Fast Pavement Detection Based on Lattice Laser

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Abstract
In this paper, in order to the demand for unmanned vehicles detected traveling road, a fast road detection technology based on laser dot is proposed. The mathematical model of the pixel coordinates and the spatial coordinates of the pixel coordinates of the projected points on the camera is established, new regional segmentation algorithm is proposed, and the extraction algorithm of the lattice laser center is introduced. The spatial coordinates of the spot are calculated according to the pixel coordinates of the spot, and the three-dimensional inspection reconstruction of the pavement is carried out through the curve fitting of the spot space position, and ultimately the three-dimensional inspection of the pavement. Experimental results show that this method can be realized on the road condition detection, it has a simple structure to detect speed, accuracy and reliability. The method can meet unmanned car driving on the road detection requirements.
Key words: FRACTIONAL LASER, PAVEMENT DETECTION, IMAGE PROCESSING, REGION SEGMENTATION, MACHINE VISION

1. Introduction

Unmanned driving technology in intelligent transportation, vehicle safety auxiliary driving, automatic vehicle remote control, factory, patrol and military and other fields have a wide range of applications. At present, the method of three-dimensional detection of obstacles is light flight time, stereo vision, laser line scanning [1] method, structured light scanning method, etc.. Optical flight time [2], that is, the use of laser radar detection of obstacles. The method can obtain the information of the distance, relative velocity and azimuth angle of the front obstacle [3-5].But the size of laser radar is too large, the technology is complex, the equipment is expensive, which limits the popularization of laser radar. Stereo vision method is a common obstacle detection method in the visual navigation of intelligent vehicle. Because of the complexity of the classical image recognition and matching algorithm, the algorithm is difficult to meet the requirements of real-time [6].

Laser line scanning method is a relatively mature three-dimensional acquisition mode, the laser source uses a very thin line laser irradiation to the object, the camera to take pictures, extract the linear laser, get the two-dimensional information, and save the acquired information. For the application of intelligent vehicles, the problem of high accuracy and high cost of the high speed, medium length and long distance, is not easy to be popularized. Structure light scanning method [7] is the projection of the object surface by the projector encoding pattern, with a camera to capture the surface deformation of objects, the use of encoding information to match the image of encoding, and ultimately the use of triangulation principle to calculate the surface space coordinates of objects. It has the advantages of high detection accuracy, but it needs to use a projector to produce a variable structure light, the structure of light intensity cannot meet the requirements of detection in the natural environment.

In view of the above problems, this paper presents a pavement detection technology based on dot matrix laser, which has the advantages of simple structure, strong real-time, low cost, small size and low weight.

2. Pavement detection principle based on lattice laser

2.1 System constitution

The pavement detection system based on dot matrix laser is shown in figure 1, which is mainly composed of lattice laser, camera and data processing unit.

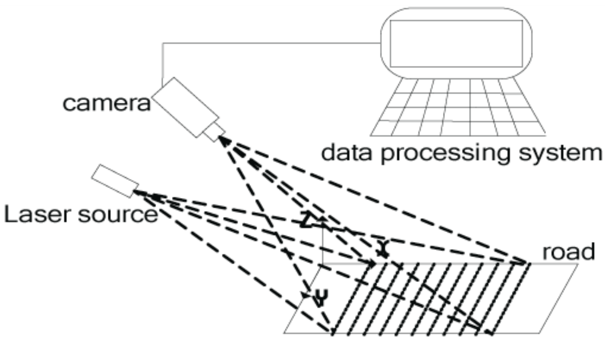

Figure 1. Schematic diagram of pavement detection system based on dot matrix laser

When the system works, the laser beam is projected onto the surface of the road, and the camera acquires the image, and the data processing unit processes the collected images, and then extracts the pixel coordinates of the lattice points. According to the pixel coordinates of the spot, the spatial position of each laser beam and the spatial position of the camera, the 3D information of the pavement can be obtained.

