IMPROVING THE SPATIAL RESOLUTION OF DICOM DATA USING THE LANCZOS RESAMPLING FILTER

POPRAWA ROZDZIELCZOŚCI PRZESTRZENNEJ DANYCH DICOM POPRZEZ ZASTOSOWANIE FILTRU LANCZOS

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ABSTRACT

This paper presents an initial study to improve the spatial resolution of DICOM data using the Lanczos resampling filter. DICOM data from the cranium area of three patients, were obtained using a Somatom Sensation Open 40 scanner. A model with voxel dimension 0.4×0.4×2.4 mm was chosen as the gold standard, over the modeling approach using voxel dimensions 0.4×0.4×4.8 mm. Using the Lanczos resampling filter, changed the slice thickness from 4.8 mm to 2.4 mm. The influence of the Lanczos resampling filter on improving the spatial resolution of data was very similar across all 3 patients. The Lanczos filter changed the spatial resolution of the data and improved the accuracy of reconstruction of cranium geometry. The presented research highlights new opportunities to control deviations at the data processing and modeling of geometry stages.

Keywords: spatial resolution, accuracy, multip-detector computer tomography, Lanczos filter, cranium

STRESZCZENIE

Artykuł przedstawia badania wstępne, dotyczące poprawy rozdzielczości przestrzennej danych DICOM, poprzez zastosowanie filtru Lanczos. Dane DICOM trzech pacjentów, zostały zebrane przy użyciu tomografu Somatom Sensation Open 40 i obrazują obszar sklepienia czaszki. Model ze strukturą voxela 0,4×0,4×2,4 mm został wybrany jako nominalny, względem modelu o strukturze voxela 0,4×0,4×4,8 mm. Stosując filtr Lanczos, zmieniono grubość warstwy obrazu z 4,8 mm na 2,4 mm. W wyniku zastosowania filtru Lanczos, polepszono rozdzielczość przestrzenną danych oraz dokładność odwzorowania geometrii sklepienia czaszki. Przedstawione badania, otwierają nowe możliwości pozwalające na minimalizacje błędów powstałych na etapie przetwarzania danych oraz odtwarzania geometrii obszaru sklepienia czaszki.

Słowa kluczowe rozdzielczość przestrzenna, dokładność, tomografia wielorzędowa, filtr Lanczos, czaszka

1. Introduction

2D images are the traditional way of presenting anatomical structures. Unfortunately, this method is sometimes ineffective. With the development of computer tomography systems, it has become possible to obtain volumetric data [1] which can be processed to create a 3D computer model of a scanned object [2, 3].

The accurate reconstruction process of the object's geometry is dependent on the: type of scanner [4, 5], method of segmentation [6, 7], software algorithm [8] and manufacturing technology [9, 10, 11]. The image quality is affected by both the spatial and contrast resolutions [12, 13]. These two main features depend on the type of computer tomography system and the scanning parameters [14]. Spatial resolution defines the ability to resolve, as separate forms, small objects that are very close together. The spatial resolution is determined by the voxel size i.e. the pixel dimensions of the reconstructed image and the thickness of the imaging layer. When the dimensions of a pixel are the same as the thickness of the layer, it is called an isotropic voxel (see fig.1a). When the thickness of the layer is incomparably greater than the pixel dimensions (see fig.1b), we refer to it as anisotropic. During data analysis characterized by irregular dimensions of a voxel, there is limited possibility to segment the data successfully. The poor quality of mapping the geometry is due to the lack of continuity of data interpolation, which in turn generates the block structure of the model (which produces the so-called staircasing artifacts).

