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3—27 Registration of Range Images Using Texture of High-Resolution Color Images

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Abstract

We propose a novel method of modeling high quality 3D model in shape and appearance by aligning multiple view range images obtained by a range scanner and multiple view color images taken by a high-resolution color camera around the object. In the proposed method, we achieve accurate registration of range images by using texture consistency of the high-resolution color images. Our registration method consists of the following two stages. First stage of registration is done by the ICP algorithm with searching corresponding points using information of the high-resolution color images. ICP algorithm is one of the registration method searching correspondence points of different range images, which greatly depends on initial position, so we improve it by using the high-resolution color images. Second stage of registration is accomplished by using difference value of the high-resolution image and the warping image. Warping image is created by viewing one data set of range image and high-resolution image from the viewpoint of another data set. Coordinate transformation is optimized to reduce differential error of high-resolution image and warping image from another viewpoint. This process drastically reduces misalignment of textures from another viewpoints on the surface of the finally reconstructed model. We present results that demonstrate our approach's ability to create realistic 3D model of the actual object.

1 Introduction

There is an increasing interest in restoring a real object by three-dimensional computer graphics in various fields, such as business, education, and amusement, with development of multimedia in recent years. In order to generate three-dimensional CG model, the shape and texture data of the object are required. If we measure the shape of the object and create model using the information, we can decrease labor and create more realistic 3D model.

The method of shape measuring is most important subject in computer vision, and there are many researches concerning about this problem. Stereo method, in which we take pictures of the object and calculate 3D shape by the position of the object in images, is popular and used in many situations. This method is good at obtaining shape and texture information at same time, the accuracy of the shape is much effected by experimental environment and isn't useful if object is deep concave. On the other hand, by using range scanner, we can get high quality shape information and the method of modeling the object using it is recently well concerned.

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The most range scanner is classified into two types. One measures only the shape of the object, and the other measures the shape and texture data. Since the former cannot acquire the texture data of the object, it needs to acquire texture data using another camera. The latter can use textures without registration but generally the resolution of this texture will be low-resolution. Therefore, even if very highly precise in shape, in respect of a texture, it will become a model with low accuracy. To create high accuracy model related with textures, it is necessary to acquire and use a high-resolution texture with a camera different from range scanner. But in this case, arrangement of a range scanner and a camera must be performed correctly, so manufacture cost goes up. If we can acquire textures with a camera from a position unrelated to a measurement position with a range scanner and align them with range data, restrictions in the measurement position of the data are lost and manufacture cost can be reduced.

In this paper, we propose the technique of creating a highly precise three-dimensional model by registering and integrating multiple view range images measured using range scanner around the object and multiple view high-resolution color images measured independently of them. Simplification of measurement equipment can be attained by losing restrictions in the relation between the measurement position of range images and texture images, and more real three-dimensional model using highly precise shape and a high-resolution texture can be created.

For generating three-dimensional CG model of all the directions, it is necessary to register the shape data from multi directions, integrate them, and detect the uniform surface. Many researches have done about these registration and integration process [8]~[10]. Various researches about the method of choosing a measurement position with range scanner have also been done[1]~[2].

In this research, for making the measurement with range scanner in free position, the registration of the range data acquired from arbitrary positions is performed. We give a rough initial position to each data, and compute the accurate relative position of each range data by two steps of registration methods based on the initial positions. ICP (Iterated Closest Point) algorithm[3]~[6] is a technique used well when the rough initial position of each data is known. In ICP algorithm, the corresponding point determination between range data is the most important, and various researches have been done also about this problem. First step of our technique performs registration by the ICP algorithm which improved corresponding point search using the information on high-resolution textures. Next, as the second step, more precise registration is performed by evaluating the error of the texture mapped by the model surface.

2 Measuring environment

Range data sets and high-resolution color images are measured using a range scanner and a high-resolution digital camera from the surroundings of the object. At this time, a user chooses a measuring positions and the number of times, so that they can acquire sufficient data according to the object. The color image is taken from the direction as close as possible to the measurement position of each range data, and they are made into a pair. A high-resolution color image is mapped to a range data for every pair, and a partial 3D model is created.

3 Calibration of high-resolution images

Since the measuring positions of high-resolution color images are unknown, in order to map a texture to the 3D model, it is necessary to carry out a geometrical calibration. In this method, calibration is performed by giving the corresponding points of the object in the range data and the color image by hand. In our method, we calibrate the high-resolution color images based on Tsai's camera model[7]. By the calibration, we can get accurate geometric information of high-resolution color images. In our method we give matching points of range data and high-resolution images by hand to get 3D-2D information. We calculate the most suitable camera parameters using this correspondence map information.