2.2 Geometry model of road space coordinates

When the camera is on the road in front of the scene acquisition, road and three-dimensional obstacle exists above objective will be projected onto a two-dimensional image plane, we use to describe the projection image conversion process [8]. In order to strike the world coordinate fractional laser, it is necessary to establish five coordinates, the five coordinates for the world coordinate system, camera coordinate system, laser coordinate system, the image plane coordinates and image pixel coordinates. World coordinate system (X_W, Y_W, Z_W) : The world coordinate system to determine the spatial relationship of the three-dimensional road, also known as real coordinate system. The camera coordinate system (X_O, Y_O, Z_O): The camera is the optical center of the imaging center, you need to use the camera coordinate system (X_C, Y_C, Z_C), Z_0 for the camera optical center, usually the Z_0 axis as the main axis of the camera. Laser coordinate system (X_L, Y_L, Z_L), C is the intersection with the X axis of the laser, MC = d. Image plane coordinate system $(x-o-y)$: the image plane coordinate system is the image coordinate system, the unit is usually expressed in millimeters. Computer image coordinate system : pixel array integer pixel coordinates of points several times, by analyzing the row and column coordinates of the pixel values can determine the spatial position of objects.

For the entire system, the first to establish the positional relationship between cameras, lasers and the road, as shown in the positional relationship between the camera and the laser shown in figure 2. For laser projection on the road at any point P, its coordinates in the world coordinate system is P'(u,v) , P point in computer graphics coordinate system coordinates P'(u,v) , the camera optical axis direction, through the camera projection imaging principle, can be obtained at P It coordinates.

Light OP and the angle of XOZ surface is Φ; OP in light plane of the projection angle XOZ and OX axis is a ; the angle between the lens axis β_0 and OM is β_0 ; O_0O_C is the camera lens focal length f; MP and light XOZ face angle is γ, γ in YOZ projection surface is θ; MP in XOZ plane projection for MP 'is in the form of clamp angle XOZ; Object point P in XOZ surface, the projection O_0Z_0 surface and the O_0Z_0 axis is respectively P' , P_C and P_C' . Camera horizontal viewing angle is $2\beta_2$, the vertical viewing angle is $2\beta_2$, the serial number of the camera image plane pixels in the horizontal direction is n, the total number of pixels is (2N + 1), the camera pixels in the vertical direction of the pixel sequence of Y_0 number is m, the total number of pixels is (2M + 1).

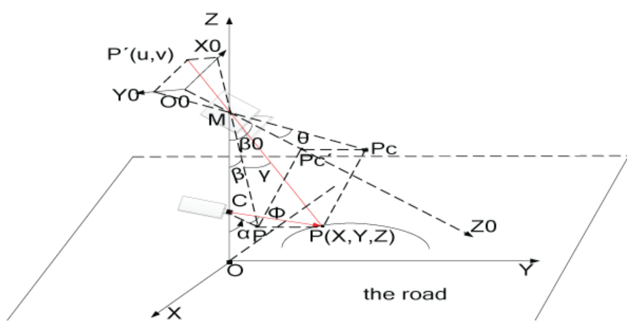

Figure 2. Camera pose

As shown in figure 3 ,it is the camera coordinate system on the XOZ plane projection, the camera coordinate system on the YOZ surface projection is shown in figure 4.

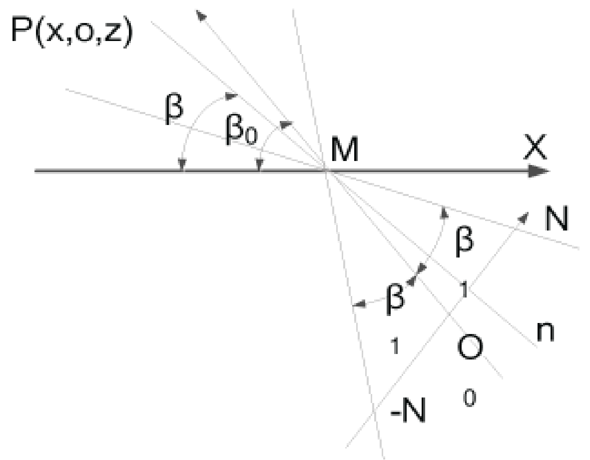

Figure 3. Camera coordinate system on the XOZ surface projection

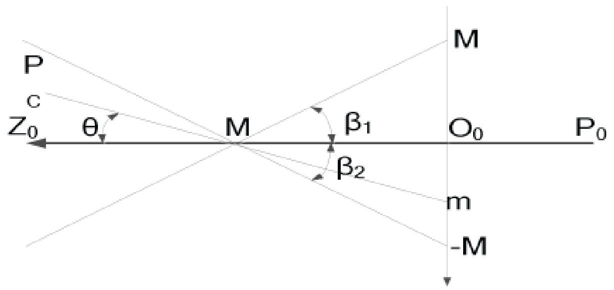

Figure 4. Projection of the camera coordinate system on the surface

From figure 3 geometric relations can be known :

