

RECONSTRUCTION OF REGISTERED RANGE DATA USING GEODESIC DOME TYPE DATA STRUCTURE

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ABSTRACT:

Previously, we presented a method for automatic registration of real time multi-view range image obtained under the condition free from any artificial restriction. This paper describes a method for real time and automatic reconstruction of thus registered multi-view range images by means of geodesic dome type data structure. It ensures isotropy of sampling region and so may faithfully represent 3-D shape data. It, however, takes a lot of time to store 3-D shape data into it because of non-systematic data structure and difficulty in defining and searching cells neighbouring to each cell in it. On the other hand, data structure based on spherical coordinate system is simple and enables us to store 3-D shape data in real time because of 2-D array type structure. But it is not isotropic and does not ensure to reconstruct 3-D shape data faithfully. So we try to overcome above-mentioned disadvantages of both data structure by storing 3-D shape data into geodesic dome type data structure through 2-D array type data structure based on spherical coordinate system. The validity of the proposed method was proved by experiments on processing time for reconstruction and accuracy of reconstructed data.

1. INTRODUCTION

Recently, it is highly expected to reconstruct 3-D shape model of real object in the fields of robotic vision, object recognition and so on. In this regards, some kinds of range finders have been gradually allowing us to input range data to computers automatically. But their data acquisition area in one measurement is limited to visible field from them. So, registration of multi-view range data is required to reconstruct whole or desired 3-D shape model of real object and so many kinds of techniques for registration such as those based on ICP algorithm have been proposed. Results obtained by means of them, however, are only a set of 3-D coordinates in which mutual relation among data points included is not clear. Moreover, generally, many data are included in one sampling region, resulting from large amount of data. Thus, reconstruction of registered multi-view range data into one data structure becomes essentially important to apply them to above-mentioned fields.

Since aim of this paper is to reconstruct 3-D shape model from registered range data, we focus into surface type data structures, excluding boxel type ones. Conventionally, 2-D array type data structures based on cylindrical or spherical coordinate system have been often used to represent 3-D shape model. Their sampling region, however, is not isotropic and data along vertical axes are lost or suffer from large error. On the other hand, geodesic dome type data structure has isotropic sampling region and so it may faithfully represent 3-D shape data. Moreover, it has some advantages in that it is closely related to extended gaussian image, which is a powerful tool for 3-D object recognition, robotic vision and so on. It, however, takes a lot of time to store 3-D shape data into it because of non-systematic data structure and difficulty in defining and searching cells neighbouring to each cell in it. On the other hand, data structure based on spherical coordinate system is simple and enables us to store 3-D shape data in real time because of 2-D array type data structure. So we try to combine

advantages of both data structures to overcome above-mentioned disadvantages of geodesic dome type data structure. In concrete, we try to store 3-D shape data into geodesic dome type data structure through 2-D array type data structure based on spherical coordinate system.

2. ACQUISITION OF MULTI-VIEW RANGE IMAGES AND REGISTRATION OF THEM

Multi-view range images are acquired by real time 3-D measurement system developed in our laboratory. Schematic diagram of it is illustrated in Figure 1. It is based on slit-ray projection method. Its key component is the non-scan-type image plane developed in our laboratory. Owing to it, our system enables us to continuously acquire 3-D shape data of the target in spatial resolution of 128x128 at video rate with an error within +/- 0.3%. Each range data obtained by our system is stored into 2-D array of 128x128 and each element of it stores 3-D range, brightness, and color data as shown in Figure 2.

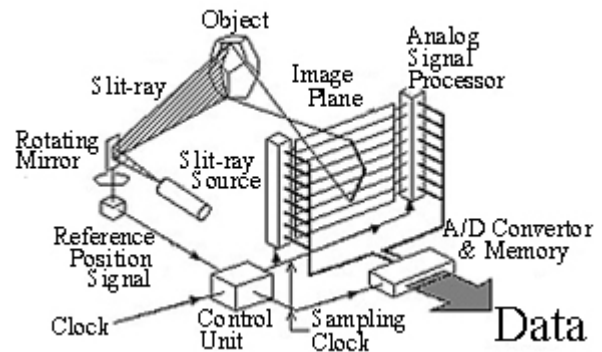


Figure 1. Schematic diagram of real-time 3-D measurement system

Registration of thus acquired multi-view range images is automatically performed by affine transformation technique in which extended gaussian images are used to search four pairs of corresponding points between two images. Details of our system and method for registration are available somewhere (K. Araki et al, 1991; K. Araki et al, 1992; Araki et al, 1995; M. Hirose et al, 2000).

