MVA'94 IAPR Workshop on Machine Vision Applications Dec. 13-15, 1994, Kawasaki

EMPLOYING SYMMETRIC SUBSETS FOR IDENTIFYING ASYMMETRY OF HUMAN SKULLS

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ABSTRACT

This paper describes a technique for analyzing shapes with potential symmetry employing symmetric subsets. The proposed technique assumes that the shapes interested have potential bilateral symmetry. The notion of potential symmetry is given to those shapes with approximate or original symmetry. As respective examples, we can imagine a human face and a partial broken vase. Although their symmetric structures need be identified for their meaningful analysis, very few researchers have ever discussed symmetry identification of those shapes with potential symmetry.

The present paper proposes a technique for identifying planes of symmetry on the shapes with potential bilateral symmetry employing the idea of symmetric subsets. The proposed technique is applied to asymmetry analysis of human skulls, and some experimental results employing real CT images of human heads are shown with discussion.

1. INTRODUCTION

Computer vision includes the analysis of 2D shapes and 3D objects as its most important field of study. Symmetry is one of the most useful indices for describing a shape and a number of symmetry finding algorithms[1,2] have been proposed with respect to 2D or 3D cases. When practical objects are taken into consideration, however, one easily finds that there are a number of asymmetric objects that are associated with certain types of symmetry such as a human face, an apple taken a bite, *etc*. They are called the shapes with potential symmetry in this paper. Although their symmetric structures need be identified for their meaningful analysis, very few researchers have ever discussed symmetry identification of those shapes with potential symmetry.

This paper proposes a technique for identifying planes of symmetry on the shapes with potential bilateral symmetry employing the idea of symmetric subsets. The technique is applied to identifying and evaluating asymmetry of human skulls which have potential bilateral symmetry. Oralsurgeons try to analyze asymmetry of a patient's skull whose distortion may cause future irrelevance in his biting or speaking. For the analysis, a plane of symmetry must be settled on a skull. If a well-established symmetry finding technique such as the one employing moments of inertia [3] is applied to finding the plane of symmetry on a skull, the obtained plane will surely disagree with the plane one expects because of the asymmetry of the skull. Therefore the proposed technique is applied to the detection of its plane of symmetry. Identification of asymmetric part and evaluation of *the asymmetry degree* are then performed employing the plane of symmetry. Experimental results are shown based on CT images of a human head and discussion is given.

2. OVERVIEW OF THE SYSTEM

A system is developed for asymmetry analysis of human skulls to support oralsurgical diagnosis. When symmetry of shapes is analyzed, a reference entity needs be defined. In order to set a reference plane of symmetry, the principal axes of an object were employed in the former system. It was difficult by the method, however, to obtain an appropriate reference plane of symmetry, because human skulls include some slightly asymmetric portions. Therefore a new technique is proposed to overcome the difficulty and it is included into the asymmetry analysis system.

This system is composed of three parts. See **Fig.1** for flow of the procedure. In the first place, a binary 3D image of a human skull or jawbone is created using real CT sliced images. Binarization of each sliced image in this procedure is achieved by a certain threshold given manually. A user can choose either a skull or a jawbone for asymmetry analysis in this system. In order to produce a lower jawbone, one is asked to edit each binarized slice image manually to extract jawbone part. In the second place(which is described in detail in the following section), setting a reference plane with respect to bilateral symmetry of a human head is executed employing symmetric subsets. Once a reference plane is established, asymmetrical portions of the skull concerned is extracted and the value of the asymmetry degree is calculated. The detected asymmetrical portions are finally displayed on CRT screen along with the original skull.

This system has octree representation for describing a 3D object. 3D voxel data is stored by octree to save memory. It should be noted that octree representation of a

3D object is efficient not only for saving memory but also for analyzing symmetry.

