

# Design and Experiment of Dynamic Measurement Method for Bulk Material of Large Volume Belt Conveyor Based on Laser Triangulation Method

Fusong Min<sup>1</sup>, Andong Lou<sup>2,3</sup> and Qun Wei<sup>1</sup>

1Nanjing Coal Science & Technology Research Co., Ltd., Nanjing, Jiangsu 210018, China

2 Luoyang Mining Machinery Engineering Design and Research Institute Co., Ltd., Luoyang, Henan 471039, China

3 Corresponding author and e-mail: Andong Lou, citichma\_louad@163.com

**Abstract.** In order to improve the measurement accuracy and efficiency of bulk material transported by large-capacity belt conveyor, an online dynamic non-contact metering system based on laser triangulation is designed on the belt conveyor platform. The system includes: laser Scanners, industrial camera, signal processing software, mechanical assemblies. High-precision basic measurement data is an important guarantee for the accuracy of bulk flow measurement. The laser scanner is used as a line source, and the scanning frequency is set to 300HZ, which is installed on the belt conveyor. Industrial camera accepts images produced by a line source projected onto the bulk surface. The signal processing software system analyzes the images, and uses the triangulation method directly calculate the three-dimensional contour information and volume flow of the bulk material. The flow filtering algorithm filters the instantaneous flow, smoothing the fluctuation of the flow data to reflect the real changes of the dry and wet degree of the bulk material on the belt, the degrees of surface cracking and shapes. Establish a mathematical model based on neural network and apply the belt shaking elimination algorithm to correct the previously calculated flow data to reduce the measurement error. In order to restore the actual belt conveyor bulk transportation conditions, a test belt with length 20m and speed 2m/s was produced according to the actual size. The physical simulation test of bulk material for potassium salt was carried out, the results show that the on-line measurement method based on laser triangular method has high efficiency and stable operation, and eliminates the influence of bulk density. The measurement error is  $\leq 3\%$ .

## 1. Introduction

The three-dimensional contour measurement method was contact measurement in the early stage. In recent years, this method has been developed unprecedentedly [1]. Currently, there are many types of non-contact contour measurement methods, including: time-of-flight method [2], holographic interferometry. [3], speckle interferometry [4], confocal microscopy [5], phase method [6], binocular stereo method [7], and laser triangulation method [8] and so on.

At present, in the production process of factories and mines, the electronic belt scale and the nuclear belt scale are the two mainstream metering devices for dynamic weighing. The electronic belt scale is a contact type measurement. It uses the pressure sensor installed under the conveyor belt to sense the mass of the bulk material on the belt. However, for the belt under motion, the measurement result is inevitably subject to the tension, rigidity and weight of the belt and so on. The nuclear scale is non-contact measurement and is made using the principle that substances absorb  $\gamma$ -ray. Due to the ever-changing shape of the bulk materials on the conveyor belt, the ionization chamber is often



covered by the material falling off the belt, which causes the accuracy of the nuclear scale to decrease, and the application of the radioactive source is cumbersome, and there are certain safety hazards in the use and storage of the radioactive source.

## 2. Measuring Principle and Process of Metering System

In this paper, a new concept based on laser triangulation is designed to measure the material flow of conveyor belt is designed. The online measurement method of bulk materials is attributed to the online measurement of bulk materials as two problems: online measurement of bulk volume and measurement of bulk density. The laser scanner emits a fan-shaped laser beam as a line source and shoots it vertically downwards to the belt. Using laser image analysis technology, a series of material surface contour coordinates can be obtained, and then triangulation can be used to calculate the flow over the belt per unit time. The bulk volume of the material is measured online, and the bulk density of the material can be determined by physical calibration. The volume and bulk density of the material on the conveyor belt are obtained, and the material flow rate is determined. This paper introduces the following three processes of the measurement.

### 2.1. Find the Surface Height of the Bulk Material

First, the line source is vertically irradiated on the surface of the calibration object. By adjusting the height of the calibration object, the industrial camera acquires the image information, and then the software performs image processing to complete the calibration of the relationship between the actual height  $h$  of the object and the distance  $d$  between the source coordinates.

