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Generation of 3-D Models Based on Image Fusion of Range Data

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ABSTRACT

This paper presents a method for measuring the entire three dimensional (3D) shape of object, which is applicable for 3D digitizing into a solid modeling CAD. The method measures the complete surface model of the object automatically and in the non-contact way. The method employs two range finders and a turn-table cooperatively: a fixed range finder using a turn table measures rough surface data of the objects, and a hand-eye range finder finds the deficit of surface data due to self occlusion and makes it up by changing to it. The 3D shape is represented in an extended octree in computer. The octree representation allows us to keep more precise shape in smaller memory storage. An experimental system based on the method shows us the good flexibility and performance of the method for 3D digitizing.

I Introduction

CAD systems are indispensable for design of industrial parts. CAD systems which can model 3D surfaces have been popularized. Conventional solid modeling CAD systems construct 3D models manually: an operator inputs and combines primitive surfaces, i.e., planes, cylinders, or spheres, by using keyboard, data tablet or mouse. If an object contains free-form surfaces such as hand-made clay models, it is very difficult to input the surface data in this manner. A non-contact range finder which can measure free-form surfaces is useful for modeling the surfaces.

We have developed a light striping range finder utilizing a liquid crystal shutter [Sato 1987]. We apply it for solid modeling to input arbitrary shaped objects into a CAD. The range finder, which employs a TV camera and a slit light projector, has a disadvantage that surfaces must be visible from both the camera and the projector. A 3D model of the object in the CAD system should consist of the entire surface data of an object. Unfortunately, range images acquired by the range finder are "$2 \cdot {}^1/_2$ dimensional". In our approach, we use a turntable and a fixed range finder to acquire image data and generate 3D surface models. While the turntable allows us to acquire data from the "hidden" side of the object by rotating the object, the range finder can measure the entire surface [Schmitt 1985, Nishino 1989]. Even though we use a fixed range finder and a turntable, it is impossible to acquire entire surface data of a complex object because of self-occlusion.

We propose a hand-eye method which can acquire entire surface data utilizing a fixed range finder, a turntable and a hand-eye range finder.

For integrating of two or more range images in order to construct the entire model, it is important to select appropriate data representation. Cylindrical coordinate representation has been considered, however, it can only represent an object based on single-valued functions of along the height. We selected octree representation. The octree is suitable for this kind of application since it simplifies fusion of multiple range images. In addition, because of its hierarchical structure, it can be efficiently stored in computer memory.

II Self-Occlusion

The active stereographic range finder cannot measure only surface regions which are not visible from either the camera or the projector. In this paper, we classify the unmeasurable regions into 3 types: (see Fig. 1)

Type 1: regions visible from the camera but invisible from the projector

Type 2: regions visible from the projector, but invisible from the camera

Type 3: regions invisible from both the camera and the projector

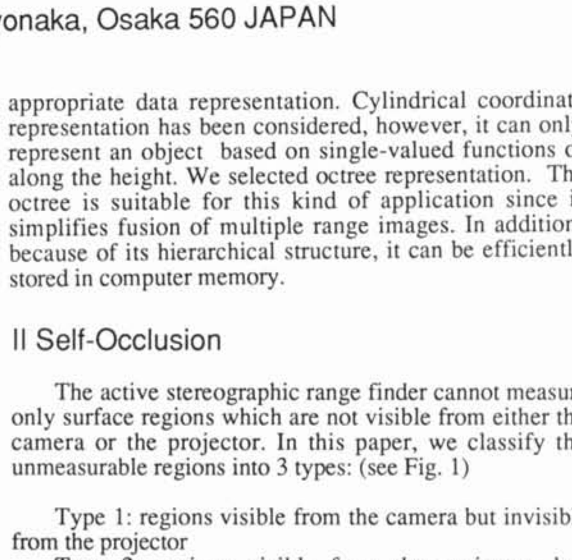


Fig. 1 Unmeasurable Regions

When integrating range images to build the entire surface of an object, it is necessary to identify a type of unmeasurable regions in the images.

III Elimination of Type 1 Unmeasurable Regions

In our system, using the fixed range finder and the turntable, type 2 and 3 unmeasurable regions can be eliminated or transformed to type 1. By only using the hand-eye range finder, Type 1 unmeasurable can be eliminated.

Type 1 unmeasurable regions are detected from the octree made from range images obtained by a fixed range finder. Then, position of the unmeasurable regions can be determined by circumference pixels in the image surrounding the regions. New sight which remeasures are also decided to use the circumference data. The hand-eye range finder is relocated to a new pose. This pose can allow the range finder to eliminate the type 1 unmeasurable region.