$$\tan(\beta_0 - \beta) = \frac{O_0 P_0^{'}}{O_0 M} = \frac{O_0 P_0^{'}}{f} \tag{1}$$

According to the triangle formula can know:

$$\tan(\beta_0 - \beta) = \frac{\tan\beta_0 - \tan\beta}{1 + \tan\beta_0 \tan\beta} \tag{2}$$

Solution equation can be obtained:

$$\tan\beta = \frac{\tan\beta_0 - \tan(\beta_0 - \beta)}{1 + \tan\beta_0 \tan(\beta_0 - \beta)} \tag{3}$$

The distance between pixels in the X_0 direction is x_0, the total number of pixels is 2N+1, the field of view is $2\beta_1$,then get by the geometric relationships of figure 3:

$$f = N \cdot x_d \cdot \cot\beta_1 \tag{4}$$

The equations (1) and (4) can be simultaneous:

$$\tan(\beta_0 - \beta) = \frac{n \cdot x_d}{N \cdot x_d \cdot \cot\beta_1} = \frac{n}{N}\tan\beta_1 \tag{5}$$

From the formula (5) can be learned:

$$Z = \frac{d}{\cot a + \dfrac{\cot\beta_0 + n/N \cdot \tan\beta_1}{1 - n/N \cdot \tan\beta_1 \cdot \cot\beta_0}} \tag{6}$$

In the same way, there is a relationship in $\Delta CP^{'}M$:

$$X = Z \cdot \cot\alpha \tag{7}$$

In figure 4, the distance between Y_0 pixels is $2\beta_2$, the total number of pixels is 2M+1, and the field of view is , so it can be obtained:

$$f = N \cdot x_d \cdot \cot\beta_1 \tag{8}$$

The geometrical relationship can be obtained by figure 4:

$$\tan\theta = \frac{O_0 P_0^{'}}{f} = \frac{m \cdot y_d}{M \cdot y_d \cdot \cot\beta_2} = \frac{m}{M}\tan\beta_2 \tag{9}$$

$$P_C^{'}M = P^{'}M \cdot (\cos\beta_0 \cdot \cos\beta + \sin\beta_0 \cdot \sin\beta) \tag{10}$$

The geometrical relationship can be got from figure 3:

$$P^{'}M = \frac{Z}{\sin\beta} \tag{11}$$

From the above formula and (10) formula can be obtained:

$$P_C^{'}M = Z \cdot (\cos\beta_0 \cdot \cot\beta + \sin\beta_0) \tag{12}$$

From (8) and (12) solution was:

$$Y = \frac{m}{M} \cdot \tan\beta_2 (d \cdot \cos\beta_0 + Z \cdot \sin\beta_0) \tag{13}$$

Among equation: β_0, β_1, d, d are calibration constants; m, m,N,M can be obtained directly from the image.

By formula (6), (7) and (13) can calculated the spatial coordinates of point P, empathy may get all the little light projection position of the space coordinates.

2.3 Matrix structured light based matrix method for mathematical model.

The coordinates of the spatial P points in the reference frame of the camera are (X_W^C, Y_W^C, Z_W^C), and the coordinates of the reference frame of the laser system are (X_W^L, Y_W^L, Z_W^L). f_p is the focal length of the camera lens, and f_p is the focal length of the laser lens. R and T are the rotation matrix and translation matrix of the reference frame of the camera to the reference frame of the laser.

