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Threshold-belt Barization Method Research of High Sampling Density Gray-coded Image

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Abstract: In order to enhance the quality of high sampling density gray code image binarization, a threshold-belt binarization method is proposed in this study. First of all, by using this method, we need to establish a single threshold and then, according to the dispersion of the background and objectives, respectively with the single threshold, we set up a collection of threshold-belts. By removing the sampling points in the threshold belt, binary the sampling points outside of the threshold belt in order to get background and objectives, namely, the fact that the black and white stripes of the gray code image. This method avoids the phenomenon of misjudgments of the gray-scale sampling points near the single threshold. It also improves anti-interference ability of the image binarization and accuracy of the measurement.

Key words: Three-dimensional measurement, binarization, threshold-belt

INTRODUCTION

Structured light (Daley and Hassebrook, 1996; Huang *et al*., 2003) method plays an important role in non-contact 3D measurement. It is characterized by its high accuracy; simplicity in principle and suitability for real-time measurement, which has been widely used in medicine, manufacturing and archaeological areas and it is an important component of reverse engineering and computer vision. Within the structured light methods, the method of structured light coding is to project stripe patterns encoded according to a certain law on the measured object. Next, to process digital images which are produced by modulating stripe patterns through projection from the camera and then to decode and obtain the information of depth of the measured object by calculating in accordance with the triangulation method and to obtain three-dimensional coordinates. Gray-coded structured light method is easier to information extract in relative with color-coded structured light method. It has the features that the sampling density is high, with relatively simple measuring and low cost. Therefore, method of gray-coded structured light has a wider application.

Firstly, gray-coded structured light method must do binarization (Li *et al*., 2004; Thillou and Gosselin, 2005; Van der Zant *et al*., 2008; Khurshid *et al*., 2009) on modulated image and then it isolates black stripes from white stripes before decoding to complete 3-dimensional measurement. Within this method, binarization is the basis of the measurement, which has a direct impact on the decoding accuracy. The threshold selection is crucial in the binarization and another different threshold selection will bring different results. Now the current threshold selection mostly adopt the single threshold method, namely, a single threshold value is established. The specific steps of which are to select a threshold value taking a different approach upon the whole gray-scale image, mark 0 as the pixels values lesser than the threshold's and 1 as greater. Single threshold method is divided into the global one and the local one, including median method, category variance method and maximum fan method and so on.

The single threshold method is featured by relatively simple calculation, fast speed of programming and good separation effects for singled background image. While as for the complicated background images and the images affected by unevenness of shadows and lighting using the structured light methods, the single threshold method has a poor anti-jamming capability, misjudgments are prone to occur in the vicinity of single threshold and it is difficult to obtain high-quality image segmentation. So the

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single threshold method is far from meeting the needs of three-dimensional measurement of structured light. In this paper, according to the gray-coded image characterized by advantages of high sampling density, it proposed a threshold-belt binarization method, through the binarization threshold (Shafait *et al*., 2008) selection to retain high-quality sampling points and rounding low-quality points which are prone to misjudgements. Because of the high-sampling-density character with the structured light measurement, in which involves tens of thousands of data points, rounding part of the sampling points does not affect the measurement accuracy, while improving the anti-jamming capability of measurement as well as the measurement speed.

THE APPROACH

The process of the threshold-belt binarization is to set a threshold-belt which is close to the single threshold to binary the value of sampling points within the compass of the value of threshold-belt and to ignore the value of range. Namely

$$g\,(i,j)=\begin{cases}1 & 1\geq f\,(i,j)\geq x+y_2\\ 0 & 0\leq f\,(i,j)\leq x-y_1\\ \text{ignore} & x-y_1<f\,(i,j<x+y_2\end{cases}\tag{1}$$

where, x is the value of single threshold, y_1 and y_2 are bandwidth of top and bottom limitation separately, f (i,j) is the pixel values in no binary situation, g (i,j) is the pixel values binary situation.