IV Integrating Range Images into an Octree

An octree is a hierarchical data structure used for volumetric representation for 3D objects (see Fig. 2) [Chien 1989]. A general octree is generated by dividing a root cube into 8 pieces, and by recursively sub-dividing each of the pieces into 8 sub-pieces until all of the cubes are either inside of the object, outside of the object, or are equal to unit volume (smallest cube in the hierarchy). In this paper, we refer to the smallest node in the hierarchy as "voxel". Each cube is labeled as "object","space", or "surface". Cubes labeled "object" are inside of the object; Ones labeled "space" are outside of the object. Cubes labeled "surface" mean that surfaces of the object intersect at the cubes.

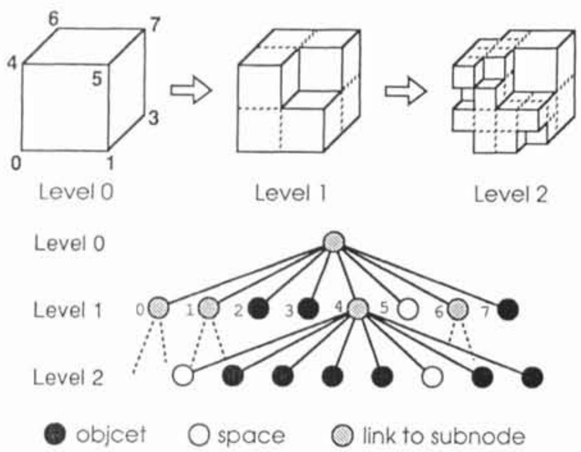


Fig. 2 Octree Representation

Integrating range images into an octree seems like a "carving" process. Voxels are removed from a root cube according to the data depth information of the range image. This process iterated until all unmeasurable region have been eliminated. Initially, we assume that the root cube includes the object to be modeled. All nodes in the octree are labeled as "object". The goal of the measurement process is to label all nodes as either "object","space", or "surface". The following procedure is executed to generate the octree from the range images: (see Fig. 3).

1. Label all nodes in the root cube "object" (Fig. 3 (a)).
2. Acquire a range image from the fixed range finder.
3. Label all nodes on the surface of the object as "surface" (Fig. 3 (b)).
4. Label all nodes between the camera and "surface" as "space" (Fig. 3 (c)).
5. Turn the turntable certain degrees.
6. Until the turntable turns back, iterate 2-5.
7. Determine where unmeasured regions are.
8. If there are no additional unmeasured regions, then quit.
9. Position the hand-eye range finder to eliminate unmeasurable regions.
10. Acquire a new range image by the hand-eye range finder.
11. Goto 7

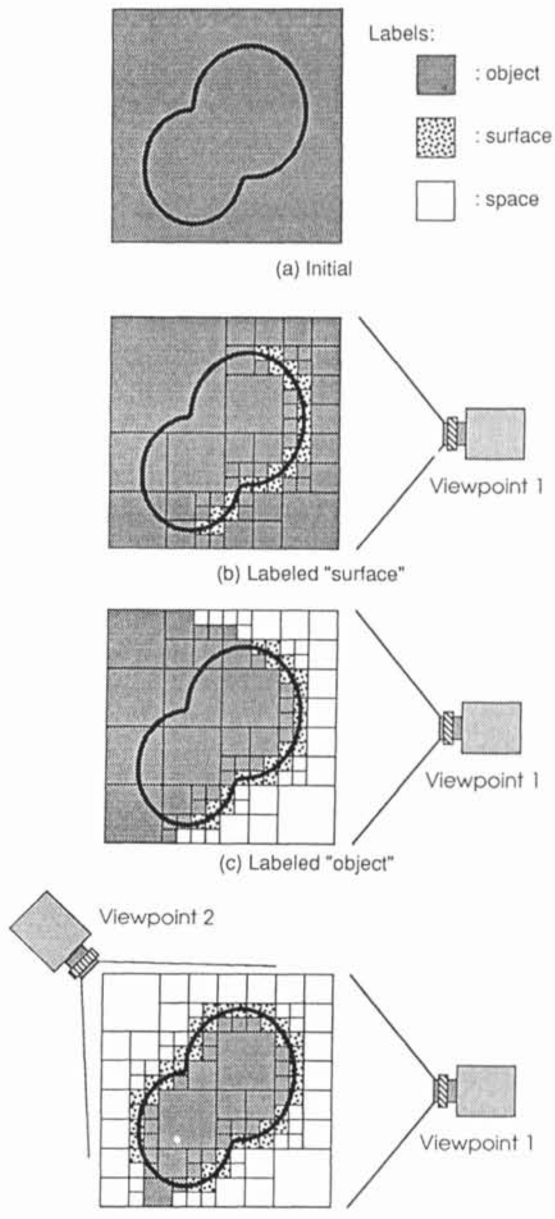


Fig. 3 Generation of an Octree

Figure 3 illustrates this process on a 2D intersection of an object. In Fig. 3 (c), the octree is first generated from one range image. Unmeasured regions labeled "object" are not changed; Only measured regions are labeled "surface" or "space". Fig. 3(d) shows an integration of two range images.

