Computer Science Department of The University of Auckland
CITR at Tamaki Campus (http://www.tcs.auckland.ac.nz**)**

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Digital Visibility and Visualisation of Magnetic Resonance Imaging Series

Ben Yip and Reinhard Klette*

Abstract

This paper reports about two new approaches to visualise the three- dimensional object that is depicted by a MR (Magnetic Resonance) imaging series. The exterior of the object is visualised with a surface rotation approach, which is based on the concept of digital visibility. The interior of the object is visualised with a cut and view approach, which is based on a special solution for resampling.

After image data pre-processing, the surface rotation approach allows the user to rotate and visualise the object in any angle of view; while the cut and view approach let the user see the interior of the object by creating a planar cut onto the three dimensional object and then visualise the cross-section.

These two approaches complement each other. Together, they provide a simple, fast processing method for the medical experts to visualise the MR imaging series. The time complexity and the quality of theoutcome are satisfactory even it is processed with Intel 486 processor.

* The University of Auckland, Tamaki Campus, Computing and Information Technology Research, Computer Vision Unit, Auckland, New Zealand

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Ben Yip and Reinhard Klette

Computing and Information Technology Research
Department of Computer Science, Tamaki Campus
The University of Auckland, Auckland
New Zealand
E-mail: {yyip003, rklette}@cs.auckland.ac.nz

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Keywords: Medical Imaging, Voxel Neighbourhood, Digital Visibility

1. Introduction

The Magnetic Resonance (MR) technique provides a reliable way to diagnose the human body. Magnetic Resonance image technique is based on estimating the local wavelength of the acoustic wave pattern that propagated through the tissue-like material of the human body [1]. Each MR image of the series depicts a slice of the actual object. The image intensity ranged from pure black to pure white, as the elasticity of the original object may be a hollow space or a dense object like a bone. The MR imaging series used in this paper depicts a human head. The 100th slice of the MR imaging series is shown in Figure 1.

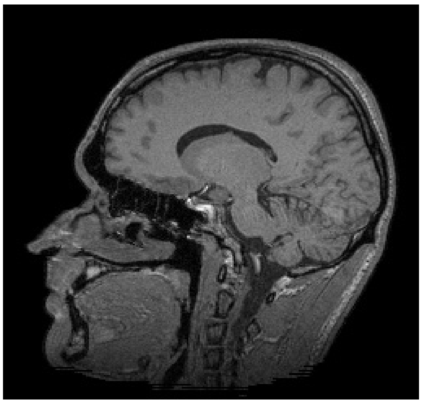

Figure 1: An MR image may be segmented into background and object by using a threshold technique.

2. Image Data Pre-processing

Before the MR imaging series can be used by the above mentioned methods, we need to perform several analysis processes; Starting with background definition, alignment verification, noise analysis, connectivity analysis and intensity analysis.

The backgrounds of the MR images used are pure black, so it is not necessary to perform further segmentation of the object and the background. It is possible to choose a threshold value with some analysis on the background noise so that a minimum error can be determined [2].

To verify the alignment of the MR imaging series, we use the cut and view approach to generate two series of orthogonal images; one viewing from the front to the back and the other one viewing from the top to the bottom. One of the images generated is shown in Figure 2. According to subjective knowledge of what human head looks like, a given MR imaging series may be judged to be aligned or not.

Figure 2: One of the images generated by the cut and view approach that is used for verifying the alignment of the MR imaging series.

When we perform noise analysis, we need to consider every pixel of each image as a ***voxel*** (a labelled grid point; after segmentation, we assume label 1 for object points) of the whole three-dimensional object. The definition of noise depends on the confidence the user has on the images but mainly it depends on the nature of the object. Assuming a smooth object, it is appropriate to define an isolated object voxel in a 6-neighbourhood as noise, while for an irregular object, a 26-neighbourhood seems to be more appropriate. It is possible to choose a different definition of noise for different partitions of the object.

Connectivity analysis can detect any object voxel that is not connected to the centre of the head. Such a voxel is considered as irrelevant and can be removed. For the details of digital geometry and topology in 3D space, see [3].

Normalisation is needed when the intensity of the images varies slightly and a more consistent appearance is required [4]. Because normalisation may lose some tiny but significant information on the images that may mean a great difference to the medical experts. The images used in this paper are not normalised.

3. Exterior Visualisation - Surface Rotation Approach

Once the MR imaging series has been verified, we may use this new approach to visualise the exterior of the object that is depicted by a series of MR images. The basic idea of the surface rotation approach is to treat the object as a set of object voxels. When the user demands to view the object in a certain angle, this method then rotates this voxel set and matches the pixels on the viewing window to the closest voxels assuming parallel projection of the voxel set, B.

3.1 Digital Visibility

Because most of the voxels inside the object are invisible, we only need to rotate the surface - the set of all the visible voxels. In the Euclidean geometry, if an item is invisible from outside then it is invisible no matter how we rotate it. Whereas, in the discrete geometry, visibility of a voxel is a property that may change (in some sense) after a rotation.

A voxel V, $V \in B$, is ***digitally visible*** for rotation R_C and projection P if for all $Y \in B$, $Y \neq V$ it holds that:

$$\mathrm{dig}(P(R_C(V))) = \mathrm{dig}(P(R_C(Y)))$$

$$\Rightarrow Z_P(R_C(V)) < Z_P(R_C(Y)),$$

where B is an object voxel set, R_C is a rotation operation in the three dimensional Euclidean space with rotation centre C, P is a parallel projection of the voxels into the Euclidean plane, Z_P is a depth function decreasing in the direction of the parallel projection P towards the projection plan with distance to the centre of the object voxel set, and $dig(p) = dig(q)$ iff points p and q are in the same grid point cell in the digital projection plane.