There are the following conversion relationship between the laser coordinate system and the camera coordinate system[9]:

$$\begin{bmatrix} X_W^L \\ Y_W^L \\ Z_W^L \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \begin{bmatrix} X_W^C \\ Y_W^C \\ Z_W^C \end{bmatrix} + \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} \quad (14)$$

From the above formula can be obtained:

$$X_W^L = r_{11}X_W^C + r_{12}Y_W^C + r_{13}Z_W^C + t_1 \quad (15)$$

$$Z_W^L = r_{31}X_W^C + r_{32}Y_W^C + r_{33}Z_W^C + t_3 \quad (16)$$

The following relations can be obtained from the laser model and the camera model:

$$\frac{u}{f_c} = \frac{X_W^C}{Z_W^C}, \quad \frac{v}{f_c} = \frac{Y_W^C}{Z_W^C}, \quad \frac{s}{f_L} = \frac{X_W^L}{Z_W^L}$$

The top three finishing formulas into the equation (15) and (16), elimination of intermediate variables Z can be obtained:

$$Z_W^C = \frac{t_1 - t_3 s}{[\frac{r_{31}us}{f_c} + \frac{r_{32}vs}{f_c} + r_{33}s] - [\frac{r_{11}u}{f_c} + \frac{r_{12}v}{f_c} + r_{13}]} \quad (17)$$

In the above formula:

(u, v)-Camera image coordinate system

f_c --Camera lens focal length

S --Horizontal coordinates of the laser reference frame

Therefore, the three-dimensional coordinates of spatial points in the camera coordinate system is:

$$[\frac{uZ_W^C}{f_c}, \frac{vZ_W^C}{f_c}, Z_W^C] \quad (18)$$

Based on the measurement of the dot matrix structure light, it can realize the real-time 3D coordinate measurement, and the measurement accuracy is high.

3. Lattice image processing algorithm

3.1 Extracting feature points

As shown in figure 5, the camera focuses on the projected laser dot on the object photographed, get the color of a single green dot color image. Read by the software to the digital information of the image, the application software platform is loaded VS2010 OpenCV2.4.8 for digital image processing. Because fractional laser used is monochrome, so the more obvious feature is the collection to the digital RGB image, each corresponding to a green laser point value is relatively high, which is given on the basis of the threshold value method for screening the laser spot.

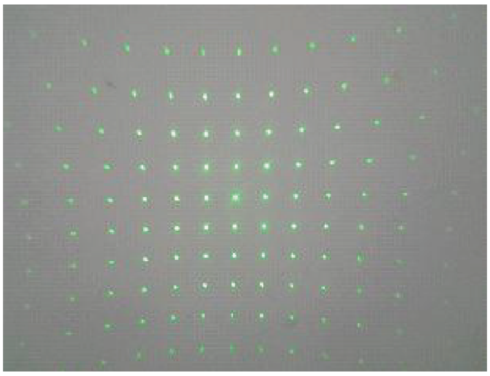

Figure 5. Pre-processed image light lattice structure

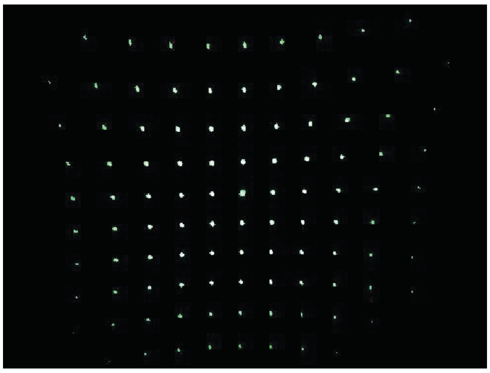

Figure 6. Thresholding processing image

Threshold is a region-based image segmentation technology, the basic principle is applied to are: data based on different characteristic features set the appropriate threshold, the resulting image is divided into appropriate categories. Suppose the original image of a feature value of 1, according to certain characteristics of the data to find value in a feature, the image is divided into two different parts, after the image segmentation feature can be expressed as:

$$g(x, y) = \begin{cases} f(x, y), f(x, y) \geq t \\ h_0, f(x, y) < t \end{cases} \quad (19)$$

From the experiments carried out processing on the image at different distances, different lighting conditions, obtained in the measuring range 0-6m range, select the laser power is 50mw, 3000lux when outside light intensity, can be extracted from the background fractional laser spot best $t = 230$. With the outside light intensity increases, the need to improve the value t in order to accurately extract the dot spot; when the ambient light intensity weakened spots dot and the environment more obvious contrast, the value of t can be smoothly without changes extracted from the background environment. Reference Test required in low light conditions, and ultimately determine $t = 230$.