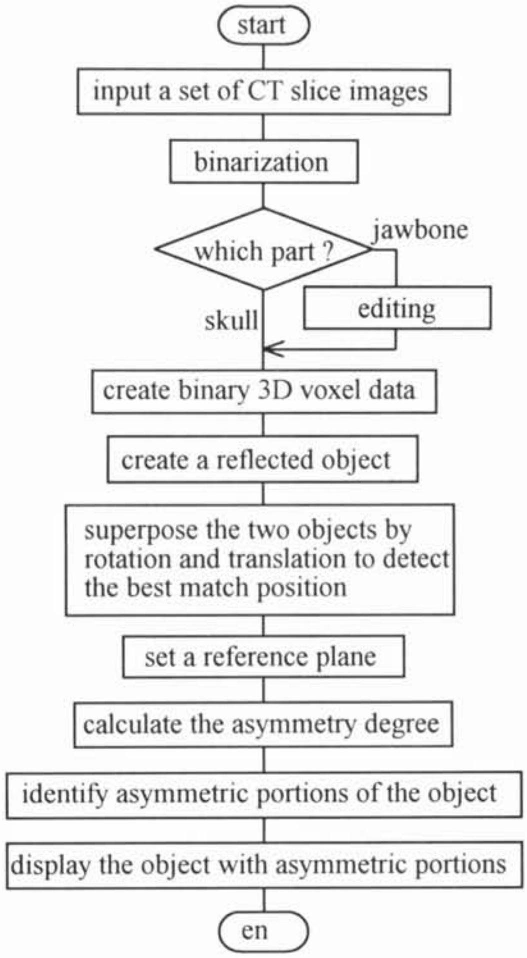

Fig.1. Flowchart of the system

3. IDENTIFYING PLANES OF SYMMETRY

3.1 PRINCIPLE

The principle of identifying a plane of symmetry on an object with potential bilateral symmetry is to find the largest symmetric subset on the object and to employ the plane of symmetry the subset provides as the plane of symmetry of the object itself. The largest symmetry subset can be calculated employing a reflected image of the object.

Let us denote an object in the xyz coordinate system and its reflected image by $O=\{(x,y,z)\}$ and $O^r=\{(x^r,y^r,z^r)\}$, respectively, and the transform by T containing the rotation around the x-axis and the z-axis and parallel transformation. Then the following value is calculated;

$$D = \min_{T} \left| \; O - T(O^r) \; \right|, \qquad (1)$$

which represents the minimum number of the voxels in the difference image between O and $T(O^r)$. Here the parallel transformation is always performed so that the difference image between O and $T(O^r)$ has always bilateral symmetry with respect to the reference plane (refer to section 3.3). The overlapped portion of O and $T(O^r)$, therefore, gives the largest symmetric subset of object O.

3.2 REFLECTED IMAGE AND SUPERPOSING

An initial reflected image of an object O is simply created by changing the sign of the y coordinate of all the voxels contained in O, *i.e.*, $O^r \equiv O(x, -y, z)$. This is equivalent to regarding the x-z plane as a tentative reference plane. In order to obtain D of Eq.(1), the two objects O and $T(O^r)$ are superposed by changing variables θ, ϕ, and y defining transform T. **Figure 2** shows the reflected image of the original and the transform T.

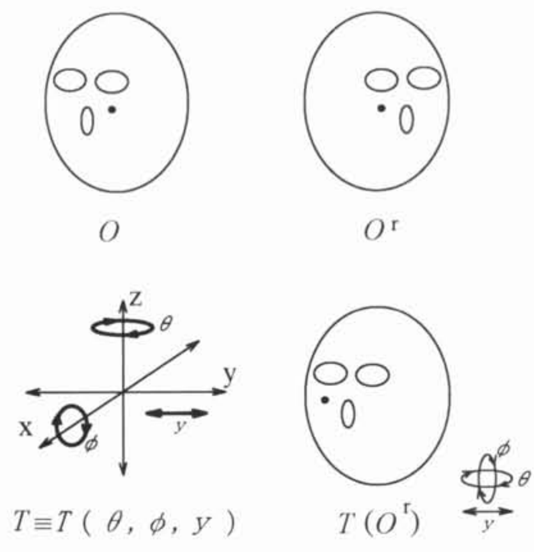

Fig.2. Reflected object and transform

3.3 RESTRICTION OF PARALLEL TRANSFORM

Parallel transform of the reflected image is given restriction, since it must satisfy the condition that the difference image between O and $T(O^r)$ has always bilateral symmetry. This comes from the fact that the idea is equivalent to finding the plane which gives the best symmetric match by examining bilateral symmetry of an object O with respect to a plane arbitrarily set on O. Therefore, when two objects are superposed, the centroid of $T(O^r)$ moves on the following straight line;

(i) in the case of $\theta=\phi=0$,

$x=0$, $z=0$ (i.e. the y-axis),

(ii) in the case of $\theta=0, \phi\neq0$,

$$x = 0 \quad , \quad \frac{y}{\cos\frac{\phi}{2}} = -\frac{z}{\sin\frac{\phi}{2}} \quad ,$$