The line source is illuminated on the surface of the mineral material, the red line (Figure. 1) in the schematic diagram of the laser stripe on the surface of the mineral material. Take the photo, and obtain the coordinate value of the line source by image processing. Using the relationship between  $h$  and  $d$  calibrated in the previous step, the actual height of the line source, that is, the height of the surface of the mineral material. The actual height of the entire line source is determined by  $n$  height values. The yellow dot in the figure below is a schematic diagram of the  $n$  feature points on the selected line source. The larger the value of  $n$ , the more accurately the real height of the mineral material required to be taken Real height.



**Figure 1.** Laser Triangulation Method for Measuring Surface Height

### 2.2. Find the Cross-sectional Area of the Bulk Material

Using the values between the point  $i$  and the point  $i+1$  ( $i=1, 2, \dots, n-1$ ) height points, the cross-sectional area is obtained by linear interpolation. The cross-sectional area of the irregular object, the sum of all the cross-sectional areas is the cross-sectional area of the mineral material.

### 2.3. Find the Flow of Bulk Material

Take a image information (picture) every  $\Delta t$  time. If the distance traveled by the material is  $k$  in  $\Delta t$  time, multiply the cross-sectional area obtained in the previous step by  $k$ , which is the volume of the material passing through  $\Delta t$  time. The volume of materials obtained during the time is all added up. If  $t$  time contains  $m$  times  $\Delta t$  times, the flow rate of the requested material is  $Q$ :

$$Q = \frac{\sum_{j=1}^m V_j}{m\Delta t}$$

### 3. Key Technologies for the Metering Systems

#### 3.1. High-frequency High-precision Outdoor Laser Scanning Instrument

High-precision basic measurement data is an important guarantee for material flow measurement accuracy. In order to improve the adaptability and stability of the metering system and improve its measurement accuracy, the main technical parameters of the selected high frequency and high precision laser scanner are shown in the following table1.

**Table 1.** Main Technical Parameters of Laser Scanner

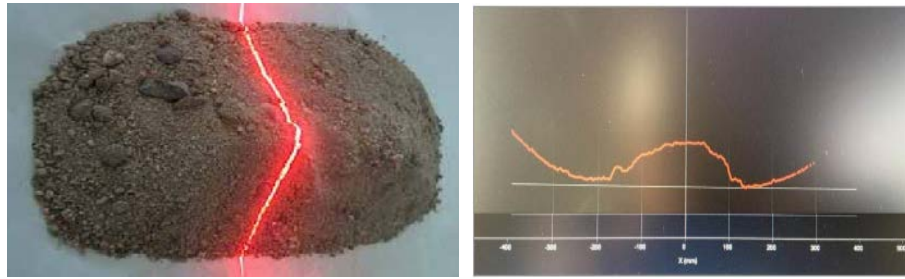
Laser scanner technical parameters		
Number	Name	Parameter
1	Data points	1280
2	Z-axis linearity	0.04%
3	Z-axis resolution	0.092-0.448 mm
4	Z-axis repeatability	12μm
5	X-axis resolution	0.375-1.1mm
6	Measuring distance	350mm
7	Measuring range	800mm
8	Scanning range	390-1260mm
9	Input voltage	24-48V
10	Scanning frequency	170-5000HZ
11	Protection level	IP67
12	Temperature	0-50°C

According to the actual working conditions, the scanning frequency of the scanner is set to 300HZ. According to the average belt speed of 1.65m/s, the surface contour line spacing of the scanned materials is 8mm, and the X-direction (vertical belt moving direction) scanning point spacing is 0.375mm. The accuracy is less than 0.5mm. The scanner itself has IP67 protection and can be used in outdoor working environment. The operating temperature range is 0-50 °C, which can meet the normal working conditions of the instrument in relatively low temperature and high temperature environment, so the instrument has the ability to work around the clock.

#### 3.2. Triangulation Method to Calculate Volume Flow

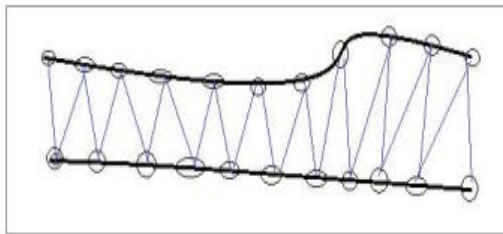
There are two ways to perform triangulation of spatial points: one is to directly triangulate points in space, and the other is to map points in space to plane and triangulate points in two-dimension. And then back map into 3D space. The latter method is relatively simple. The latter method is used to triangulate feature points in a two-dimensional image by triangulation algorithm (Shewehuk, 1995), as shown in Figure3.and then due to three-dimensionality in space. The points are calculated by the feature points, so according to this mapping relationship, the two-dimensional points of the split are mapped into the three-dimensional space, and the triangulation of the spatial points are realized as shown in Figure 4.

