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AN INTERACTIVE 3D SYMMETRY ANALYSIS SYSTEM

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ABSTRACT

The present paper describes an interactive technique for measuring the symmetry degree of an arbitrary three-dimensional object. The drawback of the automatic symmetry detection algorithm formerly proposed is that figural distortion or local mass disappearance causes detection of unacceptable principal axes. To overcome this, an interactive symmetry detection system is proposed where part of an object is specified by a user from which the principal axes are defined. These principal axes are employed for the principal axis transform to yield a principal octree of the object. The symmetry degree is calculated on the principal octree by assuming a certain type of symmetry with the object concerned. The proposed technique is applied to measure the distortion of human skulls provided by CT images. Some experimental results are shown and the performance of the proposed technique is discussed.

INTRODUCTION

Symmetry is an important feature of an object and has long been the subject of research in various fields such as aesthetics, psychology, mathematics, *etc*. Recent progress of computer has led computer scientists to study algorithms on automatic detection of symmetrical structures of objects and many techniques[1,2] have been proposed with respect to two-dimensional shapes, and a few with three-dimensional objects. Yet none of them provides a sufficient technique applicable to arbitrary objects and capable of detecting any type of symmetry. The three-dimensional symmetry analysis technique[3] we have proposed analyzes simple, rotational, and spherical symmetry of an object by calculating the symmetry degree, an index showing how close it is to a certain type of symmetry. The only prerequisite of the technique is that an object needs an octree representation.

The technique was implemented on a workstation and human skulls and lower jawbones were analyzed their closeness to bilateral symmetry[4]. Difficulty, however, remains that, since the implemented system extracts the principal axes from an object's moment of inertia matrix[6] automatically, unacceptable principal axes are sometimes extracted on account of distortion or local mass disappearance of an object.

In order to overcome this, we develop an interactive symmetry analysis system which asks a user to specify a portion of the object concerned from which the principal axes are extracted and employed for evaluating symmetry of the whole shape of the object. This makes the system capable of analyzing an almost symmetric object or an object having potential symmetry axes or symmetry planes, which may have more practical use.

In this particular research, the proposed interactive technique is applied to the measurement of the bilateral symmetry degree of human skulls provided by CT images. This application is of great importance in oral surgery where, for effective medical treatment, numerical assessment is requested of facial or skull distortion which might cause trouble in biting or speaking other than aesthetic point of view.

This paper begins with clarifying a drawback of the fully automatic three-dimensional symmetry analysis technique[3] and introduces an interactive technique employing conditional principal axis transform. It is then applied to the distortion evaluation of human skulls and some experimental results are given with discussion.

3D SYMMETRY ANALYSIS TECHNIQUE

The already proposed three-dimensional symmetry analysis technique is a general technique in the sense that any object can be dealt with only if it is represented in an octree form and that all types of symmetry, *i.e.*, simple symmetry, rotational symmetry, and spherical symmetry are within the scope of its analysis. Here simple symmetry includes bilateral symmetry, axial symmetry(rotation by π; rotation by another angle is included in rotational symmetry), and central symmetry. It is known[5] that a plane of symmetry is perpendicular to an object's principal axis, that an axis of symmetry agrees with the principal axis, and that a plane of symmetry passes through the object's centroid. These facts suggest that, for symmetry check, the *xyz* coordinates containing an object had better be aligned with the object's principal axes by translating its origin to the object's centroid and rotating the *xyz* coordinates by certain angles around those axes. Since principal axes of an object can be obtained by solving the eigenvalue problem with respect to the object's moment of inertia matrix[6], this transformation called *the principal axis transform* is done without difficulty.

All the above procedure can be done automatically once an object's shape is fed into the program. Suppose that an object A with bilateral symmetry received destruction with its small part and an asymmetrical object B was obtained. We say in this situation that the object B has a potential symmetry plane. Clearly directions of the principal axes of object B differ from those of object A. Yet still the potential symmetry plane of object B will make sense when both objects are compared with respect to their shape. This leads to the modification of the automatic three-dimensional symmetry analysis system[3] into an interactive system.