The process of setting threshold is to use the traditional method to determine the single threshold value x, the threshold value is the average of the gray of the whole site gray projected image. We set the collection of threshold-belt, according to the range of reading error c which is allowed in the process of binarization and with average of the difference between background and a single threshold value and that between goals and a single threshold value. The average of the difference between pixels value of background, objectives and the single threshold value reflects the extent of dispersion that is the distance of gray-scale pixel value and a single threshold value and then determine the scope of points according to the extent of dispersion. Finally, we could ascertain the bandwidth according to the percentage of points which is greater than or less than the single threshold value.

The allowed range of the maximum error of the data extraction based on binarization is:

$$u\in(x-y_1,x+y_2)\tag{2}$$

where, u is Collection of Threshold band

$$y_1=(x-\overline{x_{min}})\times c\times p\tag{3}$$

$$y_2=(\overline{x_{min}}-x)\times c\times q\tag{4}$$

where, $\overline{x_{min}}$ is the average value of pixels values which are Greater than the threshold value x namely:

$$\overline{x_{max}}=\frac{\sum_{i=1}^{m}x_i}{m}\tag{5}$$

where, m is the total number of the pixels which are Greater than the single-threshold.

$\overline{x_{max}}$ is the average value of pixels values which are less than the threshold value x namely:

$$\overline{x_{min}}=\frac{\sum_{i=1}^{m}x_i}{n}\tag{6}$$

p is the ratio of the pixels which are lesser than the threshold to the total pixels, namely:

$$p=\frac{n}{(m+n)}\tag{7}$$

q is the ratio of the pixels which are greater than the threshold to the total pixels, namely:

$$q=\frac{m}{(m+n)}\tag{8}$$

ERROR ANALYSIS OF THE SINGLE THRESHOLD BINARIZATION METHOD

When single threshold method is binaring the image, if the errors appear in the vicinity of the threshold, the results of the big errors of binary and the big deformation of binary image will appear. Such as, the single-value threshold is set to intermediate value which is 0.5, when the high-value pixels point A which is 0.55 is leaded to read 0.6 due to interference and then it is still the high-value 1. And when the interference increases, the pixel value is leaded to be less than 0.5, such as it is 0.4 after interference, it will be translated into low-value 0 and then the binarization result is wrong, large error

Table 1: Error analysis of single threshold binarization method

The real value	The threshold	Small interfering	Binarization	Large disturbance (mm)	Binarization
----------	(mm)	----------			
0.55	0.5	0.6	1	0.4	0
0.45	0.5	0.4	0	0.6	1

occurs. Similarly, when the low-value pixels point B which is 0.45 is leaded to read 0.4 due to interference, then it is still low-value 0 and when the interference increases, the pixel value is leaded to be more than 0.5, such as it is 0.6 after interference, it will be translated into high-value 1, then large error occurs. Single-value threshold method will generate miscarriage of justice, so anti-interference ability of it is poor. It is shown in Table 1. Single threshold method can not suit density of structured light three-dimensional measurement gray-scale coding method is high, so it can be sure to extract the accurate points after binarization and to remove the points which are easy to be wrong near the threshold and to reserve high-quality points. It can increase anti-interference ability and not affect the result. In this study, the threshold-belt binarization method can achieve this effect.

EXPERIMENTAL RESULTS AND ANALYSIS

The single image binarization: As it only includes the gray level information in the projected coding patterns by structured light system and the intensity images. However, each partial pixel gray value in the intensity image inconsistently ranges with upper and lower limits. It has difficulties in accurate binarization of the intensity image and accurate position of edge stripes. For the objects and environment of complex measurement, obviously, reflectivity of measured surface is clearly uneven. Factors ambient light unevenly expose on the measured surface, could lead to inconsistently range with each partial pixel gray value of intensity image. Therefore, this paper introduces the adaptive threshold method in order to reduce the slope of the measured surface reflectivity, color, ambient light and the impact of contrast. Firstly, the image is normalized,and then, it is binarized respectively through the single threshold method and the threshold-belt method. The Fig. 1-3 show all bright and all-dark light as the coding patterns are respectively projected to the pyramid. The single-threshold binarization result and the threshold-belt binarization result are shown in the Fig. 4 and 5.