The laser is projected onto the surface of the material on the belt, which results in a series of scan point coordinates that form a material surface profile on the XZ coordinate plane. As shown in Figure 2.

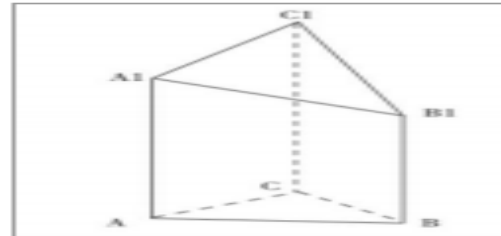


**Figure 2.** Material Profile Contour Laser Contour

Assuming the number of scanning points  $N$  on the contour line, two adjacent contour lines triangulate from the minimum to the maximum along the  $X$  coordinate, and  $2(N-1)$  bevel triangular prisms can be obtained. The distance of the contour line in the belt movement direction ( $Y$  direction) is the product of the belt speed and the time interval between the contour lines. By accumulating the volumes of these  $2(N-1)$  bevel triangular prisms, the volume of materials between the two contours can be obtained. The triangulation method is shown in Figure 2.



**Figure 3.** Interface Triangulation Diagram



**Figure 4.** Beveled Triangular Prism

Assume that in Figure 3, the  $i$ -th beveled triangular prism has a volume of:

$$dV_i = \frac{1}{3} S_{\triangle ABC} * (Z_{A1} + Z_{B1} + Z_{C1})$$

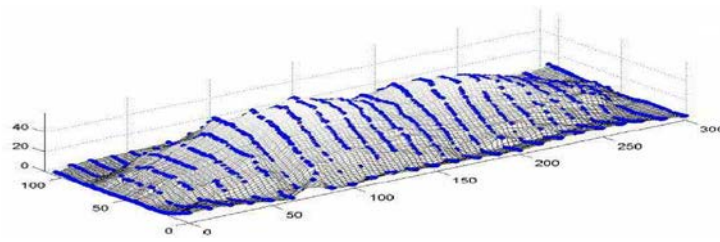
The volume between the two contour lines is:

$$V = \sum_{i=1}^{2(N-1)} dV_i$$

Assuming that the time interval between the two contour lines is  $\Delta t$ , the instantaneous volumetric flow rate of the material on the belt is:

$$F = \frac{V}{\Delta t}$$

As shown in Figure 5, the feature points acquired by the high-frequency scanning picture set are combined, and the information of all the feature points obtained by the picture set is integrated to obtain the reconstructed three-dimensional contour figure by triangulation, thereby calculating the volume flow rate.

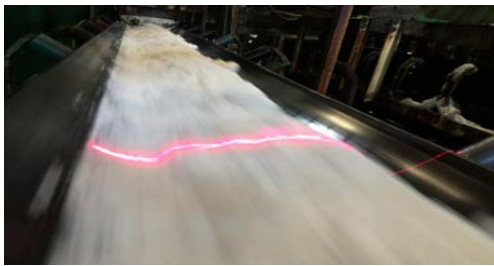


**Figure 5.** Reconstructed 3D Contour Graphics

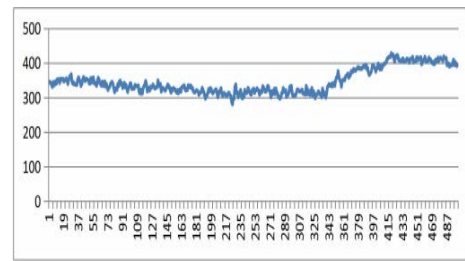
The instantaneous weight flow of the material is obtained by multiplying the instantaneous volume flow by the bulk density of the material.

### 3.3. Traffic Filtering Algorithm

Due to the change of the dryness and wetness of the material during the conveying process of the belt conveyor, when the material falls onto the belt, the surface cracking degree is different and the shape is also ever-changing, resulting in a large fluctuation of the measured instantaneous flow. As shown in Figure 6. The purpose of filtering the instantaneous flow is to smooth the fluctuation of the flow data and reflect the real change of the material on the belt in real time.