A voxel is said to be digitally invisible if it is not digitally visible for any rotation R and projection P.

For example, the middle voxel of a 3x3x3 cellular complex is visible. After a rotation of 141° on the XZ plane and 54° on the YZ plane, the projection of the centre of the middle voxel is a unique point in a grid point cell of the viewing plane, hence it is visible. This is shown in figure 3.

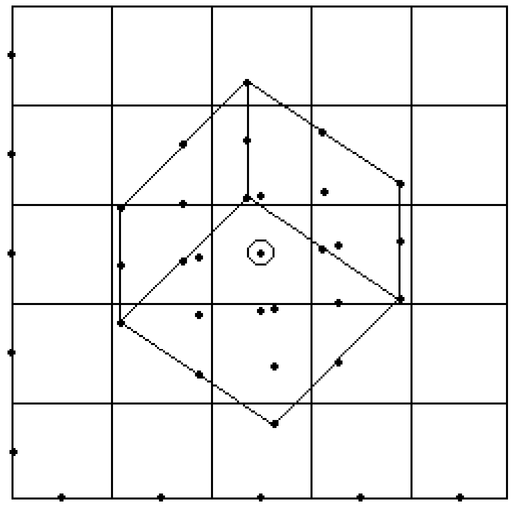

Figure 3: After a rotation of 141° on the XZ plane and 54° on the YZ plane, the voxel in the middle of a 3x3x3 cellular complex becomes visible.

In the Surface Rotation Approach, we decide about the digital visibility of the voxels based on the surface selection criterion. This is an appropriate approach to simplify the algorithm.

3.2 Surface Selection Criterion

The aim of the surface selection criterion is to judge correctly the visibility of a voxel within the given voxel sets. There are two types of errors:

- Type I Error - Judging an invisible voxel as visible, and
- Type II Error - Judging a visible voxel as invisible.

Having a Type I error causes unnecessary processing time and hence slows down the surface rotation approach. On the other hand, having Type II error means failing to show a voxel and hence generates noise to the view that the user demands. Usually there is a trade off between the level of Type I and Type II errors.

There are many different surface selection criteria that we may apply based on our desire balance of Type I and Type II errors, which in some sense is a trade off between processing time and the quality of the output.

Root-N Criterion:

It assumes that a voxel is invisible if it is surrounded by all the voxels within the topological closed Euclidean sphere of radius $\sqrt{N}$.

As higher the N value we choose, there are more Type I errors and less Type II error. The comparisons among the criteria can be see in table 1.

The probability of having Type II error in each of the criteria is estimated by generating 30000 random rotations on a synthetic object that satisfy the criterion. A 0% means the program

N	1	2	3	4	5	6	8	9	12
Neighbourhood Size	6	18	26	30	56	80	92	116	124
Probability of having Type II error (%)	44.37	14.48	2.85	2.81	2.52	0	0	0	0

Table 1: Comparison on the neighbourhood size and the probability of having a Type II error of the Root-N criterion for different values of N.

fails to detect any Type II error, and needs to be proven that there is no Type II error. A further analysis is required to estimate the probability of having a Type I error.

As a conclusion, we suggest that a root-3 criterion is a practical selection, because of its small neighbourhood size and because 2.85% chance of having Type II errors is acceptable. With the aid of more advance technology, a root-6 criterion is also recommended.

Once the surface is defined by the root-3 criterion, rotations and projections can be done within a short period of time. The Z_P values form a depth map as a by-product, which is useful for gradient analysis and contour tracing.

The surface rotation approach provides a simple, fast and accurate method to rotate and visualise the three-dimensional object that is depicted by a MR imaging series. This method works with any shape of objects, and performs comparatively well on detailed convex object with rough surfaces.

4. Interior Visualisation - Cut and ViewApproach

This new method allows the user to see the interior of an object by viewing the intersection between a cut and the object.

A cut is a plane in three-dimensional space that is represented by three points that the user may move them around the frame that contains the object. Hence it can define all the possible cuts, calculate and view the cross-section. When we calculate the intersection, the exact position is most likely to lie between two voxels, therefore, resampling is needed. Interpolation provides a smooth image, but it may generate some unusual intensity that mean a great difference to the medical experts. Such problem would not occur if we simply select the closest voxel. The resampling method used applies interpolation if the grey values of the voxels are close, otherwise the closest voxel is selected.

Since only simple linear algebra is required, the calculation time for the cut and view approach is minimal. Most time is spent on opening the image files, which can be minimized if all the images are stored in RAM.

5. Conclusions

MR imaging series provides essential data, which can be visualised by the two new approaches, mentioned in this paper. Once the MR imaging series has been verified, the surface rotation approach is used to rotate and to view the exterior of the object, and the cut and view approach is used to see the interior of the object by viewing the cross-section of a virtual cut in any direction.

Based on the concept of digital visibility, the surface rotation approach works well with objects having complex surface colour, complex shapes or objects that require a high degree of accuracy. In other methods like polygonalization, the data required to model such an object can be very large, as well as the complexity of the program and time needed for rotation [5]. The surface rotation approach provides fast rotation, simpler programs and nearly no loss of information. (See table 1)

The cut and view approach gives an intuitive way to see the interior of an object accurately. With a special resampling technique, it gives a smooth and accurate result. The calculation is simple and the processing time is short.

Sometimes, the surface grey-scaled values of MR images may be effected by the phase of acoustic waves. Some intensity re-organisation can be done with the aid of gradient analysis. Also, the outcome images will be better if the resolution of the MR imaging series is higher.

The two methods proposed in this paper are simple, feasible and reliable under the technology used by the clinics today. The result is satisfactory.

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