When $t = 230$, $h_0 = 0$, the camera captures the figure 5 on the basis of the above formula for its green color with threshold processing, can get the results as shown in figure 6.

As can be seen from the above results, at a given threshold condition, the algorithm described above can correctly extract in the spotlight as the center of the spot 11 * 11 dot from the background environment. In practice, in order to improve system speed, do not process the coordinate point $f(x, y) < t$; only horizontal and vertical coordinates of a pixel of points $f(x, y) \ge t$ is stored . This simplifies the calculation algorithm structure, saving the software running time, while improving the operational efficiency of the software.

The image processing method is based on the point of the global threshold segmentation algorithm, compared with other methods based on region global threshold segmentation, the algorithm takes the shortest time and is easy to implement, and has a great advantage in the online real-time image processing system.

For the difficulty of threshold segmentation method is to select the appropriate threshold is selected in the above discussion T values. This article finally selected threshold is a combination of practical experience given experimental environment.

3.2 The new region segmentation algorithm

Effective pixel threshold to achieve rapid extraction region segmentation, needs to be based in this article actual application environment and propose a new algorithm theory, improve the efficiency of the regional division. From the above experimental results, at a given threshold value T = 2 for each spot segmentation obviously, so when the effective area division points need not consider the issue of the separation between each dot laser spot.

Traditional regional segmentation method applied to the classical theory of law foundation for the 8 connected region. For the calculation of multiple spot coordinates, connected component labeling methods using various spot area, and then to strike the center of each spot.

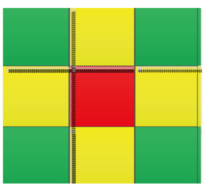

Figure 7. 8 Neighborhood diagram

The method can realize the extraction of the center point coordinates of a number of points, as shown in figure 7, 8 neighborhood region growing algorithm for each pair of adjacent coordinate points needs to be compared with all the points in the image, the search for the existence of the neighborhood points in the database. This algorithm has a large amount of data operations, which not only need large memory, but also greatly reduce the real-time performance of the system.

This paper presents the final comparison of adjacent rows, it can quickly extract the individual spot area, and can be extracted spot center through the center of gravity method. The basic idea of this algorithm is as follows:

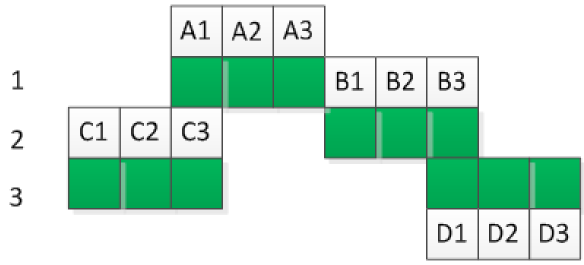

Figure 8. LWT algorithm

As shown in figure 8, the green part of each square represents a pixel, the figure represents the number of columns of letters such as A1 of the pixel, the digital 1,2,3 represents the number of rows in the pixel is located. Analyzing the first row and the second row of pixels is based on whether the same is to determine the relationship between the region A1 and B3, or between A3 and B1.

If $B1-1 \le A1 \le B3+1$ or $B1-1 \le A3 \le B3+1$, you can determine the first line in the A1-A3 and the next line of B1-B3 for the same neighborhood, if the two conditions are not set up to determine the corresponding column in the two row is not the same neighborhood. After determining the same neighborhood, the corresponding point coordinates are stored in the same area, and the center of the spot is calculated by the method of gravity center.

This paper eventually took two different region segmentation method for multiple images have been processed, final LWT single image processing algorithm time-consuming is always less than 1s; and 8-connected region code algorithm based single image processing needs time in more than 10s level.

The experiments show LWT region growing method has reduced the complexity of the system compared to the eight-neighbor algorithm and improves the system operation speed.

3.3 The extraction of the center coordinates of the spot

An ideal optical system, then one is still an object point imaged object point; but the actual object point in the optical system after the optical imaging system, is a diffuse point. Monochrome laser with and linear features, but the image acquired by the camera is spot image, rather than a single pixel images.