In the threshold-belt method, the points are shown with gray which are less than the threshold-belt lower in order to display clearly the effect and then the points are expressed which are eliminated with the black. The threshold-belt binarization method can easily remove

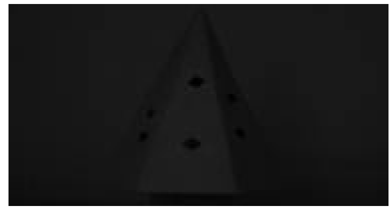

Fig. 1: Wide dark

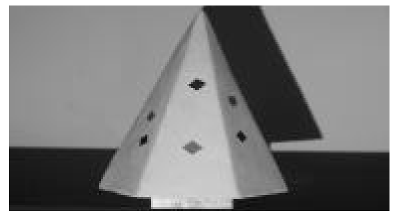

Fig. 2: Wide bright

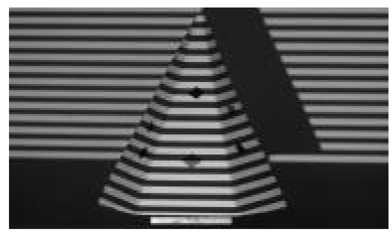

Fig. 3: Projected gray coded image on to the object

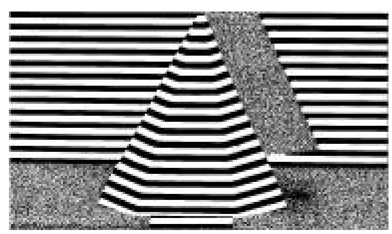

Fig. 4: The single-threshold binarization result

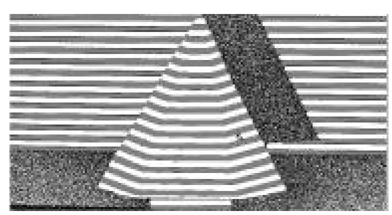

Fig. 5: The threshold-belt binarization result

these points which are easy to generate miscarriage of justice. The edge of a black long-term in the figure is removed and the binarization edge is made more smoothly. The results are shown in the Fig. 6.

Table 2: Experimental results of plane

Methods	The average threshold (x)	The threshold-belt lower ($x-y_1$)	The threshold-belt limit ($x+y_2$)	Wrong data points
The single threshold	0.55289	Nothing	Nothing	276
The threshold-belt	0.55289	0.42139	0.66789	30

Fig. 6: Amplified the single threshold binarization results map

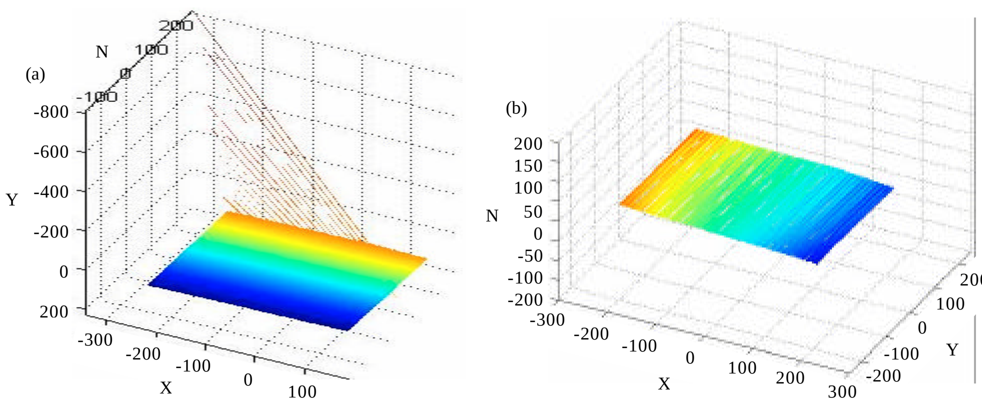

Fig. 7: Comparison of two methods. (a) The single threshold reconstruction and (b) the threshold-belt reconstruction

There is more than a dozen black points in the white stripe from the single threshold binarization which effects picture clearly. They are the errors points which are caused by interference of the points which are near the single threshold. The gray point in the white stripes is only one which is miscarriage of justice in the threshold-belt binarization effect picture. Figure 6 shows that in the circle black points are removed which are easy to generate miscarriage of justice. Obviously, the threshold-belt is a strong anti-interference method.

