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RANGE IMAGE INTEGRATION BASED ON 2D SHAPE MATCHING

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ABSTRACT

This paper describes an integration technique of multiple range images. The range image integration is to estimate transfer parameters between two shape data, and it consists of an initial guess and a correction of the parameters. The initial guess process is based on 2D shape integration under a condition that the rotation axis of an object is parallel to one of sensor coordinate axes. After the initial guess, the transfer parameters are corrected using an iterative method. The correction makes the locational setup condition of the sensor and the object easier. This technique does not utilize geometric features but some sampled points which are free from self-occlusion; there is no constraint on the object shape. Experiments for synthesis 2D shape data and real range images show the possibility of practical use.

INTRODUCTION

Range sensors have been developed recently and shape data of objects are easily acquired. The applications of the 3D shape data are such as measurement of human body, tooth in medical field , profile data for 3D CAM or 3D robot vision in industrial field, and so on. A range image acquired with a range sensor is consists of range data from the sensor to an object. The profile where the object itself occludes from the sensor can not be measured (what we call self-occlusion). One of the technique to make up the occluded profile is the integration of multiple range images which are acquired at different viewpoints of the range sensor. This paper presents a range image integration method.

The range image integration is to estimate transfer parameters between multiple range images. In conventional method[1], a range sensor is fixed and an object is rotated on a turn table to acquire range images. The transfer parameters are computed from the rotation angle of the turn table. Another integration method[2] applies object recognition technique. It extracts geometric features in range images and search the correspondences of the features among each range image. The transfer parameters are computed from the correspondences. This method utilizes geometric features, thus the objects should include those features.

The presented integration method is based on 2D shape integration without any turn tables, and does not utilize geometric features but some sampled points which are free from self-occlusion; there is no constraint on the object shape. We make a condition on the relative location between a range sensor and an object as shown in Fig.1. The sensor is fixed and range images are acquired rotating the object. The sensor coordinates are as follows; x and y axes are sampling direction and z coordinate indicates range data. The condition is that the rotation axis of the object and x axis are parallel. Thanks to this condition, the range image integration can be regarded as the integration of 2D shape data in yz plane. However, it is more practical that the locational condition is less strict. The range image integration consists of an initial guess and a correction process. The initial guess estimates transfer parameters based on the integration of the 2D shape data of which the range images consist, and the parameters are corrected using an iterative method. The correction makes the locational setup condition easier.

2D SHAPE INTEGRATION

The 2D shape integration also consists of the initial guess and the correction of transfer parameters between 2D shape data before and after an object rotation in yz plane. The parameters express the transfer from the 2D shape data after the rotation to one before the rotation, and they are represented by a 3×3 rotation matrix $\boldsymbol{R}_2$ and a 3D translation vector $\boldsymbol{t}_2$, where the components of $\boldsymbol{R}_2$ which express rotations around y and z axes and the x component of $\boldsymbol{t}_2$ are zero.

Initial guess: Fig 2 shows synthetic 2D range data in yz plane. (a) is an object profile; the object turns clockwise and the rotation angle is not so big. (b) and

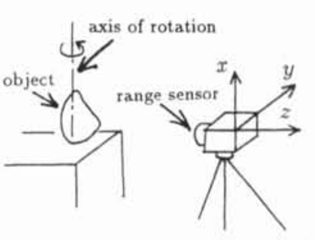


Fig.1 A range sensor and an object

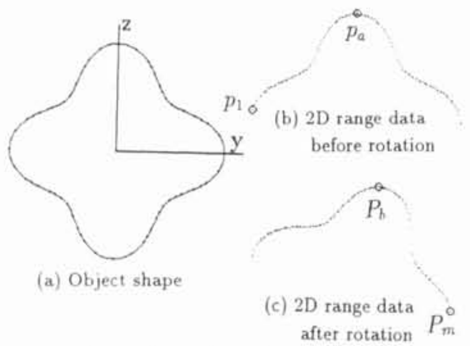


Fig.2 Example of 2D shape data

(c) are range data before and after the rotation. A range sensor would be located at positive z axis. The sampling direction is positive y direction, z coordinate indicates range data. Let $p_1, .., p_n$ and $P_1, .., P_m$ be sampled points before and after the rotation respectively. We assume that the following four points p_1, P_m, p_a, and P_b are free from self-occlusion, that is, they exist on both range data (see Fig.2); the initial guess uses those points.

p_1, P_m **:** The left and right end points of the range data before and after the rotation respectively.

p_a, P_b **:** The closest points to the sensor before and after the rotation.