4 Registration of range images

After the color images are calibrated with the paired range data and partial models are created, we tackle registration between range data sets. By this technique, the texture information on the high-resolution color images that are calibrated previously is used effectively, and more exact registration of range images is performed as compared with conventional registration method that only uses only the information of range data. Two steps of following registration process are performed. At first step, registration is performed by the technique of having improved the conventional ICP algorithm. The information on the high-resolution textures mapped on the surface of a partial model is used, and more precise registration is performed by evaluating the texture error on the surface at second step.

4.1 ICP algorithm[3]

ICP algorithm is an effective registration technique when the rough position between range data sets is known. An outline is shown below.

At all the vertices of the range data, we search for the nearest point by the Euclid distance out of vertices of other range data that exist in a nearby area. If a corresponding point exists in a nearby area, the distance to the point will be computed. It carries out to all the data points of range data, and total of the distance between all the acquired corresponding points is computed. Then the coordinates conversion (translation and rotation parameters) is optimized so that sum of distance may be minimized. If the optimal coordinates conversion is determined, we will search for other corresponding points again, and the same processing will be repeated. If completed by coordinates conversion, the same processing will be repeated to next range data. After repeating to the range data of all viewpoints, the corresponding point search area is narrowed. Then we search for a corresponding point again, and coordinates conversion is optimized. This processing is repeated until the amount of change of coordinates conversion becomes fixed, even if we search for a corresponding point again.

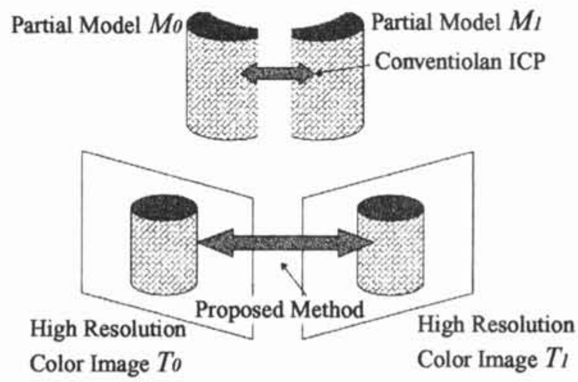


Figure 1: Searching corresponding points using high-resolution images.

This is the fundamental flow of normal ICP algorithm. If we can obtain good initial estimate of the registration of the range data sets, the algorithm converges to an exact registration. However, it is not easy to get the initial estimate such that the satisfactory registration can be achieved. This is because the relation of a corresponding point is mistaken and many incorrect correspondences have arisen. Although the technique of searching for a corresponding point also using the information on the color of the vertices has been studied[6] in order to solve this mistaken correspondence relation, but it does not still provide sufficient accuracy.

4.2 Step1 : Determination corresponding points using high-resolution images

To solve the above problem, we propose a method such that the accuracy of corresponding point can be improved by taking into account the texture information in the high-resolution color images as shown in Fig.1. We explain the case where registration of the range data R_0, R_1 obtained from two viewpoints. We call the high-resolution image T_0 which is pair with R_0 and T_1 with R_1. We beforehand connect the vertices of range data, and make the triangular meshes. The high-resolution image of the pair is mapped in this triangular mesh, and the partial 3D model M_0, M_1 is created. Next, using the position in this time of M_0 and M_1, M_0 is projected to the image plane of T_1 and the warping image W_{0to1} is created. Corresponding points are searched using this warping image as the following flows. When we name the vertex of R_0 p_{R_0}, then p_{R_0} is first projected on W_{0to1} and the texture of the near window area of the projected point of the image is acquired (referred to as W'_{0to1}). On the other hand, for each point of R_1 which exists near p_{R_0}, we project on T_1 and the texture of a nearby window area is acquired similarly (referred to as T'_1). This correlation value cor of W'_{0to1} and T'_1 is computed as equation1.

$$cor = \sum_u \sum_v \{(R_0 - R_1)^2 + (G_0 - G_1)^2 + (B_0 - B_1)^2\} \quad (1)$$

R, G, and B are the values of the color of each pixel, and u and v are the 2D coordinates in an image. If the appropriate correlation value is more than a threshold, it is judged as a corresponding point. If it becomes below the threshold, it will be judged that the corresponding point of p_{R_0} does not exist in R_1. The corresponding point set of R_0 and R_1 is acquired by performing this processing to all the points of R_0. A coordinates conversion parameter is optimized based on the corresponding point sets, and ICP registration is performed. In this way, it becomes possible to transpose the corresponding point search by 3D coordinates of the Euclid space to the corresponding point search between high-resolution textures. Thereby, more accurate corresponding points can be determined.

In the case that warp picture W_{0to1} is created, the surface which cannot be visible from T_1 may appear in W_{0to1}, if all triangular patches of R_0 are simply projected on T_1. In order to prevent this situation, when the angle which the normal of a triangular patch of R_0 and the vector to the camera viewpoint of T_1 make is over certain threshold angle, the triangular patch is excluded to create the warping image.