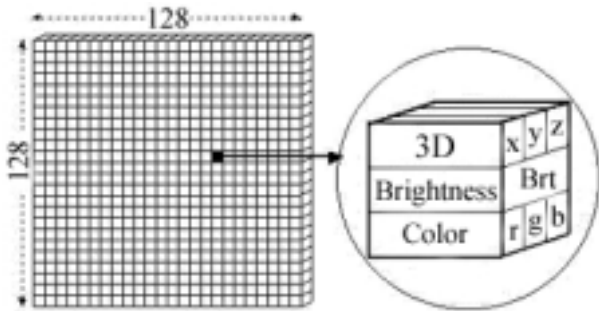


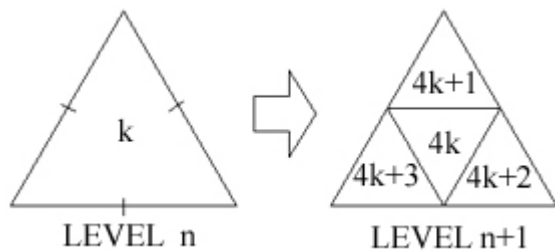
Figure 2. Two-dimensional array type data structure and data stored in each element of it.

3. GEODESIC DOME TYPE DATA STRUCTURE

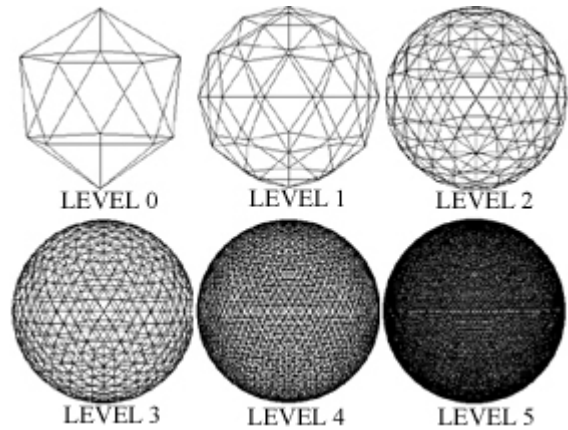
Geodesic dome type data structure composed from a regular icosahedron is adopted as fundamental one. Higher-level geodesic dome type data structures are composed from semi regular polyhedrons formed by dividing each regular triangle into four regular triangles in order as illustrated in Figures 3. Thus they ensure isotropic division of 3-D space for sampling. Hereafter, they are called level 0, level 1, level 2, level 3, level 4, level 5 geodesic dome type data structure, starting from the fundamental one composed from a icosahedron and each triangle facet is called cell. Figures 4 show geodesic domes from level 0 to level 5. Total cell numbers of level n geodesic dome type data structure becomes 20×4^n

Allocation of cell number for data processing is defined as shown in Figures 3. Center cell formed by dividing original cell into four sub cells is allocated the number of $4k$, where k is that of the original cell.

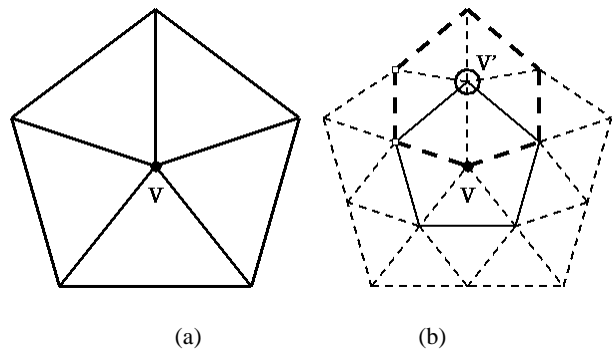
For fast and effective data processing, it is desirable that cells neighbouring to any chosen cell are easily searched. In this paper, they are defined as those which common vertex of that cell in process (see Figures 5). Therefore, since each cell has three vertexes, it has three sets of neighbouring cells. Thus, if once the geodesic dome type data structure is determined, sets of cells neighbouring to each cell are defined and so cell number of them can be stored as data of each cell in advance.