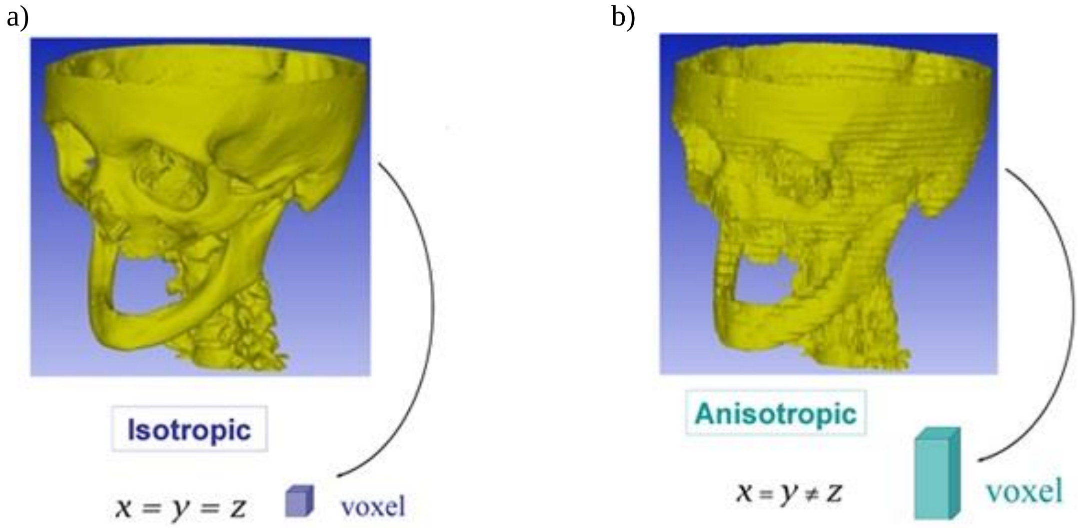


Fig. 1. Structure of voxel a) isotropic, b) anisotropic

The anisotropic nature of many datasets can be a severe quality issue for image analysis and visualization techniques. Therefore, a resampling step is often included to transform data to an isotropic grid. In this process, the accuracy of the data should not be degraded. Therefore, resampling is driven by the highest resolution (usually in-plane) and interpolates additional data in the dimension with lower resolution (usually the z dimension). There are many algorithms available that can accomplish the interpolation. They differ in their quality and computational effort. Fast methods interpolate the value at a particular position, by taking into account the neighboring voxels only. Better results are achieved with triquadratic or tricubic interpolation. Based on reconstruction theory, the Lanczos filter, based on the sinc-function, has optimal properties. This filter can be used to sharpen images. It performs a convolution with a Lanczos kernel. The kernel size in each dimension can be adjusted, using the kernel size input parameter where value of 3 denotes a 3×3×3 kernel. Parameter *sigma* determines the effective size of the Lanczos function. For large values of *sigma*, the effect of the filter will be smoothing rather than sharpening.

Currently, scientists are working toward reasonable accuracy at the stage of processing 2D data as well as on methods to improve the quality of medical manufacturing models using Rapid Prototyping and Computer Numerical Control techniques [15, 16]. A particularly difficult task is to determine the accuracy of digital models at the stage of acquisition and data processing. Computer Tomography scanners installed in clinics usually produce data with an anisotropic structure of voxels. This structure generates geometry errors, which influence the final accuracy of digital models. Currently, no one has precisely improved DICOM data and the accuracy of reconstruction of cranium geometry. The presented research highlights new opportunities to control deviations at the stage of data processing and modeling geometry of the cranium.

2. Method

Research was performed on three different patients. DICOM data was obtained on the Somatom Sensation Open 40 scanner installed in the Regional Clinical Hospital No. 1 in Rzeszow using the scanning protocol 'Head Routine Sequence' (see table 1). This sequence mode is used for routine head studies, e.g. in suspected cases of stroke, brain tumors, cranial trauma, cerebral atrophy, hydrocephalus etc. At the stage of reconstruction, the same parameters were used, while only the slice thickness was changed (see table 1)

Table 1. Scanning protocol

Somatom Sensation 40		
Name of parameters	**Value of parameters (first measurements)**	**Value of parameters (second measurements)**
kV	120	120
mAs	380	380
Rotation time	1 sec.	1 sec.
Acquisition	24×1.2 mm	24×1.2 mm
Slice collimation	1.2 mm	1.2 mm
Kernel	H31s	H31s
Matrix size	512×512	512×512
Pixel size	0.4×0.4 mm	0.4×0.4 mm
Slice thickness	2.4 mm	4.8 mm