IV.1 Extended Octree - Variable Resolution and Raw Data

We improved the octree representation to increase the accuracy and the memory efficiency.

The raw range data of the object's surface are stored in each "surface" voxel (Fig. 4). Its coordinate data of the point is set in correspondence to the voxel. In this way, although the resolution of each voxel isn't very high (2-4 mm), the surface coordinates are known very accurately from the raw sensor data. Thus, shape of the object can be

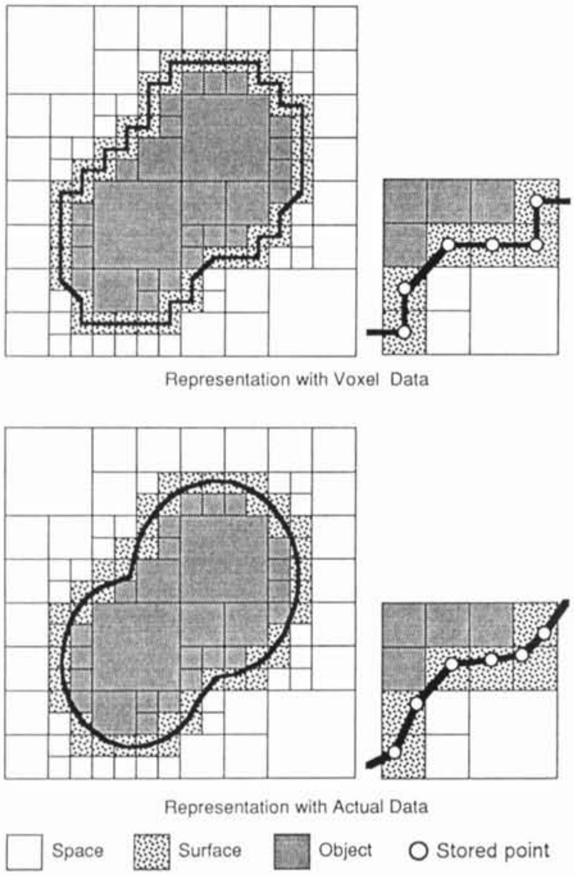


Fig. 4 Actual Data Representation in Octree

represent with high accuracy that is less than resolution of voxels.

Generally, an octree with the higher resolution, needs the bigger memory. In order to solve the tradeoff relationship between with high accuracy and small storage requirement, we vary the resolution of the octree adapted to object shape. As shown in Fig. 5, high resolution part of the octree corresponds with a large curvature surface large curvature. Resolution of each voxel is determined by an evaluation function which satisfies Shannon's sampling theorem at spatial frequency in the neighborhood of the voxel.

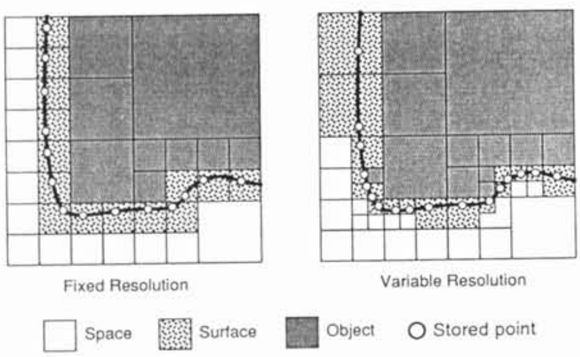


Fig. 5 Variable Resolution of Octree

V System Configuration

The configuration of the system is shown in Fig. 6. The hand-eye range finder, developed by Toyota Central Research & Development Laboratories Inc. is a light-weight small light striping finder. It is attached to the end-effector of a 5-freedom PUMA type robot arm. Fig. 7 shows the hand-eye range finder measuring an object. The workstation calculates the range images, generates the octree, detects unmeasurable regions, and controls the robot arm and the turntable. The PC controls the hand-eye range finder and transfers the measurement data to the workstation.