Figures 3. Division of cell and allocation of cell number



Figures 4. Geodesic domes



V, Vertex of regular icosahedron
V', Generated vertex by division

Figures 5. Neighbouring cells at cell vertex

4. STORING OF RANGE DATA INTO GEODESIC DOME TYPE DATA STRUCTURE

Range data should be stored into the cell, vector product of whose unit normal vector with coordinate vector of the range data becomes the smallest. If many data are stored into one cell, averaged data of them is stored into it. But, data-storing time becomes longer with level of geodesic dome type data structure. Level n one takes above mentioned process of as much times as 20×4^n .

To overcome this problem, the hierarchical structure of cell number is utilized as shown in Figure 6. That is, optimal cell is firstly searched among cells in level 0 geodesic dome type data structure and next among sub cells in higher level one related to that cell. This method decreases searching times to $20 + 4n$ in level n geodesic dome type data structure and remarkably speed up data storing process. It, however, does not ensure real time processing especially in higher-level geodesic dome type data structure.

Generally speaking, although geodesic dome type data structure may faithfully represent 3-D shape data, it may take a lot of time to store them into it because of its non-systematic data structure. On the other hand, data structure based on spherical coordinate system is simple and enables us to store 3-D shape data in real time but it is not isotropic and does not ensure to reconstruct 3-D shape data faithfully.

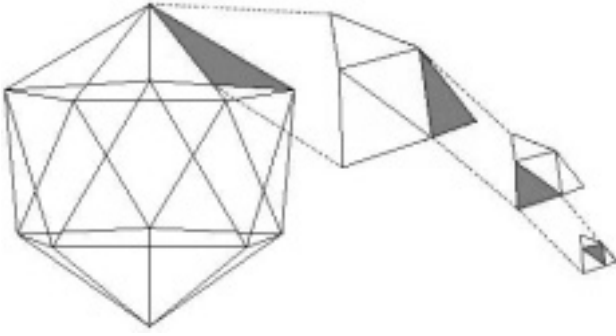


Figure 6. Searching of optimal cell using hierarchical structure of cell number

So, in this paper, advantages of both data structures are combined to overcome above-mentioned disadvantages of them. In concrete, 3-D shape data is stored into geodesic dome type data structure through 2-D array type data structure based on spherical coordinate system, following next four steps:

Step1: Sampling regions in 3-D space are constructed by equally dividing a declination and an azimuth of spherical coordinate system (Figures 7(a)), which result in 2-D array type data structure (Figures 7(b)).

Step2: All cells of geodesic dome type data structure that common the spatial area with each cell of above-mentioned 2-D array type data structure are considered as candidate cells to store range data and named "candidate cells". Cell numbers and unit normal vectors of them are stored into the corresponding cell of 2-D array type data structure in advance.