In order to extract the cranium model with voxel dimensions 0.4×0.4×2.4 mm (first measurements) and voxel dimensions 0.4×0.4×4.8 mm (second measurements) from DICOM data, a region-growing algorithm was used [17]. Thresholds were set above 200 HU to select only craniofacial tissue. After a 3D image was segmented, a marching cubes algorithm was used for computing isosurfaces [18, 19]. This algorithm proceeds through the scalar field, taking eight neighbor locations at a time (thus forming an imaginary cube), then determining the polygon(s) needed to represent the part of the isosurface that passes through this cube. The individual polygons are then fused into the desired surface. This is done by creating an index to a recalculated array of 256 possible polygon configurations within the cube, by treating each of the 8 scalar values as a bit in an 8-bit integer. If the scalar's value is higher than the iso-value (i.e., it is inside the surface), then the appropriate bit is set to one. If it is lower (outside), it is set to zero. The final value, after all eight scalars are checked, is the actual index to the polygon indices array. Finally, each vertex of the generated polygons is placed on the appropriate position along the cube's edge by linearly interpolating the two scalar values that are connected by that edge. This algorithm guarantees that the resulting surfaces are free from cracks and holes, that no triangles (single surface build on three nearest points) intersect each other, and that all regions assigned to different materials are well separated from each other. The final surface was saved in STL format, which is used to represent the 3D model. To show improved spatial resolution of cranium geometry reconstruction, slice thickness of the image was changed from 4.8 mm to 2.4 mm using the Lanczos resampling filter in the model with voxel dimensions 0.4×0.4×4.8 mm.

The best results were obtained for a reconstruction model with voxel dimensions 0.4×0.4×2.4 mm (first measurements). In this model, artifact-associated errors in the interpolation data were minimized. In addition, a single voxel had the smallest volume relative to the reconstructed model with voxel dimensions 0.4×0.4×4.8 mm (second measurements). Therefore, a model with voxel dimensions 0.4×0.4×2.4 mm was chosen as the gold standard over the model reconstructed with voxel dimensions 00.4×0.4×4.8 mm, and was further improved using a Lanczos resampling filter (see fig. 2).