**Figure 6.** Surface Profile (potassium salt) on the Belt



**Figure 7.** Filtered Flow Curve

First of all, the instantaneous flow data is accumulated in unit time  $\Delta t$ , and one actual flow data is calculated per unit time  $\Delta t$ , which can reduce the output frequency of the actual flow data and reduce the fluctuation. Assuming that the number of scanners in per unit time is  $M$  scanning contour lines, two adjacent contour lines calculate a instantaneous flow data, and the total number is  $M-1$ , then the volume flow in  $\Delta t$  is:

$$F = \frac{\sum_{i=1}^{M-1} V_i}{\Delta t}$$

Secondly, the flow data calculated in unit time is subjected to five-point method smoothing filtering. The filtering formula is:

$$FR_k = \alpha_{k-2}F_{k-2} + \alpha_{k-1}F_{k-1} + \alpha_k F_k + \alpha_{k+1}F_{k+1} + \alpha_{k+2}F_{k+2}$$

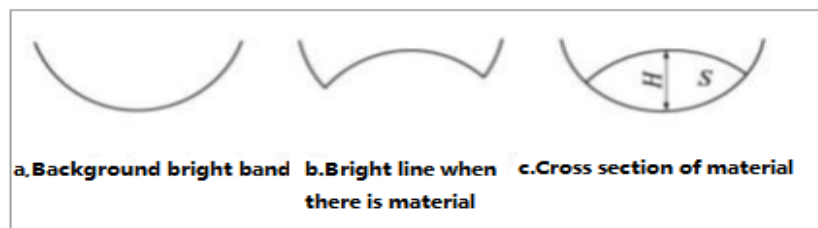
The real flow values  $F_{k-2}$ ,  $F_{k-1}$ ,  $F_k$ ,  $F_{k+1}$ , and  $F_{k+2}$  of the  $k$ -th cycle of  $FR_k$  are the volume flow values calculated in units of 5 consecutive cycles.  $\alpha_{k-2}$ ,  $\alpha_{k-1}$ ,  $\alpha_k$ ,  $\alpha_{k+1}$ ,  $\alpha_{k+2}$  are smoothing coefficients, which are calculated according to the Hamming function, and are taken as 0.04, 0.24, 0.44, 0.24, and 0.04, respectively.

Figure 7 shows the filtered flow data curve for a certain period of time. The burr-like value jump on the curve is reduced, which can also reflect the material change on the belt.

### 3.4. Belt Jitter Effect Elimination Algorithm Based on Neural Network

When there is no material transport on the belt, the laser source projects a bright band formed on the

belt, which is called "background bright band". Since the bright band is composed of a series of spots, the geometric coordinates of each spot can be obtained through a series of transformations. In the case of materials on the belt, the scanner continuously ingests the contour lines of the material surface at a certain time interval, that is, the bright lines, and calculates their geometric coordinates. By comparing with the background bright bands, a series of material cross sections are obtained. Shape and calculate its area. As shown in Figure 8. The background bright band coordinates data of the laser scanning, so the contour data of the empty belt is an important basic factor affecting the measurement accuracy.



**Figure 8.** Background Bright Band

When the belt moving at high speed passes by the roller, there will be obvious up and down jitter, which will cause the Zcoordinate of the contour of the background light to move up and down. When calculating the cross section of the material, deviation will occur, which will cause measurement error. When there are materials on the belt, the materials cover the bottom of the belt, so the coordinates of the background light strip cannot be accurately obtained. By adjusting the field of view of the scanner, the scanner can always scan the marked area where the edge of the belt is never covered by the materials. At the time the belt is empty, a neural network model between the marker region coordinates and the center point Zcoordinate on the background light band is established. When the belt is covered by the materials, the coordinate change of the marked area is obtained, and the neural network model can be used to predict the change of the Zcoordinate of the center point of the background light band, thereby eliminating the influence of the belt jitter effect.

The neural network is recognized as an effective model building method that can be used to establish a mathematical model between the coordinates of the marker area and the Zcoordinate of the center point on the background light strip. In this way, during the measurement process, the change of the coordinate of the background bright band contour can be calculated according to the coordinate change of the mark area, which is used to correct the data of the flow calculated in the foregoing, and reduce the measurement error.

