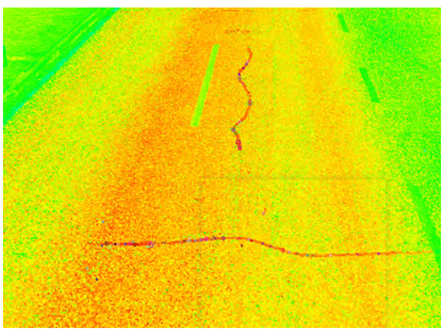

FIGURE 15. Multi-fracture detection diagram.

First, STAR was used for feature detection, and then SIFT was used for feature screening to obtain the results as shown in figure 8 below. The description of feature point matrix is generally used for automatic crack detection. The feature point matrix can be used to calculate and compare the probability results. The feature point matrix is described as shown in figure 9 below.

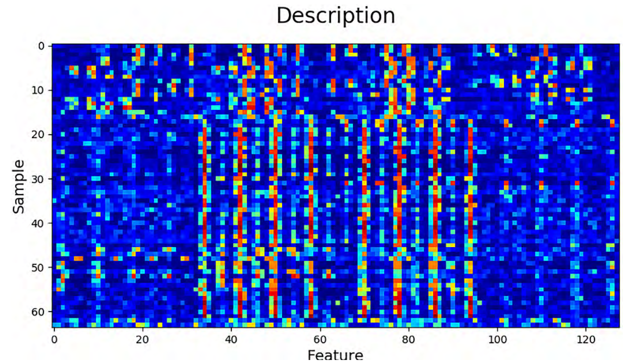

FIGURE 16. Description of multi-fracture feature point matrix.

E. INCLUDES MULTIPLE CRACK MONITORING

This method can also be used for fracture monitoring of point cloud image data containing multiple fractures. Figure 10 shows the point cloud graphical data of multiple fractures. Figure 11 shows the grayscale processing of the image data. Figure 12 shows the focus detection diagram. Figure 13 shows the STAR detection. Figure 14 shows the SIFT detection. Figure 15 shows the final detection result. Figure 16 is the matrix data description of feature points. The specific results are shown in the figure below.

V. CONCLUSION

From the perspective of artificial intelligence theory, this paper proposes an application method of intelligent pavement damage monitoring by analyzing the actual situation of China's highways and aiming at the actual road maintenance engineering application. The conclusions and problems obtained through the experiment are as follows:

Experimental conclusion:

(1) The application data is point cloud data, which reduces the complexity of data analysis by transforming point cloud data into images as raw data.

(2) A variety of feature detection methods are applied to the point cloud image data for comparison, and it is found that the combination of multiple feature detection methods is more effective than a single detection method. From the results of the combination of multiple feature detection methods, it can be seen that both single and multiple cracks can achieve the detection effect.

(3) The feature point matrix description of different types of fracture image information is used as auxiliary monitoring data to provide a kind of basic data for the comparison of fracture monitoring.

The main idea of this paper is to use the driverless technology, combine with the road laser data acquisition equipment to automatically obtain data, and use the idea of real-time data processing to realize the intelligent real-time dynamic monitoring of the road. The existing problems in the experiment and the subsequent attempts can be made as follows:

(1) Unmanned driving technology is not mature yet, and it can only be combined with further development.
(2) At present, there is no software available in the market, which can be applied in this study to meet the demand of processing a large amount of real-time data.
(3) The feature point matrix description of different types of fracture image information is used as auxiliary monitoring data to provide a kind of basic data for the comparison of fracture monitoring.

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XIANLIN LIU is currently an Expert of photogrammetry and remote sensing, surveying, and mapping. He has made a series of important scientific research achievements, many of which have filled in the gaps in China and ended the history of China's total dependence on the imports of advanced surveying and mapping instruments. He has vigorously promoted the development of the whole industry through the development of instruments and accelerated greatly the transformation of China's surveying and mapping technology system from traditional to digital.