4.3 Step2 : Registration using texture error

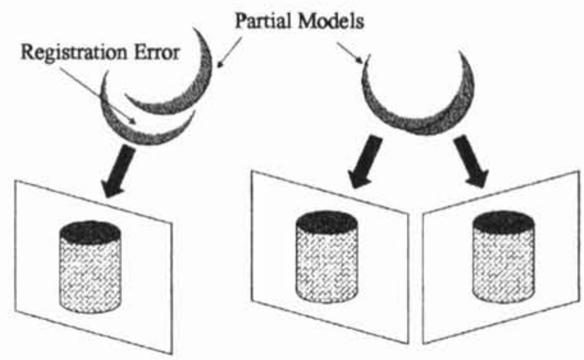
As a following step, registration by using the texture error of the warping images is performed. For registration of two partial models M_0 and M_1 of two viewpoints, warping images W_{0to1} and W_{1to0} are first created in the same way of Step 1. Then the error of the RGB value between texture T_0 of a viewpoint 0 and W_{1to0}(referred to as $Error0$), and the error between T_1 of a viewpoint 1 and W_{0to1} (referred to as $error1$) are computed. This value express registration error and it is the gap which appears when some texture images are mapped to the unified surface. By finding the minimum of this error value, the difference of the texture that appears in the surface of the model can finally be decreased, and then the quality of the model in appearance can be improved.

Although registration of range images should be performed essentially in 3D space, if this is performed by 2D like our method, sometimes obstacle may happen. We explain this case using Fig.2(a). If only one texture error in viewpoint0 is estimated and used, the optimization process may converge by mistake in spite of shifting the surface forward and backward in fact. To avoid this, the texture error in viewpoint1 will also be computed simultaneously, and we add it to evaluation (Fig.2(b)). A situation like Fig.2(a) is avoidable by computing the error value in these two viewpoints whenever coordinates are changed, and minimizing this.

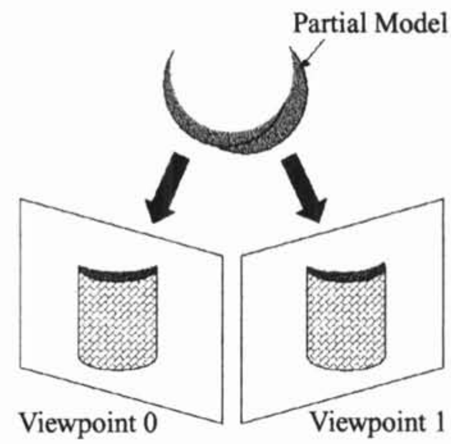
5 Integration of shape and texture data

After registration of all the range data sets is completed, all these data are integrated and converted into a single surface model. Firstly we create a volume data merging all range points in voxel grid space referring to Consensus Surface method [10]. Then marching Cubes method [11] is applied to this volume data, and a single surface model is created.

Next, textures of the high-resolution images being already calibrated are mapped onto a surface model. For every triangular mesh, the visibility from every viewpoint of the high-resolution image is checked according to the normal of the patch and vector to the camera viewpoint. If the triangular patch is captured to two or more high-resolution images, we choose the textures mapping onto the surface concerning about the angle between the normal of the patch and the vector to the camera viewpoint. We select textures



(a)Evaluation at one direction.



(b)Evaluation at two directions.

Figure 2: Registration error at two directions.

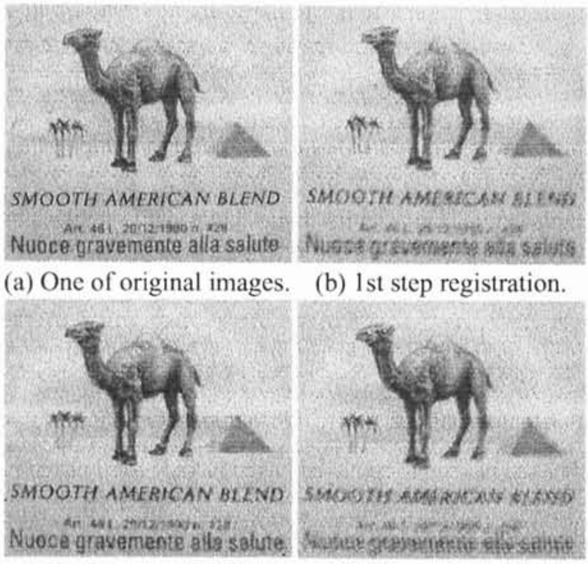
up to two, then they are mixed and mapped to a model. When there is a triangular mesh caught by no images, the texture is interpolated by the texture of the near mesh.

