녹-청 띠 패턴을 이용한 단일이미지로부터의 거리영상획득

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Green-Blue Stripe Pattern for Range Sensing from Single Image

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Abstract

In this paper, we present new methods for rapid high-resolution range sensing using green-blue stripe pattern. We use green and blue for designing high-frequency stripe projection pattern. For accurate and reliable range recovery, we identify the stripe patterns by our color-stripe segmentation and unwrapping method. The experimental result for a naked human face shows the effectiveness of our method.

1. INTRODUCTION

Three-dimensional (3D) geometrical information is what many people on earth love to obtain to know about physical objects and to utilize them for various purposes. For this reason, various 3D data acquisition systems have been proposed. Among them, active sensing systems based on structured lights and cameras are popular since they usually provide satisfactory accuracy and reliability.

The goal of our research is to develop a realistic way of acquiring high-resolution dynamic (moving or deforming) 3D data using a single video frame for real-time capture. 3D reconstruction of dynamic objects is highly challenging in that single projection of structured light pattern should be used for real-time capture.

Many kinds of active sensing systems were designed for high-resolution 3D ranging or for high-speed scanning. The laser stripe-based system, one of the simple active systems, can estimate depths with high resolution using sensor-light calibration and triangulation. However, it requires mechanical motion of the light for object scanning, and this prohibits real-time sensing in most cases. Various methods using structured light with encoded patterns are free from mechanical scanning. The well-established structured-light sensing uses multiple projections of binary-encoded light stripes, but this requirement of multiple projections also makes real-time imaging difficult. The depth resolution is dependent on the number of binary stripe patterns, i.e., the number of projections.

Color can be used to decrease the number of projections, and a color-encoded discrete-stripe structured light method was proposed [1]. On the other hand, phase-shifted three-cosine fringe method [2] and rainbow range finder (RRF) [3] used color continuous patterns. An attempt was made to minimize the number of color patterns, and detailed methods are given [4]. However, in spite of much research on color-encoded structured-light, high-resolution real-time ranging has been hindered by the problems in color-resolution and colorimetric calibration.

In addition, color is difficult to be treated well in structured-light ranging while it is good for increasing data resolution. These difficulties made some previous methods limited to gray or BW (black and white). A method using gray-level ratio for real-time ranging was proposed for obtaining rather crude data [5]. A new BW stripe pattern method for real-time ranging was proposed [6], but it is appropriate only for slowly moving rigid bodies but not for deforming objects.

In this paper, we present our research on rapid high-resolution range imaging based on green-blue stripe pattern. The focus of our research is to investigate accurate and convenient color-stripe identification, and reliable unwrapping.

The rest of this paper is organized as follows. Section 2 describes the design of green-blue stripe pattern for accurate 3D data acquisition, and Section 3 presents methods for accurate color-stripe segmentation. Section 4 presents unwrapping algorithm to remove discontinuity due to the repetitive use of GB stripes. In Section 5, experimental results are presented, and section 6 concludes this paper.

2. GREEN-BLUE STRIPE PATTERN DESIGN

We assigned maximum intensity difference for coding the stripe boundaries in structured-light pattern design to maximize the reliability of stripe segmentation. The two fairly-responded channels of colors, green (0, 255, 0) and blue (0, 0, 255) are used in creating the stripe pattern since the variation range of red is too small as projector-camera response. The pair of GB

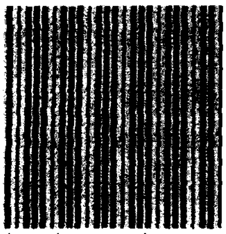

Figure 1. The green-blue stripe pattern image.

stripes is repeated in the pattern image for widening the projection area of the light pattern and increasing the data resolution. Figure 1 shows the green-blue stripe pattern image.

3. COLOR-STRIPE SEGMENTATION

The green-blue stripe colors in the captured scene image need to be reliably recognized (color-stripe segmentation) before the repetition of green-blue color codes is removed (unwrapping, see section 4) for identifying the light planes built by the projection patterns. Our color-stripe segmentation consists of motion-blurring, color balancing, and thresholding.

3.1. Motion Blurring

The green-blue stripe pattern is directional in that all the stripes in the projection image are mutually parallel. Therefore, the captured images of the scene in which the pattern is projected contain the directionality of the stripe patterns. However, the directionality information in captured images is degenerated by the surface reflectance and noise. We use motion-blurring filter (directional Gaussian filter) to reduce the degeneration effect. Consequently, the stripe color recovery is improved in most images, and Figure 3 shows the comparison of the original and motion-blurred cases.

3.2. Color Balancing

The camera we used has white balance function but it doesn뭪 make exact color balance. In addition, this color balance function can뭪solve local color unbalance problem of objects with non-uniform albedo. So we need to add color-balancing step before determination of color-code.

First, we compute the average color vector in a certain size of area:

$$\bar{C}_i(x,y) = \frac{\sum_{x,y} C_i(x,y)}{\sum_{x,y}}, \quad i = 1,2,3. \tag{3.1}$$

where $(C_1, C_2, C_3) \equiv (Red, Green, Blue)$. For color balance, we will use the color vector defined by the equation,

$$c_i = \frac{C_i}{\bar{C}_i}, \quad i = 1,2,3. \tag{3.2}$$

Using c_i is especially good at range sensing of a human face because a human face has non-uniform albedo. In case the surface color varies gently with the spatial position like a human face, the local average values of RGB are recommended for $\bar{C}_i$, and in case the albedo is relatively uniform like a plaster figure, the window size for color balancing can be large or whole image size.