The initial guess executes the following steps 1)$\sim$3) and Fig.3 illustrates the process using the range data (b) and (c) of Fig.2.

1) Compute $\boldsymbol{R}_2$ and $\boldsymbol{t}_2$ so that P_i is on p_1 and P_m is on a corresponding point in $p_2, .., p_n$.

2) Move $P_1, .., P_m$ by $\boldsymbol{R}_2$ and $\boldsymbol{t}_2$ and compute $l_a + l_b$, where l_a and l_b are lengths from p_a and P_b to their nearest points in the other range data respectively.

3) Repeat **1)** and **2)** for $i = 2, .., m$ and $\boldsymbol{R}_2$ and $\boldsymbol{t}_2$ are chosen when $l_a + l_b$ is minimum.

Correction: In the initial guess, $\boldsymbol{R}_2$ and $\boldsymbol{t}_2$ is computed so that p_1 and P_m will be transferred to their corresponding points in the other range data (let p_k be the corresponding point of P_m). The corresponding points are not always coincident, thus the two range data may not fit well by the computed $\boldsymbol{R}_2$ and $\boldsymbol{t}_2$. The correction process corrects $\boldsymbol{R}_2$ and $\boldsymbol{t}_2$ in the following steps 1)$\sim$3):

1) Move $P_1, .., P_m$ by $\boldsymbol{R}_2$ and $\boldsymbol{t}_2$ and compute corresponding points q_i of p_i from the transffered points $P_1, .., P_m$ for $i = 1, .., k$.

2) Compute $\boldsymbol{R}_2$ and $\boldsymbol{t}_2$ which minimize an evaluation value w_2 define as

$$w_2 = \sum_{1 \le i \le k} \overline{p_i q_i}^2$$

3) Repeat **1)** and **2)** until w_2 converges.

RANGE IMAGE INTEGRATION

The range image integration estimates transfer parameters between two range images before and after an object rotation in 3D space. The parameters express the transfer from the range image after the rotation to

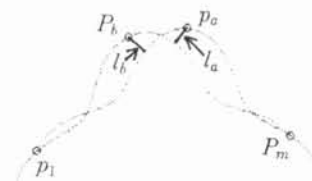


Fig.3 Initial guess of $\boldsymbol{R}_2$ and $\boldsymbol{t}_2$

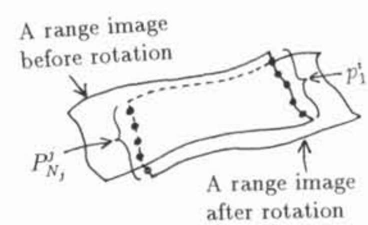


Fig.4 p_1^i and $P_{N_j}^j$

one before the rotation, and they are represented by a 3×3 rotation matrix $\boldsymbol{R}_3$ and a 3D translation vector $\boldsymbol{t}_3$. The range image integration consists of the initial guess and the correction of them. The initial guess estimates $\boldsymbol{R}_3$ and $\boldsymbol{t}_3$ from the integration of the 2D shape data of which the range images consist, and the parameters are corrected using an iterative method.

Data structure of range image: A laser-scan-type range sensor[3] is used for range image acquisition; the sensor is mounted on a linear slider and slided perpendicularly to the laser scan plane. The sensor coordinates are as follows; the laser beam is scanned in the positive y direction, and z coordinate indicates a range value. The linear slider moves the sensor in the positive x direction at the interval of D. Thus, the value of x is kD where k is an integer. When $x = kD$, let p_i^k $(i = 1, .., n_k)$ and $\{p^k\}$ be sampled points and the set of them before the rotation, and P_j^k $(j = 1, .., N_k)$ and $\{P^k\}$ be sampled points and the set of them after the rotation.