Through the experiment a group of data, as shown in Table 2. The threshold value in single-threshold method for 0.55289

From Table 2, wrong data points are 30 with the threshold-belt method, wrong data points are 276 with the single method. Obviously, the wrong data points have been greatly reduced through the threshold-belt method.

Experimental reconstruction of plane: The 2 methods are used for structured light 3-dimensional reconstruction of planar and also used for comparation analysis. Clearly, because the read data and the points around the the requirements of structured light three-dimensional measurement. Because the sampling threshold value are wrong, the single threshold value method generates the error points. Reconstructed image is not ideal. Figure 7a and b show the reconstructed image with the threshold-belt binarization method is ideal. But also it losses some information points which are right. Therefore, this method can reduce the reconstruction errors and has a very strong anti-interference capability.

Experimental reconstruction of portrait: Two methods are used to reconstruct the portraits with complex morphology. The results are shown in Fig. 8a-c. The results show that there is a big error in the eye with the single threshold method. Reconstruction is less ideal. However, the threshold-belt method should correct these errors. But it also loss some information points which are useful. Better reconstruction validates that the proposed method is feasible.

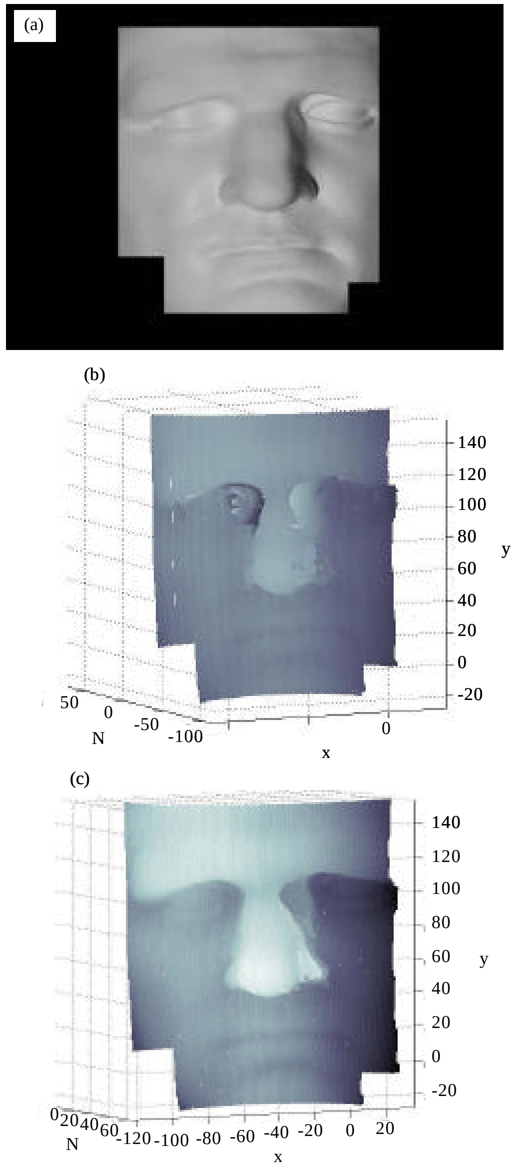

Fig. 8: Comparison of two methods. (a) Original image, (b) reconstruction of single threshold results and (c) reconstruction of threshold belt results

CONCLUSIONS

The study proposes a threshold-belt binarization method in connection with the requests of structured light three-dimensional measurement. Comparing with the traditional single threshold method, under the conditions of not affecting the accuracy of measurement, the threshold-belt method improves anti-interference capability to the noise, reduces measurement errors and improves the accuracy of the measurement. Moreover, this method can also be applied to other digital image processing that the points which can be ignored and are easy to generate miscarriage of justice near the single threshold. There will be a broad application prospect about the threshold-belt binarization method.

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