(iii) in the case of $\theta \neq 0, \phi = 0$,

$$\frac{x}{\sin\frac{\theta}{2}} = \frac{y}{\cos\frac{\theta}{2}} \quad , \quad z = 0 \quad ,$$

(iv) in the case of $\theta \neq 0, \phi \neq 0$,

$$\frac{x}{\sin\frac{\theta}{2}} = \frac{y}{\cos\frac{\theta}{2}\cdot\cos\frac{\phi}{2}} = -\frac{z}{\cos\frac{\theta}{2}\cdot\sin\frac{\phi}{2}}$$

3.4 SETTING A REFERENCE PLANE

When Eq.(1) is achieved by the transform $T(\theta^*, \phi^*, y^*) \equiv T^*$, the reference plane of symmetry is defined as the perpendicular bisector between the centroid of O (denoted by G) and that of $T^*(O^r)$ (denoted by G^r)(See **Fig.3**).

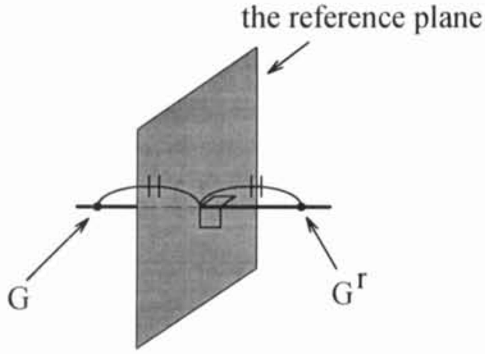

Fig.3. Reference plane

4. EVALUATION OF ASYMMETRY

Once the plane of symmetry is established on an object, every voxel on one side of the plane is taken correspondence (if any) with the voxel on the other side and those voxels with no partners are marked as asymmetric voxels. This asymmetric part finding process works systematically even on octree representation of an object[4] as well as voxel representation. The asymmetric voxels and the plane of symmetry are shown on a CRT display along with the object concerned. Finally a volumetric ratio of asymmetric part to the whole object, defined as *the asymmetry degree*, is calculated by Eq.(2) and reported. An alternative numerical index, *the symmetry degree*[3], can also be employed by Eq.(3).

$$asd = \frac{\text{asymmetric volume}}{\text{whole volume}} \tag{2}$$

$$sd = 1 - asd \tag{3}$$

5. EXPERIMENTAL RESULTS

The proposed technique was applied to a skull and a jawbone reconstructed from a set of CT sliced images of a patient. The 3D voxel image of the skull with the resolution of 128 × 128 × 128 was analyzed on a workstation(SS10). **Figure 4** shows the original 3D images of patients' skulls and the resultant images with the detected planes of symmetry. The plane in the original image is an initial plane which is not coincident with the saggital plane in order to inspect the performance of the proposed technique. Note that the plane of symmetry is successfully extracted at the saggital plane of the skull. The detected asymmetric voxels are superposed onto the examined skull and jawbone, and shown in **Fig.5** where the resolution lower than that of the skull is employed with respect to the asymmetric voxels to emphasize strong asymmetry.

6. CONCLUSION

A technique was presented for identifying a plane of symmetry on an object with potential bilateral symmetry employing the notion of a symmetric subset and a scheme for evaluating asymmetry of the object was also described. The technique was applied to a human skull which has potential bilateral symmetry and its plane of symmetry was successfully detected. By subsequent asymmetry evaluation, portions with strong asymmetry were extracted as well on the skull. Extracting asymmetric part of a human skull is very useful for easily understanding the shape and the position of deformed part and this leads to supporting oralsurgical diagnosis. Foreseeable applications of the technique other than the aid to oralsurgical diagnosis may include the analysis of Moire topographic images for observing osteoarthritis of spines.

Introducing the gradient decent method is now under consideration in the process of setting reference planes to realize improvement of processing time.