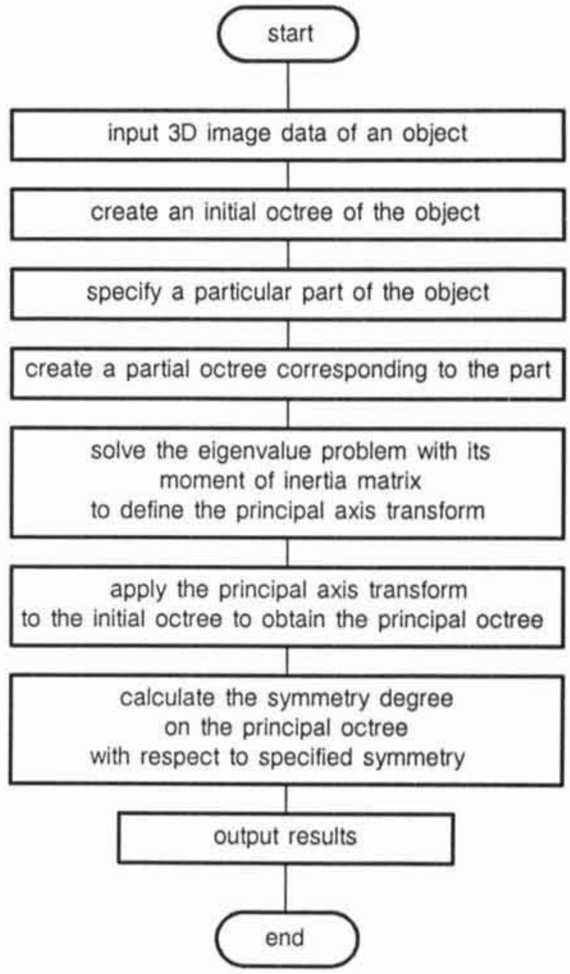


Fig. 1. Flowchart of the interactive three-dimensional symmetry analysis employing the conditional principal axis transform.

CONDITIONAL PRINCIPAL AXIS TRANSFORM

It is possible to extract a potential symmetry axis/plane, if object's destroyed part is only local. The untouched symmetrical part has enough information on the principal axes associated with the symmetry. Such symmetrical part needs be specified by a user, however. The principal axes obtained from the specified symmetrical part define the principal axis transform associated with the particular part. This transform is applied to the whole shape of the object (which is represented initially by *an initial octree*) to yield *a principal octree* representation of the object on which assumed symmetry is examined. For the symmetry examination, an index called *the symmetry degree*[3] denoted by *sd* is employed. This real-valued index defined as the ratio of the mass of object's symmetrical part to the entire mass of the object ranges between 0 and 1. If an object has a certain symmetrical form, *sd*=1.

The whole procedure of the proposed interactive three-dimensional symmetry analysis is given in **Fig.1**. The principal axis transform employing those principal axes obtained locally from part of an object is called *the conditional principal axis transform*.

When this technique is applied to a certain object, an initial octree needs be created from acquired object data. One of the simplest ways of creating an octree of a three-dimensional object is to employ its CT images[7,8]. In this particular research, therefore, we expect that a set of CT images of an object are provided as input data. In this situation, a user is only asked to give appropriate CT slice numbers in order to specify certain part of the object.

EXPERIMENT

Method: The proposed technique is applied to the measurement of the symmetry degrees of human skulls with respect to bilateral symmetry. The CT images of a human head contain approximately 100 sliced digital images each with 256×256 pixels and successive slices are *2mm* apart from each other. These images are thresholded by a certain CT value to extract skull areas and they are merged into a single skull which is represented by an octree. This is the initial octree. If a user specifies CT slice number *k* through the keyboard, *k* sliced images from top of the head receive the same procedure as the above to result in a partial octree representing the specified head part. This defines the conditional principal axis transform and it is applied to the initial octree to obtain the principal octree. The symmetry degree is calculated on the principal octree with respect to each assumed plane of symmetry. The octree resolution level is eight. Note that an octree space is represented by $2^i \times 2^i \times 2^i$ voxels, when the octree resolution level is *i*. The experimental system is the same as that shown in [8].