In the lattice structured light 3D measurement system, a single point laser is emitted by the laser, which is then expanded into a lattice laser, and each of the points in the lattice laser is projected into a spot.

Extraction accuracy spot center is to ensure the accuracy of the entire system is one important factor. Calculation method for spot center is the center of gravity method, curve fitting method and so on.

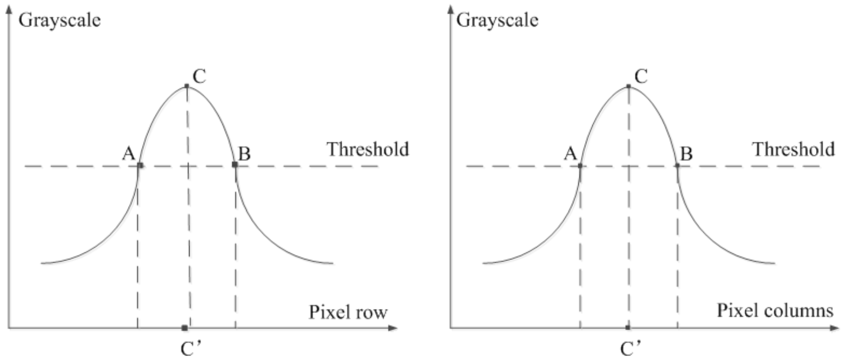

Figure 9. Ideal gray distribution of laser spot

As shown in figure 9, the ideal gray distribution of the laser spot is Gauss distribution, and the C point is the center of the laser spot, and the Gaussian curve algebraic expression is:

$$G(x) = A\frac{1}{\sqrt{2\pi}\delta}\exp\left[-\frac{(x-u)^2}{2\delta^2}\right] \quad (20)$$

After extracting the coordinates of the feature points, the RGB image is converted to gray value images. Because the energy distribution of the spot is subject to Gauss distribution, the center point coordinates of the points in the lattice laser can be obtained respectively according to the distribution characteristics of Gauss. The 3D coordinates of the space points can be obtained from the angle of the center point coordinate of the laser projection angle.

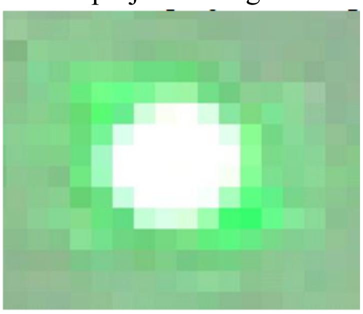

Figure 10. Actual laser spot diagram

In the practical application, as shown in figure 10, since the center spot area is saturated, it cannot apply a Gaussian distribution curve function extracted directly center spot. In view of this situation, the Hough transform method, the circle fitting method and the center of gravity method can be used. The Hough change and circle fitting method have higher accuracy, but because of the large amount of calculation of these two methods, it is difficult to achieve real-time processing, so the center of gravity method is adopted. The calculating formula of the center of gravity method is as follows:

$$\overline{x_0} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} x_i f^2(x_i, y_i)}{\sum_{i=1}^{n}\sum_{j=1}^{n} f^2(x_i, y_i)} \quad (21)$$

$$\overline{y_0} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} y_i f^2(x_i, y_i)}{\sum_{i=1}^{n}\sum_{j=1}^{n} f^2(x_i, y_i)} \quad (22)$$

4. Test and data analysis

This experiment needs to be carried out in the weak light condition. If the light intensity is too high, the lattice spot will be submerged in the environment which cannot be extracted for lattice spot. The camera's field of view is large enough to capture the desired fractional laser spot position.

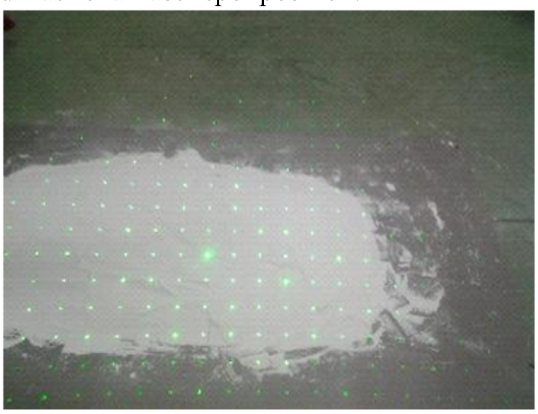

Figure 11. lattice structure light image of the measurement region

By the laser emitting lattice structure light, the camera gets to the picture as figure 11, the computer is responsible for sending out the acquisition photo command, while the computer to collect the lattice laser photo processing, after calculation can be obtained as shown in figure 12, the space position of the dot matrix. The interpolation method can be used to insert enough points in three-dimensional space, and then the 3D simulation can be obtained by 3D fitting.