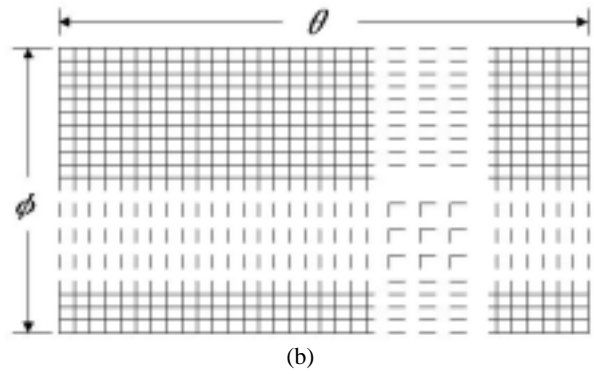
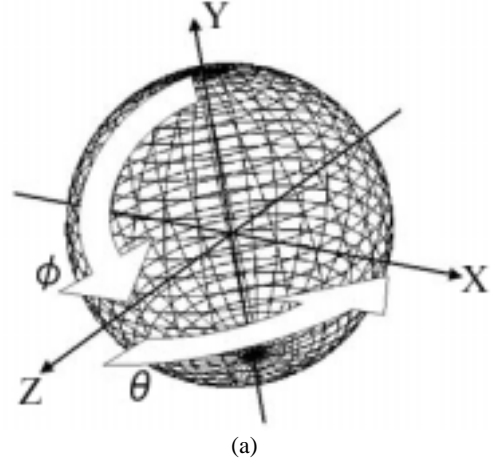
Step3: Equation 1 transforms range data expressed in orthogonal coordinate system to that of spherical coordinate system and then, the corresponding cell of 2-D array type data structure is determined to limit cells of geodesic dome type data structure to be searched to its candidate cell.

$$\theta = \tan^{-1} \frac{x}{z} \quad (1)$$

$$\phi = \tan^{-1} \frac{\sqrt{x^2 + z^2}}{y}$$

Step4: Range data is stored into one of candidate cells determined in step 3 which satisfy the condition that unit normal vector of it is the nearest to coordinate vector of the range data i.e., vector product of them becomes the smallest.

The key point of this procedure is to rapidly limit cells of geodesic dome type data structure to be searched to candidate cells related to the cell of 2-D array type data structure through Equation 1. Further, to make data storing process more rapid, the candidate cell of geodesic dome type data structure which satisfy the condition that unit normal vector of it has the smallest vector product with unit normal vector of the cell of 2-D array type data structure is considered as an approximate cell and its cell number is stored into the corresponding cell of 2-D array type data structure in advance.



Figures 7. (a) Sampling region and (b) array type data structure based on spherical coordinate system

5. CONSTRUCTION OF TRIANGLE PATCH

To reconstruct 3-D surface model, triangle patches are constructed as follows. Coordinate vectors of cell in process and its neighbouring cells around a vertex of it are averaged and triangle patches are constructed among thus averaged coordinate vector and those of cell in process and its neighbouring cells as illustrated in Figures 8.

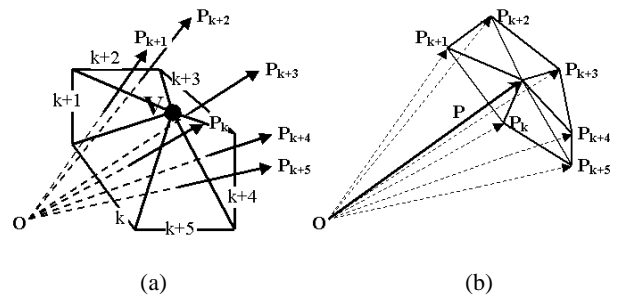


Figure 8. Construction of triangle patch

For example, let k be cell number of cell in process; $k+1, k+2, k+3, k+4, k+5$ those of neighbouring cells around the vertex V of cell k ; $P_k, P_{k+1}, P_{k+2}, P_{k+3}, P_{k+4}, P_{k+5}$ coordinate vectors of cell $k, k+1, k+2, k+3, k+4, k+5$; P averaged coordinate vector of $P_k, P_{k+1}, P_{k+2}, P_{k+3}, P_{k+4}, P_{k+5}$. Then six triangle patches are constructed among $P, P_k, P_{k+1}, P_{k+2}, P_{k+3}, P_{k+4}, P_{k+5}$ locating P at center as illustrated in Figures 8(b).

6. EXPERIMENTS

Computational experiments are performed on processing time for reconstruction of range data and accuracy of reconstructed range data about next four cases.

Case1: Storing directly into 2-D array type data structure based on spherical coordinate system.

Case2: Storing into geodesic dome type data structure using hierarchical structure of it shown in Figure 6.