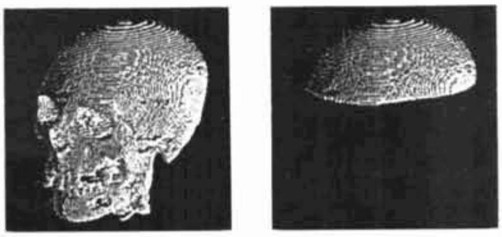
Results: In order to show performance of the proposed technique, a synthesized head model is employed whose original *sd* value is unity with respect to its sagittal plane (See **Fig.2a**). Its lower part is locally eliminated as shown in Fig.2b to realize asymmetry as a whole. An upper part of the model shown in Fig.2c is used for defining the conditional principal axis transform and, as the result of having applied this transform to the asymmetrical model in Fig.2b, *sd*=0.89 is obtained with respect to its sagittal plane, which agrees with the true value.

In the next stage, actual human skulls are employed for the experiment. Two specimens shown in **Fig.3** and **Fig.4** are calculated their bilateral symmetry degrees. These data have some oral surgical problems: In the former skull, the lower right jawbone loses its substance, while in the latter, all the upper left jawbone is removed on account of a tumor. These facts suggest asymmetry of their shape with respect to the sagittal plane.

The skull shown in Fig.3a is reconstructed using 111 CT sliced images, and the specified upper head part shown in Fig.3b contains 36 sliced images, while 117 sliced images are employed for recovering the skull shown in Fig.4a and 50 for the part shown in Fig.4b. Results are given in **Table 1** where the previous symmetry degree employing the automatic symmetry analysis technique, sd_{prev}, the symmetry degree of the specified part, $sd_{partial}$, and the symmetry degree by the proposed technique, $sd_{props'd}$, are shown.

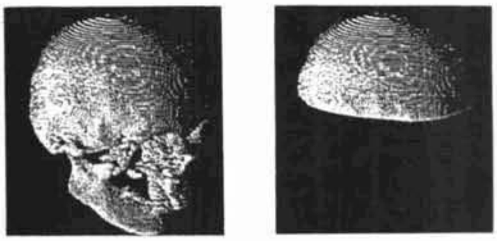
(a) (b) (c)

Fig.2. A synthesized head model.



(a) (b)

Fig.3. The skull employed in the experiment.



(a) (b)

Fig.4. The other skull employed in the experiment.

Table 1. Experimental results.

case	sd_{prev}	$sd_{partial}$	$sd_{props'd}$
Skull of Fig.3a	0.66	0.77	0.75
Skull of Fig.4a	0.58	0.60	0.66

DISCUSSION

As shown in Table 1, the symmetry degrees are larger in the proposed technique compared with the values obtained by the previous technique. Although symmetry degrees do not necessarily become larger even if the proposed technique is employed, it offers at least more reliable principal axes for symmetry analysis than the previous technique. The values of $sd_{props'd}$ may depend on the part specified by a user. **Table 2** shows the relation between specified CT sliced images and $sd_{partial}$ with respect to the skull of Fig.3a. There we can see similar $sd_{partial}$ values with the three cases, which suggests stable directions of the principal axes extracted from the head part shown in Fig.3b. It is, however, reasonable to think that a larger number of CT slices provide more reliable results.

It should be noted that the candidate plane of symmetry obtained as the result of having applied the conditional principal axis transform to a skull does not usually agree with its sagittal plane because of the specified head part's (or the skull's) distortion. If this difference needs to be minimized, another interactive procedure should be employed, which is left for further study.

The technique's favorite application is the application to the measurement of the symmetry degrees of those originally symmetrical objects which have local missing part. Another attractive application may be to compare the symmetry degrees before oral surgical operation and after it, which is actually within the scope of our study. In this application, it should be assumed that the location and the direction of the patient's head has strict agreement on the coordinate system in the CT measurement environment before and after the operation. Otherwise we might employ some landmarks on patient's head to take correspondence between the reconstructed images before and after the operation.

CONCLUSION

An interactive technique was proposed for analyzing three-dimensional symmetry of an object. It was applied to the measurement of the bilateral symmetry degrees of human skulls and experimental results were shown. Typical applications of the proposed technique include the symmetry analysis of an originally symmetrical object which has some local missing part. In oral surgical application, comparison of the symmetry degrees between the skulls before and after the operation may have practical meanings. Another interactive technique remains to be studied for minimizing the difference between the extracted candidate symmetrical plane and the actual sagittal plane on a skull.

Table 2. The relation between the specified head part and the value of $sd_{partial}$.

number of CT slices from top of the head	$sd_{partial}$
30	0.77
35	0.77
40	0.75

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