RBF network (radial basis function neural network) is a very popular modeling method. Consider an RBF network: it has  $n$  inputs,  $M$  hidden nodes and an output, and uses Gaussian radial basis functions. Before using the RBF network, you must first determine the hidden node data center (including: number, value, expansion constant) and a corresponding set of weights.

According to the on-site calibration result, the Z coordinate of 10 consecutive scanning points in the marking area is used to form the input vector. When the belt is empty, the Z coordinate of the center point is the target value, the belt is idling for 5 minutes (the belt runs about two times), and 15000 sets of data are collected for Neural network training. The training process is as follows:

1) First, 50 sets of data are randomly selected as the data center vector, and the data center distance threshold  $\delta$  is set.

2) Cross-calculate the Euclidean distance between 50 sets of data center vectors, and eliminate vectors with high similarity.

3) Calculate the Euclidean distance of the remaining 14950 data sets, comparing the remaining data center vectors in 2), and add the vector with the distance greater than  $\delta$  into the data center vector until the number of vectors reaches 50, and the number of hidden nodes in the neural network is 50.

4) Training a neural network uses a two-step approach. Idea: The first step is to determine the data center of  $h$  hidden nodes in the RBF network by unsupervised learning method, and determine the



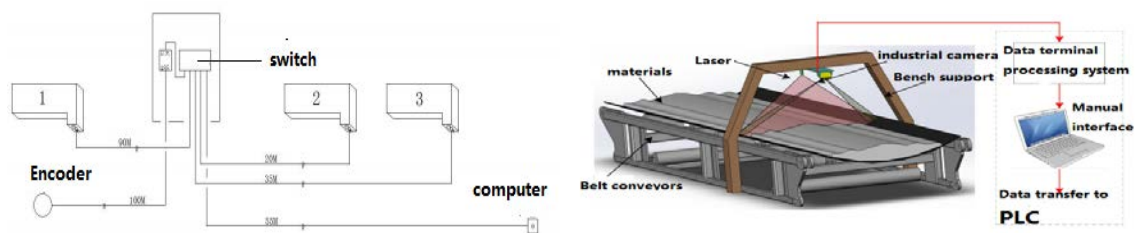
expansion constant of the hidden node according to the distance between each data center. The second step is to use supervised learning (gradient method) training. The output weight of each hidden node.

After determining the extension constant of the data center and the output weight of the hidden node, the neural network model  $f(X)$  is determined. In the actual measurement process, the input vector  $X$  is the Z coordinate of 10 consecutive scanning points in the marking area, and the input neural network  $f(X)$  to the network output value  $Z_x$ ,  $Z_x$  is the center point Z coordinates of the neural network prediction.  $Z_x$  is subtracted from The Z coordinate of all the scanning points on the contour line, and then the triangulation, volume calculation and filtering budget are performed to obtain real flow data.

#### 4. Overall Design of the Metering System

##### 4.1. Structure of the Metering System

The metering system is designed not only to measure the flow volume measurement of the fine particles on the transport belt but also to meet the requirements of measuring the volume flow of large materials. When measuring large materials, it can be adjusted by increasing the power of the laser source. The parameters of the motion control module of the system realize the measurement and calculation of the contour and volume of large materials. As shown in Figure 9.



**Figure 9.** Test System Structure

##### 4.2. Computer Data Information Processing Software

According to the application measurement requirements and marketing of the measurement system for actual working conditions, a dedicated measurement and test system software has been developed , can set the system technical parameters according to the production requirements.

#### 5. Test Results and Analysis

##### 5.1. Laboratory Physical Simulation Test

The metering system installation and simulation tests were carried out in the laboratory. According to the size specification of the 105 belt, a belt with a length of about 20 meters was produced, and the belt speed was 2m/s. Physical simulation tests and verification were carried out. Install the branch support above the belt conveyor to install the equipment in the normal working form. The installation height of the equipment takes into account the measuring range. And then the calibration and scanning area settings are performed according to the equipment usage specifications. The entire laboratory test environment is shown in Figures 10.



(a) Schematic diagram of installation and scanning range



(b) Device initialization settings

**Figure10.** Physical Simulation Test Scenario

In order to verify the measurement accuracy of the system, two laboratory tests were carried out: carton volume measurement and potassium salt volume measurement. The fixed volume of the carton and the potassium salt are stacked on the belt, the belt is started, and the volume and actual volume are measured by the device to calculate the measurement error. As shown in Figure 11, the measurement results are shown in Table 2 and Table 3.