3.3. Global and Local Thresholding

Our green-blue stripe pattern has just two intensity codes (green and blue) and thus thresholding method is quite recommended for green-blue color classification. We use local threshold rather than global threshold because most objects surfaces are not uniform. The difference between the results by global and local thresholdings is showed in Figure 4.

4. UNWRAPPING

The classified color codes need to be unwrapped for removing the color-stripe redundancies. Since we use extremely high frequency patterns, unwrapping is so difficult. We assumed the color codes of most pixels in the captured image are correctly classified. Our unwrapping algorithm works well though some misclassified pixels exist in most images. The proposed unwrapping algorithm is as following (see Figure 5).

------------- **The Unwrapping Algorithm** ----------------------

1. Unroll each row by transition through the row
2. Unroll every row by relation with upper neighbor row
3. Determine Believable Rows
4. Unroll each pixel by relation with upper neighbor pixel in believable row
5. Unroll each row by transition through the row
6. Unroll every row by relation with upper neighbor pixel
7. Unroll each pixel by relation with upper neighbor pixel

The strong points of our unwrapping algorithm are robustness (despite of high frequency stripe pattern, much redundancy, and misclassified pixels), feasibility (pixel-by-pixel processing), low cost (no functional optimization) and flexibility (the number of reference pixels and that of reference rows is changeable).

5. EXPERIMENTAL RESULT

The experimental setup consists of an Infocus DLP 1024 x 768 color projector, a Sony XC-003 640 x 480 3-CCD camera, and Pentium III computers for projecting, capturing and processing.

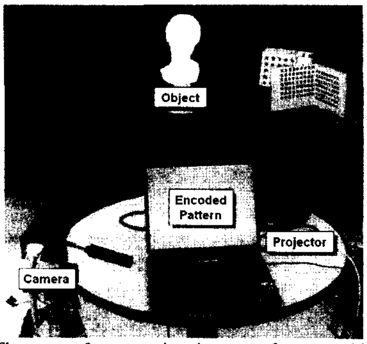

Figure 2. The setup for capturing images of scene which encoded pattern is projected on an object.

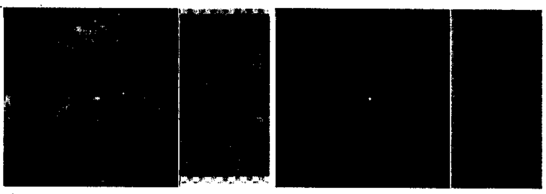

Figure 3. The captured image of a human face and its enlarged small part (left), and the motion-blurred image of the captured image and its enlarged small part (right).

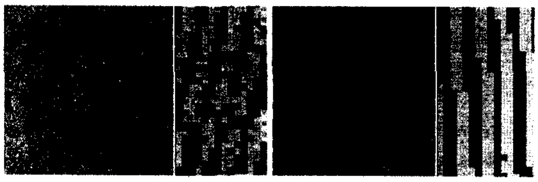

Figure 4. The global-threshold-based color-classified image and its enlarged small part (left), and the local-threshold-based color-classified image and its enlarged small part (right).

Figure 2 shows the setup for experiment. The range result is obtained from single image, and the experimental result (see Figure 3~5) for a naked human face shows the effectiveness of our method.

6. CONCLUSION

We described new methods for rapid high-resolution range sensing using green-blue stripe pattern. We use green and blue for designing high-frequency stripe projection pattern. For accurate and reliable range recovery, we identify the stripe patterns by our color-classification and unwrapping method. We proposed some methodologies of range sensing from single image: (1) Motion-blurring, color-balancing and local thresholding for correct color-stripe segmentation, (2) the reliable unwrapping algorithm for removing high-frequency redundancy. The experimental result from single image for a naked human face showed the effectiveness of our method.

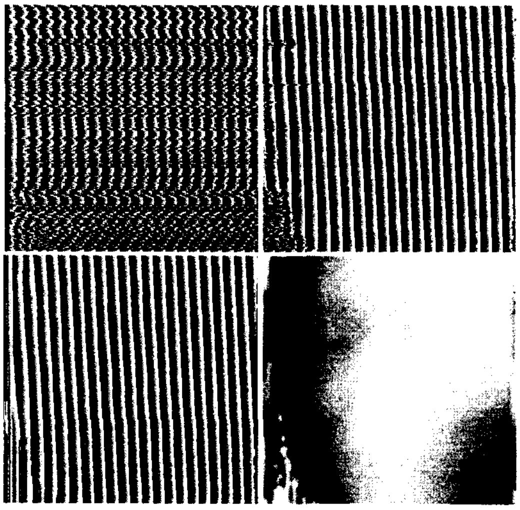

Figure 5. The sequence of the range recovery processing. Unrolling each row by transition through the row (top left). Unrolling every row by relation with upper neighbor row (top right). Correction (bottom left). The range result of a naked human face from single image (bottom right).

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