Case3: Storing into geodesic dome type data structure by limiting cells to be searched to candidate cells through 2-D array type data structure based on spherical coordinate system.

Case4: Storing into approximate cell of geodesic dome type data structure through 2-D array type data structure.

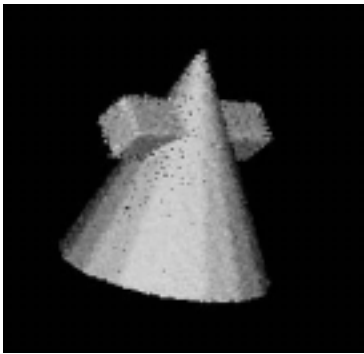
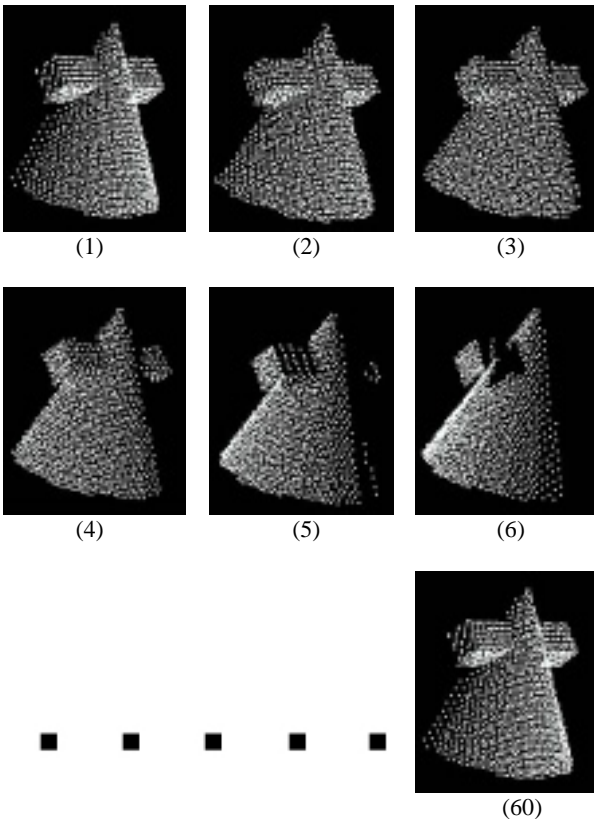


Figure 9. Target object for experiment



Figures 10. Multi-view range images

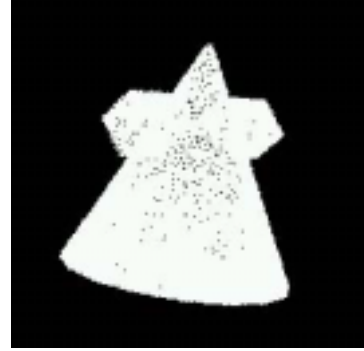


Figure 11. Registration range datum

Direct storing without usage of hierarchy structure of geodesic dome type data structure takes as much time as more than several ours or so, that case is omitted from experiments.

Target object is shown in Figure 9, which is a cone penetrated by a rectangular parallelepiped. 60 range images are obtained from viewpoints varied horizontally and vertically around target, several examples of which are shown in Figures 10.

Figure 11 shows registered result of them by the previously reported method (M. Hirose et al, 2000) and it used in this experiments. Total number of this registered range data is 85,656.

Experimental systems are composed from PC with Pentium III 1GHz, RAM: 512MB, OS: Windows2000 and Visual C++ 6.0.

6.1 Processing time for reconstruction

Experimental results on processing time for reconstruction are shown against level of geodesic dome type data structure (hereafter called "divisional level") in Figure 12. Processing time for reconstruction shown is averaged time per scene. In Case 2, it becomes longer proportionally with divisional level and takes as much time as 0.17 sec/scene in divisional level 5. Generally speaking, real time processing is not ensured in Case 2. On the other hand, in Case 1 and 4, it is nearly constant with divisional level and about 0.02 sec/scene even in divisional level 5. That in Case 3 is also nearly constant with divisional level and about 0.03 sec/scene in divisional level 5. Thus, Case 1, 3 and 4 ensure real time reconstruction.