**Figure11.** Laboratory Simulation Test

**Table 2.** Carton Volume Measurement Results

Carton volume	Number	Measuring volume	Actual volume	error
0.01584m <sup>3</sup>	10	0.16074m <sup>3</sup>	0.158m <sup>3</sup>	1.47%

**Table 3.** Volumetric Measurements of Potassium Salts on the Belt

Number	Salt volume	Measure volume	Error
1	0.03654m <sup>3</sup>	0.03765m <sup>3</sup>	0.00111m <sup>3</sup>
2	0.03654m <sup>3</sup>	0.03564m <sup>3</sup>	-0.00090m <sup>3</sup>
3	0.03654m <sup>3</sup>	0.03544m <sup>3</sup>	-0.00110m <sup>3</sup>
4	0.03654m <sup>3</sup>	0.03550m <sup>3</sup>	-0.00104m <sup>3</sup>
5	0.03654m <sup>3</sup>	0.03735m <sup>3</sup>	0.00081m <sup>3</sup>
6	0.03654m <sup>3</sup>	0.03560m <sup>3</sup>	-0.00094m <sup>3</sup>
7	0.03654m <sup>3</sup>	0.03760m <sup>3</sup>	0.00106m <sup>3</sup>
8	0.03654m <sup>3</sup>	0.03736m <sup>3</sup>	0.00082m <sup>3</sup>
9	0.03654m <sup>3</sup>	0.03591m <sup>3</sup>	-0.00063m <sup>3</sup>
10	0.03654m <sup>3</sup>	0.03770m <sup>3</sup>	0.00116m <sup>3</sup>

The accuracy of the measuring instrument is expressed by the standard deviation  $\sigma$ :

$$\sigma = \sqrt{\frac{\delta_1^2 + \delta_2^2 + \dots + \delta_n^2}{n}} = \sqrt{\frac{\sum_{i=1}^n \delta_i^2}{n}}$$

$\sigma$ --standard deviation

$\Delta$ --measurement error

$n$ --Number of measurements

Result:  $\sigma=0.00097\text{m}^3$

Measurement error:  $f = \frac{0.00097}{0.03654} = 2.65\%$

## 6. Conclusion

The online dynamic non-contact metering system based on laser triangulation method has some advantages, such as simple structure, high degree of automation and good stability. The system uses a line laser source in the measurement process, which improves the measurement system compared with the traditional point laser source. In the actual working conditions of the factory belt conveyor to



transport bulk material, the metering volume flow error  $2.65\% \leq 3\%$ , the metering system designed in this paper meets the real-time measurement requirements of the factory belt conveyor, which is a good application prospect in the practice of fine industrial metering.

## 7. Acknowledgement

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## 8. References

- [1] Javier Garcia, Jose J. Esteve-Taboada, Jose J. Valles. Detection of Three Dimensional Objects Based on Phase Encoded Range Images [J]. Proc SPIE Vol.5477, 2002,158 ~167
- [2] Markus-Christian Amann, Thierry Bosch Risto Myllyla, et.al. Laser ranging: A critical review of usual techniques or distance measurement[J].Opt Eng,2001,40(1):10 ~19
- [3] Goodman J W, Lawrence R W. Digital image formulation from electronically detected hologram. Appl phys letter, 1967,11(3):77 ~ 99
- [4] Le Kaiduan et al. Large dynamic range deformation measurement [J]. Acta Photonica Sinica, 1998, 27(6): 6Wilson T, C J R Sheppard. Theory and practice of scanning optical microscopy [M].London Academic Press, London. 1984. 1~ 65
- [5] Huang J, Zhang X B. 3D measuring techniques based on image processing[J].Chinese Journal of Electron Devices, 2002, 25(4): 364 ~ 368
- [6] Coodall A J, Burton D R .The future of 3D range image measurement using binary-encoded pattern projection [J]. Opt. Loers Eng.,1994, 21(1-2): 99 ~ 110
- [7] Huang J, Zhang X B. 3D measuring techniques based on image processing[J].Chinese Journal of Electron Devices, 2002, 25(4):364~368
- [8] Coodall A J, Burton D R .The future of 3D range image measurement using binary-encoded pattern projection[J]. Opt.Loers Eng.,1994,21(1-2):99~110