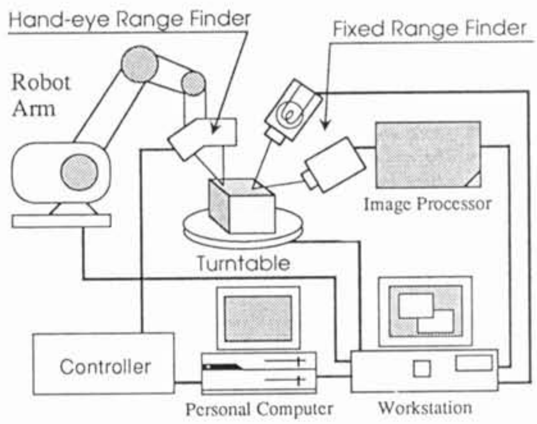


Fig. 6 System Configuration

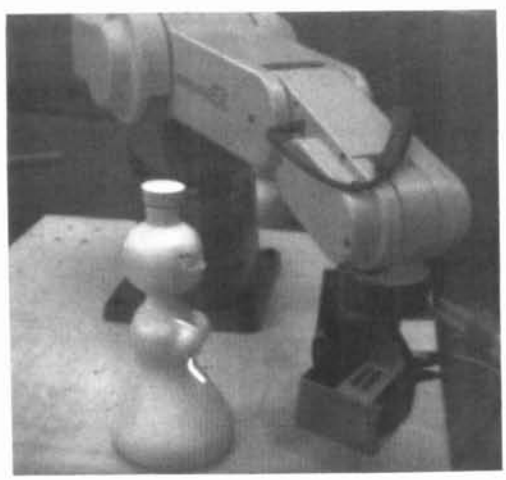


Fig.7 Measurement with the Hand-eye Range Finder

VI Experimental Results

In the experiment, we measured an object as shown in Fig. 8. Fig. 9 shows a result of measurement of the entire surface data using the fixed range finder and the turntable.

Figure 10 shows an example of elimination of unmeasurable regions using the hand-eye range finder. We can confirm than missing portions at the neck of the bottle-like object in Fig. 10(a) disappear and correct surface data is created.

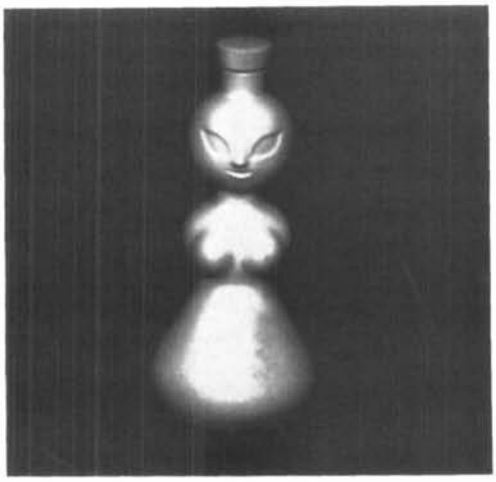
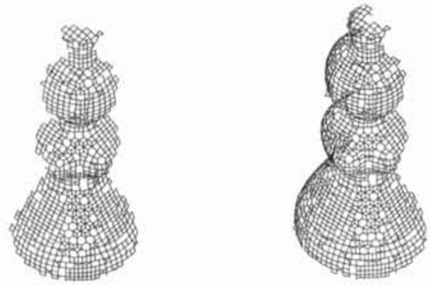
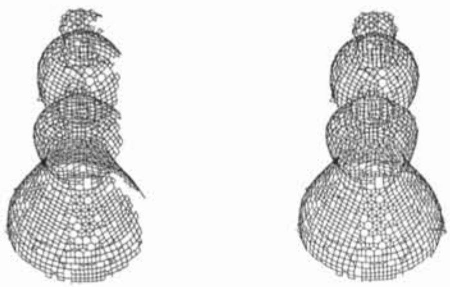


Fig. 8 Experimental Object

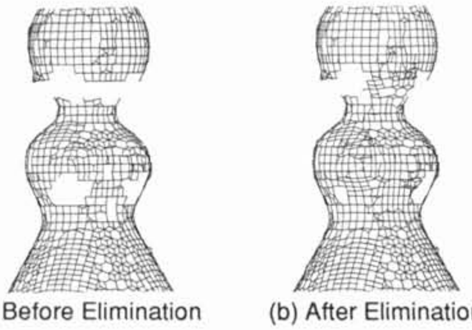


(a) 1 Image (b) Merged 2 Images



(c) Merged 3 Images (d) Merged All Images

Fig. 9 Integration Result Range Images



(a) Before Elimination (b) After Elimination

Fig. 10 Elimination Result of Type 1 Unmeasurable Region

VII Conclusion

Manual solid modeling using a CAD system has been being time consuming and lazy task. It is difficult to model object consisting of free-form surfaces. The proposed method can automatically acquire almost complete models of objects containing free-form surfaces. In order to create CAD models for industrial design, a designer can construct clay or wood prototypes of an object which can then be input to the system. It will also be useful for interactive design like cut-and-try.

The octree is a suitable volumetric representation for solid modeling of objects. It is also suitable for fusing multiple range images. Variable resolution and raw data representation make the octree representation more flexible.

Generation of octree is a kind of bottle-neck of the whole procedure. It currently takes about an hour to generate an octree from several range images. To increase system efficiency is also an issue which must be addressed in the future work.

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