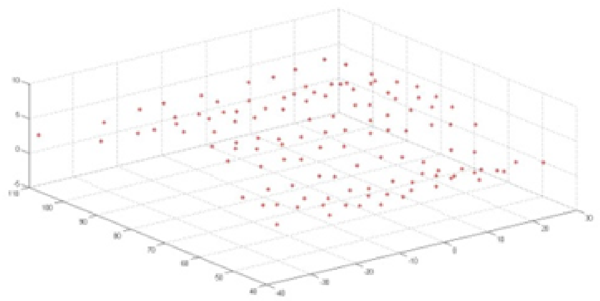

Figure 12. The space coordinates of the laser space of the object lattice

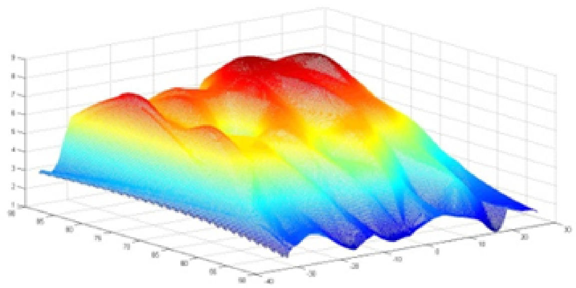

Figure 13. Three-dimensional reconstruction of the measured object diagram

By sampling measurement on the experimental lattice spot in the spatial position, we can know the actual position error of the obtained data and spatial point is in the millimeter level, which meets the requirements of the road detection in the actual application of the vehicle.

5. Conclusions

Three-dimensional scanning equipment in the field of product design, quality detection, precision machine tool control and reverse engineering and other fields has been widely used, in addition, in the face acquisition, bionics research, human detection, computer animation, electronic entertainment, costume design , biomedical, heritage, accident investigation, evidence identification and many other areas also has a wide range of applications prospect.

With the rapid development of production and the improvement of the quality of products, the demand for 3D measurement technology is more and more, the performance is also more and more high. At present, according to the requirement of production and life, the three-dimensional measurement technology is limited by the technical requirements of high detection accuracy, fast detection speed and detection distance. The paper has carried on the thorough analysis and the research to the lattice structured light three dimensional inspection technology, the subject has the profound theory value and the important application value.

In this paper, based on the research of the existing three-dimensional measurement technology, combined with stereo vision principle and image processing technology, the paper presents a method of three-dimensional terrain measurement based on lattice structured light. The experimental results show that the proposed method has the advantages of simple structure, practical, convenient operation, strong adaptability to environment and high reliability.

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Biomimicry of Symbiotic Multi-Species Coevolution for Global Optimization

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Abstract

In recent years, symbiosis as a rich source of potential engineering applications and computational model has attracted more and more attentions in the adaptive complex systems and evolution computing domains. Inspired by different symbiotic coevolution forms in nature, this paper proposed a series of multi-swarm particle swarm optimizers called PS^2Os, which extend the single population particle swarm optimization (PSO) [1] algorithm to interacting multi-swarms model by constructing hierarchical interaction topologies and enhanced dynamical update equations. According to different symbiotic interrelationships, four versions of PS^2O are initiated to mimic mutualism, commensalism, predation, and competition mechanism, respectively. In the experiments, with five benchmark problems, the proposed algorithms are proved to have considerable potential for solving complex optimization problems. The coevolutionary dynamics of symbiotic species in each PS^2O vesion are also studied respectively to demonstrate the heterogeneity of different symbiotic interrelationships that effect on the algorithm's performance.

Key Words: SYMBIOSIS, PARTICLE SWARM OPTIMIZATION, MULTI-SWARM COEVOLUTION, GLOBAL OPTIMIZATION.