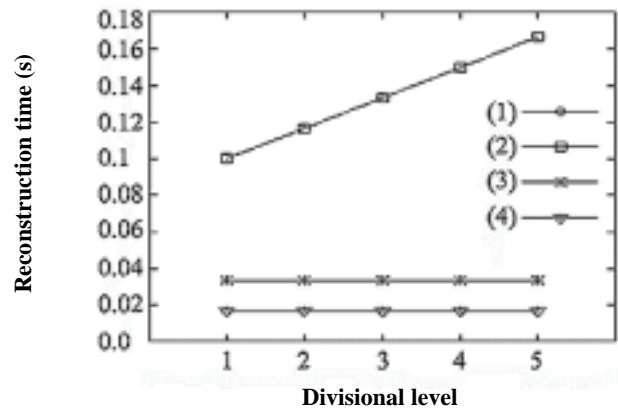


Figure 12. Processing time for reconstruction in each method

6.2 Accuracy of reconstruction

Accuracy of reconstruction is quantitatively defined as total sum of absolute value of difference between reconstructed range data and original one as expressed in Equation 2.

$$\delta = \sum |x_p - x_q| \quad (2)$$

Figure 13 shows accuracy per one reconstructed range data against divisional level. Accuracy based on geodesic dome type data structure, i.e., that in Case 2, Case 3 or Case 4, is higher than that based on 2-D array type data structure (Case 1) at all divisional level. Although accuracy in Case 3 is higher than that in Case 4, reconstructed range data in both Cases is seemed sufficiently accurate at level 5 or so.

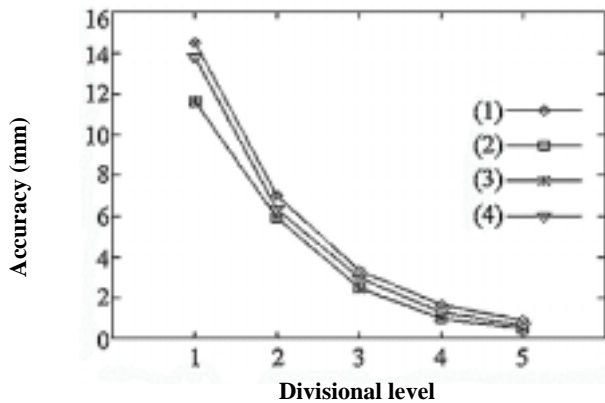
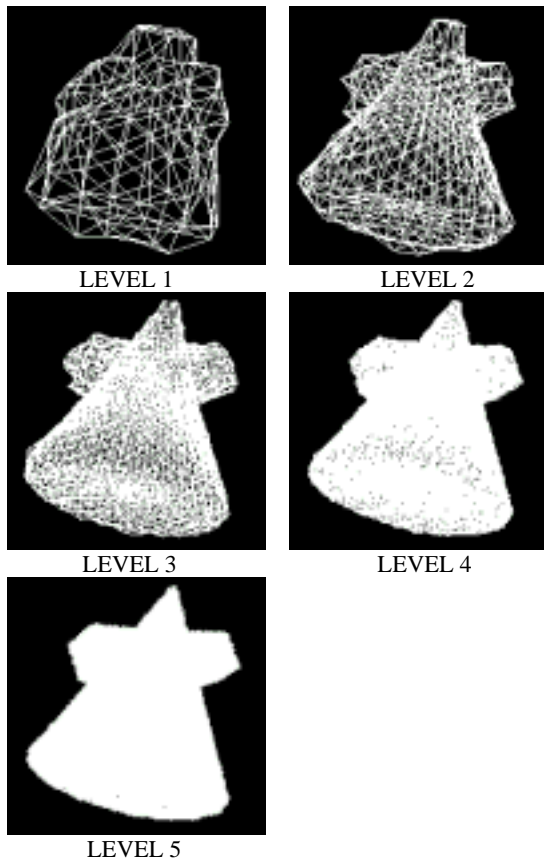
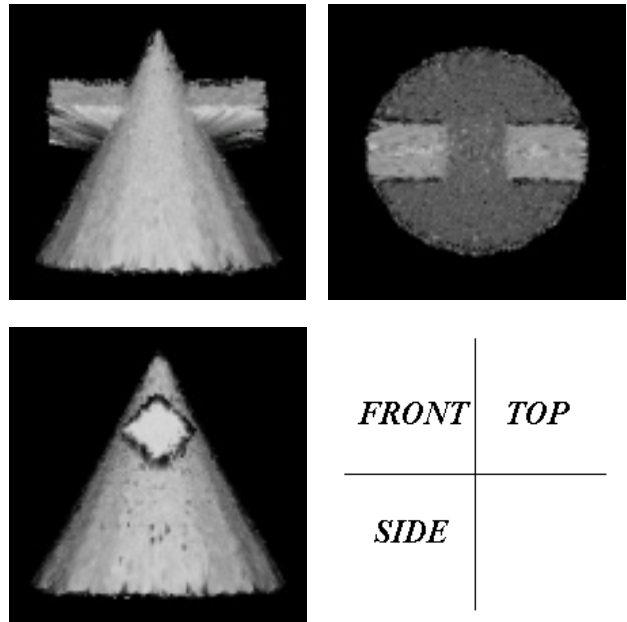