6 Experimental Results

For demonstrating the validity of the proposed technique, we perform experiments with the range scanner, VIVID700 by Minolta Camera Co., Ltd, and the high-resolution color camera, OLYMPUS CAMEDIA C-2100 Ultra Zoom by Olympus.. The size of the range image measured by it is 200×200, and the color image obtained together is 400×400. The size of the high-resolution camera images used as textures is 1600×1200 captured by a digital camera. Since we think that it is easier to observe the registration error by a simple shape object, we used a cigarette box as an experimental object.We measured shapes and textures from 16 viewpoints around the object and tried to reconstruct a model of all the directions. Results are shown below.

The texture model reconstructed by our technique is shown in Fig.3. The original high-resolution image used for texture mapping is shown in Fig.4(a), reconstructed model with the texture by our 1st step registration(improved ICP) is shown in Fig.4(b), and the model by our 2nd step registration is in Fig.4(c). The result which registered by the usual ICP algorithm for comparison is shown in Fig.4(d). As shown in these figures, the registration accuracy can be

Figure 3: Reconstructed model by proposed method.



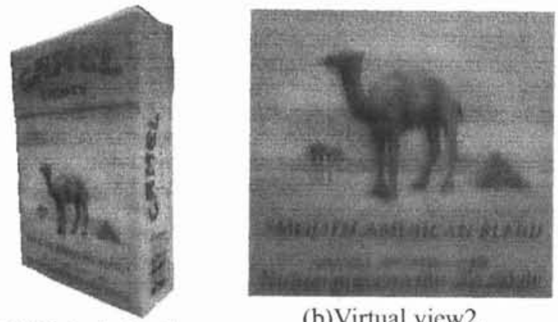
(a) One of original images. (b) 1st step registration.

(c) 2nd step registration. (d) Conventional ICP.

Figure 4: Comparison of registration error.

improved in our method comparing with the conventional ICP algorithm. While the registration in the conventional ICP is performed using only the Euclid distance of the nearest 3D data point, our method can improve the accuracy of registration by corresponding 3D data point using a high-resolution textures. Moreover, by employing the registration using the texture gap evaluation in the 2nd step, our method can finally reconstruct the gap of the texture in the surface of the model.

Instead of the texture mapping with the high-resolution color images, we can also use the color images that are captured by the range scanner. However, the quality of the texture mapped model with the color images of range scanner, shown in Fig.5, is naturally worse than the texture mapped model with the color images of the high-resolution camera, shown in Fig.4(c)). Thus, in order to create a model with high quality texture, it is indispensable to acquire high-resolution color images independently from object shape measurement. In the proposed method, the high-resolution color images contribute to improve not only the texture resolution, but also the accuracy in the range image registration.



(a)Virtual view1. (b)Virtual view2.

Figure 5: Reconstructed model mapped with color images of the range scanner.

7 Conclusion

We proposed the method for building the three-dimensional model of a real object using the range images and high-quality camera images from multiple viewpoints. By using texture information of high-resolution images acquired apart from range images to register range images, we can improve the accuracy of registration, and quality of the texture in the surface of the model.

References

[1] M. Ashida, S. Dan, and T. Kitahashi, "Inferring appropriate camera positions for observing invisible parts," Proc. ACCV '93, pp.692-695, 1993.

[2] Y. Sato and M. Otsuki, "Three-dimensional shape reconstruction by active rangefinder," Proc. CVPR, '93, pp.142-147, 1993.

[3] P. Besl, N. McKay, "A method of registration of 3-D shapes," IEEE Trans. PAMI, vol.12 (2), pp.239-256 (1992).

[4] Y. Chen and G. Medioni, "Object modeling by registration of multiple range images," Image and Vision Computing, vol.10, no.3, pp.145-155, (1992)

[5] Z. Zhang, "Iterative point matching for registration of free-form curves and surfaces," Int. J. Computer Vision, vol.13 (2), pp.119-152, (1994)

[6] Andrew Edie Johnson, Sing Bing Kang, "Registration and integration of textured 3D data," Image and Vision Computing, vol.17, pp.135-147, (1999)

[7] Roger Y. Tsai, "An Efficient and Accurate Camera Calibration Technique for 3D Machine Vision," Proceedings of IEEE Conference on Computer Vision and Pattern Recognition, Miami Beach, FL, pp.364-374, (1986)

[8] Y. Chen and G. Medioni, "Surface description of complex objects from range images," Proc. CVPR, pp.153-158, (1994)

[9] B. Curless and M. Levoy, "A volumetric method for building complex models from range images," Proc. SIGGRAPH, pp.303-312, (1996)

[10] M. D. Wheeler, Y. Sato, K. Ikeuchi, "Consensus surfaces for modeling 3D objects from multiple range images," Proc.Image Understanding Workshop, pp.911-920, (1997)

[11] W. E. Lorensen, H. E. Cline, "Marching cubes: A high resolution 3D surface construction algorithm," Computer Graphics, vol.21, No.4, pp.163-169, July (1987)