Initial guess: The initial guess estimates the transfer parameters $\boldsymbol{R}_3$ and $\boldsymbol{t}_3$ from $\boldsymbol{R}_2$ and $\boldsymbol{t}_2$ computed in the 2D shape integration. $\boldsymbol{R}_3$ and $\boldsymbol{t}_3$ are functions of $\theta_x, \theta_y, \theta_z, t_x, t_y$, and t_z, where θ_x, θ_y, and θ_z are rotation angles around x, y, and z axes respectively, and t_x, t_y, and t_z are translations in x, y, and z direction. $\boldsymbol{R}_2$ is a function of θ_x and $\boldsymbol{t}_2$ is a function of t_y and t_z. In the initial guess, θ_y and θ_z are put zero and θ_x, t_x, t_y and t_z are estimated in the following steps 1)$\sim$3) :

1) Compute $\boldsymbol{R}_2$,$\boldsymbol{t}_2$ and w_2 from the integration of 2D shape data $\{p^n\}$ and $\{P^m\}$.

2) Repeat **1)** for $m = n - 5, .., n + 5$, and when w_2 is minimum let $\theta_x^{(n)}, t_x^{(n)}, t_y^{(n)}$, and $t_z^{(n)}$ be θ_x of $\boldsymbol{R}_2$, $(m - n)D$, and t_y, t_z of $\boldsymbol{t}_2$, respectively.

3) Repeat **2)** for $n = n_s, .., n_e$, and θ_x, t_x, t_y, and t_z of $\boldsymbol{R}_3$ and $\boldsymbol{t}_3$ are given by the averages of $\theta_x^{(n)}$,$t_x^{(n)}$,$t_y^{(n)}$, and $t_z^{(n)}$ respectively.

To use all of the 2D shape data of the range images is time consuming. We specify the integrated area by n_s and n_e; uneven profile is desirable.

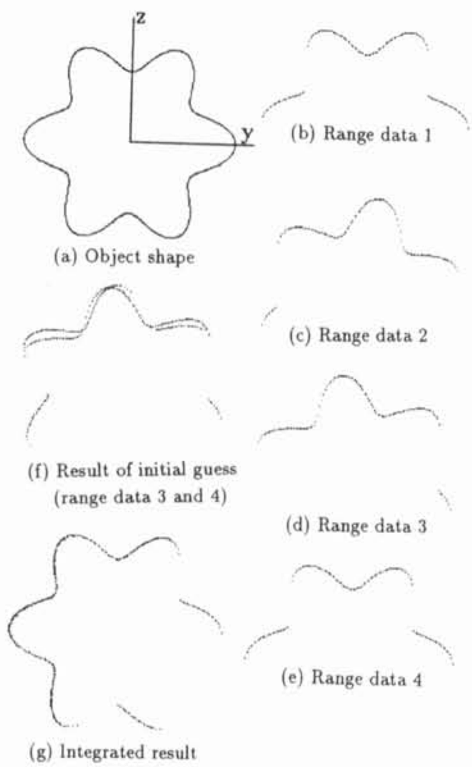


Fig.5 Experimental result (1)

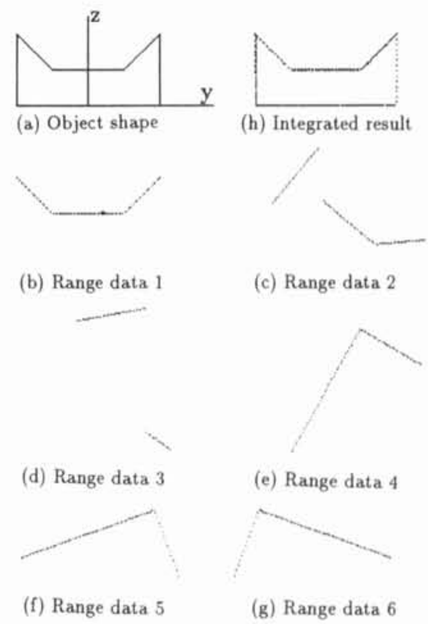


Fig.6 Experimental result (2)