References

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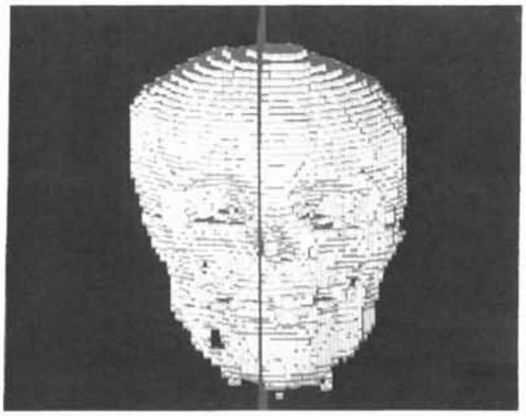
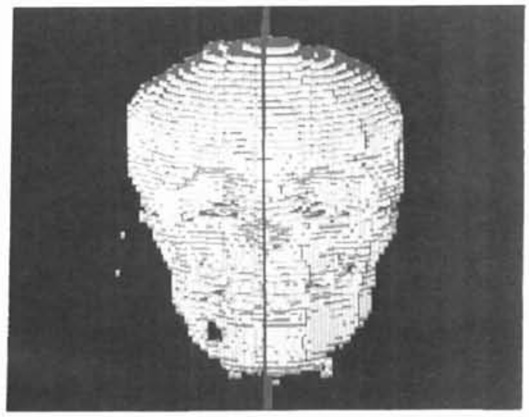
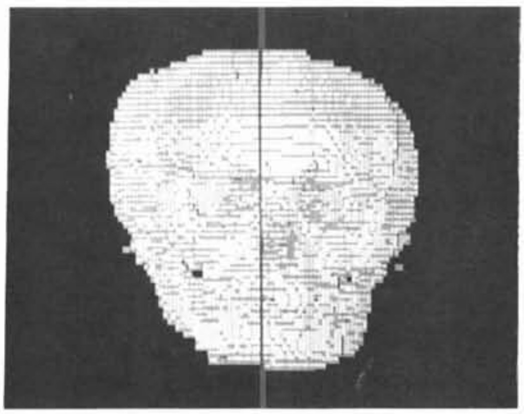
[4] Ishikawa, S., Takeda, T., Kato, K.: " Asymmetry detection of a human skull represented by an octree" , *Proc. ACCV'93*, 818-821(1993).



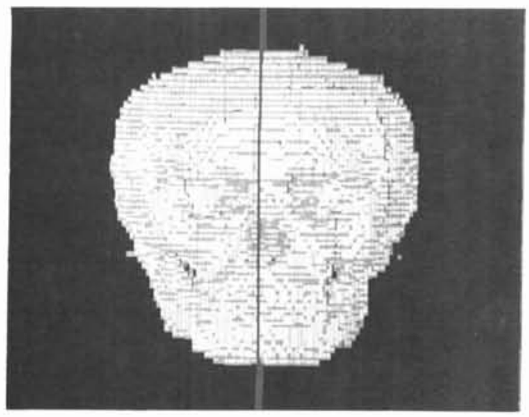
(a1) Input 3D image of a patient's skull



(b1) Detected plane of symmetry

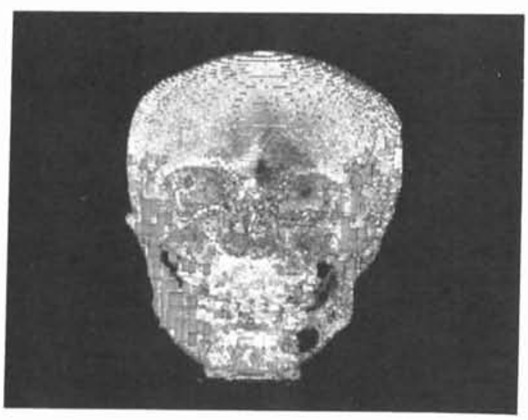


(a2) Input 3D image of a patient's skull

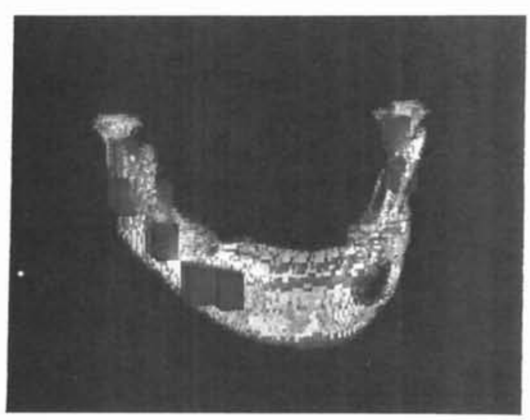


(b2) Detected plane of symmetry

Fig.4. Identifying a reference plane



skull



jawbone

Fig.5. Asymmetric part