Figure 13. Accuracy of reconstruction in each method



Figures 14. Experimental result in each division level

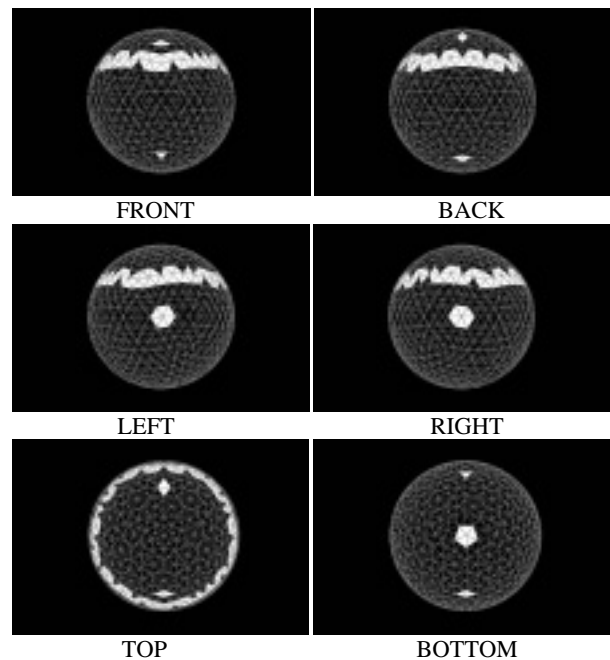


Figures 15. Experimental result (level 5)

6.3 Representation of reconstructed range data

Wire-frame like representation of reconstructed range data is shown for each level in Figures 14. It is clear that divisional level higher than level 3 is required to reconstruct range data faithfully. In this regards, Figures 15 demonstrate front, side and top views of reconstructed result at divisional level 5. Finally, extended gaussian image of reconstructed range data at divisional level 3 is shown figures 16.

Finally, total number of reconstructed data is 16,445, which is about 1/5 of original registered data ; 85,656. This fact will serve remarkably to data processing in many applications.



Figures 16. Extended gaussian image

7. CONCLUSIONS

This paper proposed a method for reconstruction of registered range data using geodesic dome type data structure. In the method, cell number and a set of neighbouring cells are properly defined and range data is stored into geodesic dome type data structure through 2-D array type data structure based on spherical coordinate system. As the result, it ensures isotropy of sampling region, represents 3-D shape data faithfully and realizes highly accurate reconstruction in real time. Additionally, our method reduces total number of data to about 1/5 of that of original data.

Since geodesic dome type data structure is also utilized in extended gaussian image, which is a powerful tool for object recognition, robotic vision and so on, our method will serve to data processing in many application of those field. .

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