Table 1 Computation result of $\boldsymbol{R}_2$ and $\boldsymbol{t}_2$

Range data	θ_x(deg.)	t_y	t_z
1 & 2	39.960	−0.06499	−0.06584
2 & 3	39.985	0.04603	0.03141
3 & 4	40.027	0.24556	0.08844

Correction: Two range images approach each other by R3 and $\boldsymbol{t}_3$ estimated in the initial guess, but they don't fit well due to the deviation between x axis of the sensor coordinates and the rotation axis of the object. The correction corrects $\boldsymbol{R}_3$ and $\boldsymbol{t}_3$ using the end points p_1^i and $P_{N_j}^j$ of the range images as shown in Fig.4. They are equivalent to p_1, P_m used in the 2D shape integration, and supposed to be free from self-occlusion. The correction process is the following steps 1)∼3) :

1) Move the range image after the rotation by $\boldsymbol{R}_3$ and $\boldsymbol{t}_3$ and find the corresponding points q^i and Q^j of p_1^i and $P_{N_j}^j$ from the other range data, respectively, for $i = i_1, i_2, .., j = j_1, j_2, ..$.

2) Computes $\boldsymbol{R}_3$ and $\boldsymbol{t}_3$ which minimise an evaluation value w_3 define as

$$w_3 = \sum_{i=i_1,i_2,..} \overline{p_1^i q^i}^2 + \sum_{j=j_1,j_2,..} \overline{P_{N_j}^j Q^j}^2$$

3) Repeat **1)** and **2)** until w_3 converges.

To use all of the end points is time consuming; we specify the end points by $i_1, i_2, ..$ and $j_1, j_2, ..$.

EXPERIMENT

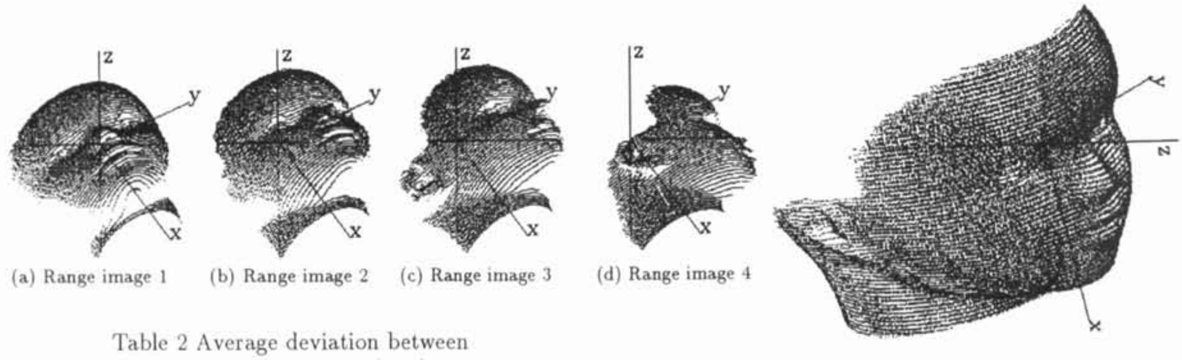
This section demonstrates experimental results of the integration of 2D shape data and range images.

2D shape integration: Fig.5 and 6 show the integrations of synthesis 2D shape data. In Fig.5, the object(a) is a curved shape. (b)∼(e) are its range data which are computed rotating the object every 40 degrees clockwise around the origin. The sampling interval of the range data is 1 in y direction. The range data (b) and (c), (c) and (d) , and (d) and (e) are integrated respectively. (f) shows the result of the initial guess in the integration of (d) and (e). They don't fit well. (g) shows the final result, in which the range data (c)∼(e) are transferred by the computed $\boldsymbol{R}_2$ and $\boldsymbol{t}_2$ to fit the range data (b). The final result is very similar to the object profile (a). Table 1 shows the computation results of θ_x, t_y and t_z. The true value of θ_x is 40.0 degrees, and those of t_y and t_z are zero.

In Fig.6, the object(a) is polygonal. (b)∼(g) are range data, (h) shows the integrated result. It is also similar to the object profile (a).

Range image integration: Fig.7 and 8 show the integrations of real range images, which are acquired as mentioned before; the sampling interval D is 2mm.

In Fig.7, the object is a doll face. The range images (a)∼(d) are acquired rotating the doll. The rotation axis is not fixed nor parallel exactly to x axis of the range image. The range images (a) and (b) , (b) and (c), and (c) and (d) are integrated respectively. In the initial guess, the 2D shape data of the nose area are utilized by specifying n_s and n_e. In the correction, three end points of each range image are selected. (e) shows the integrated image in which the range images (b)∼(d) are transferred by the computed $\boldsymbol{R}_3$ and $\boldsymbol{t}_3$ to fit the range image (a). The rage images are integrated smoothly.



(a) Range image 1 (b) Range image 2 (c) Range image 3 (d) Range image 4

(e) Integrated result

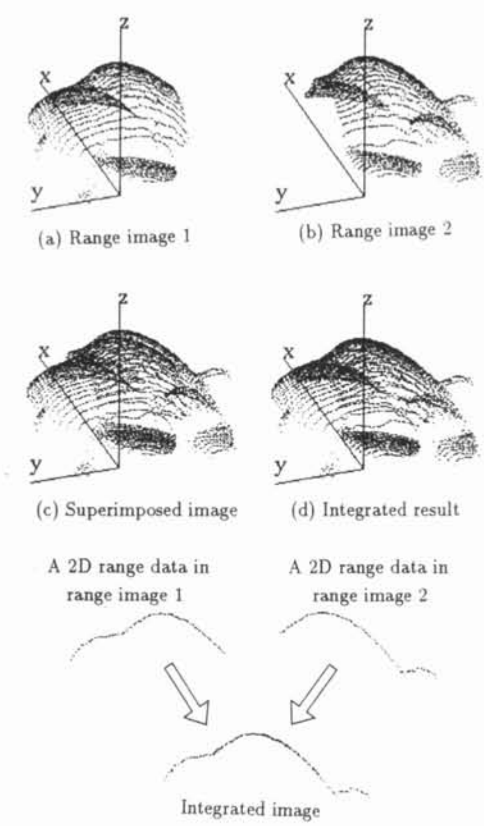
Fig.7 Experimental result (3)

Table 2 Average deviation between corresponding points (mm)

iteration time	range image 1 & 2	range image 2 & 3	range image 3 & 4
0	1.841048	2.108812	3.763281
1	1.415769	1.718943	1.739073
2	1.026666	1.575727	1.430396
3	0.849592	1.477355	1.419609
4	0.838444	1.473005	1.419609
5	0.838444	1.473005	1.419610

Table 2 shows an average length from the selected end points to the other range image. After 3 or 4 iterations, the values are converging and they are smaller than the sampling interval D (2mm).

Fig.8 demonstrates another experiment. The object is a toy plane. The range images (a) and (b) are the head and tail of it. Though the range images are not acquired rotating the object, this technique is applicable by using the range image (a) as one before the rotation, and the range image (b) as one after the rotation. (c) is the superimposed image, and (d) shows the integrated image. (e) illustrates a process of the 2D shape integration in the initial guess.



(a) Range image 1 (b) Range image 2

(c) Superimposed image (d) Integrated result

(e) Example of 2D shape integration

Fig.8 Experimental result (4)

SUMMARY

This paper described the range image integration. It consists of the initial guess and the correction of the transfer parameters between two shape data. The initial guess process is based on 2D shape integration under the locational condition between the range sensor and the object. After the initial guess, the transfer parameters are corrected using an iterative method. The correction makes the locational condition easier. The experiments show the possibility of practical use. The motivation of this research is a model construction for our 3D object detection system[4]. The data transformation from the integrated range image to the model data is the feature work.

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