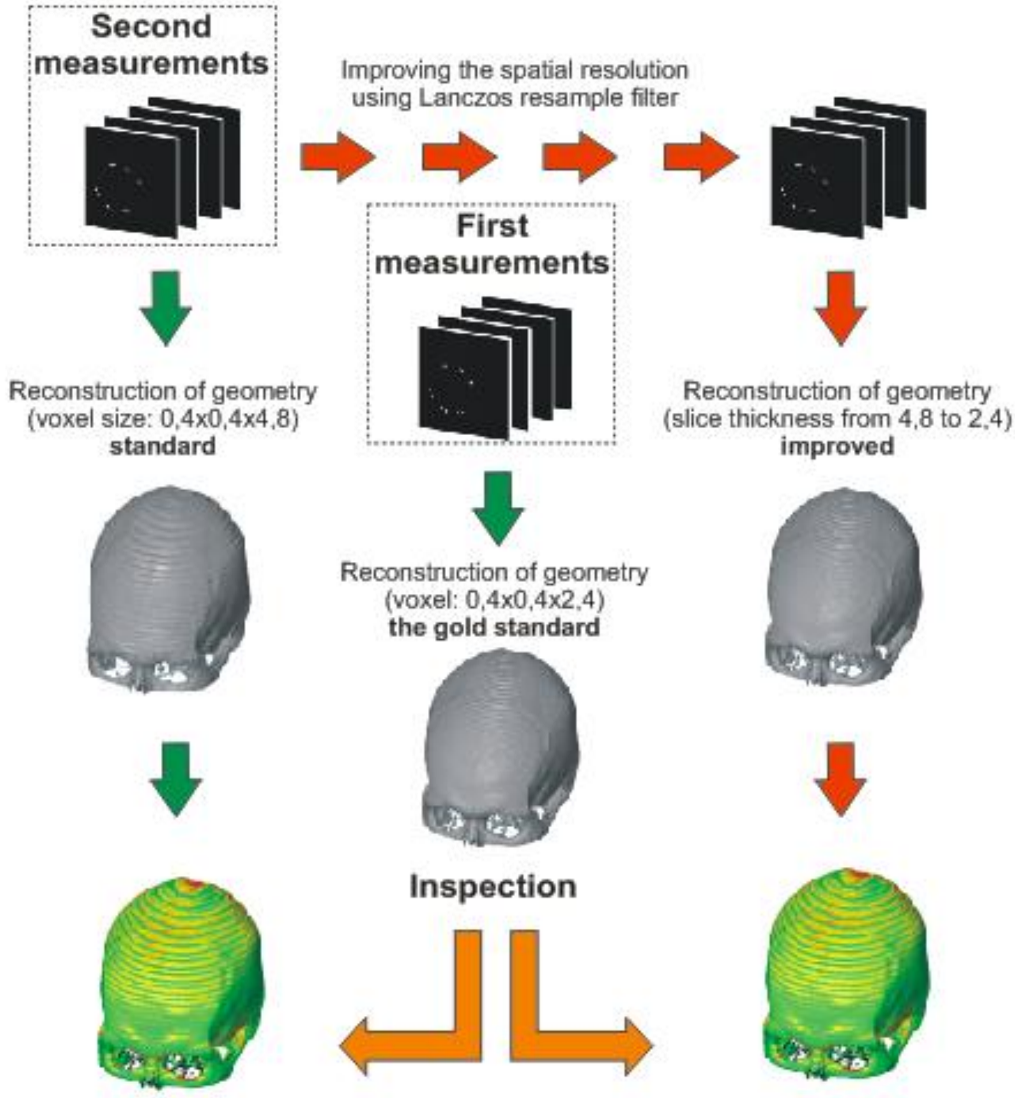


Fig. 2. The process of reconstruction and inspection of cranium geometry

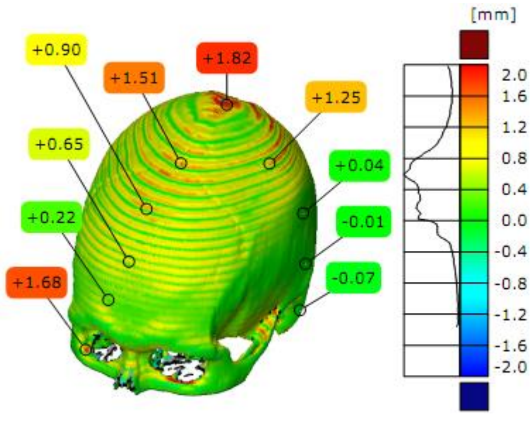
To analyze the accuracy of the reconstruction of 3D models, the process was carried out using a best-fit algorithm, which is most appropriate for analyzing deviations in models with complex shapes. Adjustment of point clouds using the best-fit was carried out to an accuracy of 0.001 mm.

3. Results

The models of the three crania obtained with voxel size 0.4×0.4×4.8 mm and improved using the Lanczos resampling filter were compared with the same crania based on modelling with voxel size 0.4×0.4×2.4 mm to examine the influence of filtration on the accuracy of reconstruction. Statistical parameters (mean value, SD) and distributions of the reconstructed models from DICOM data are presented in figures 3–6.

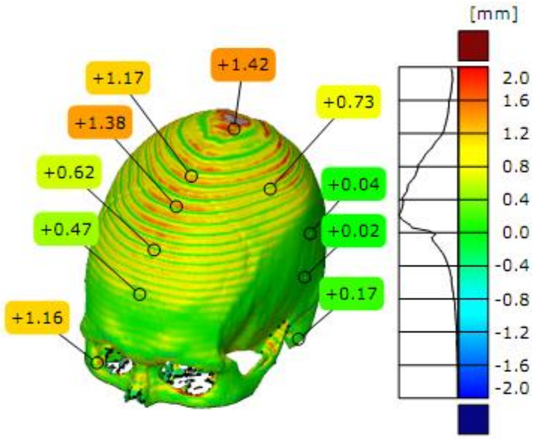
The influence of layer thickness on the accuracy of cranium geometry is very similar among the three presented patients. Maximum deviation occurred in the same region of the cranium. Most of the deviations were in tolerance from 0 mm to 0.7 mm. The poor quality of this region of geometry is due to the lack of continuity of data interpolation, which in turn generates the block structure of the model (staircasing artifact). All presented values confirmed that distribution is characterized by positive skew.

Model obtained without using Lanczos resample filter	
Number of points	**451917**



Mean value	**0.491 mm**
Standard deviation (SD)	**0.552 mm**

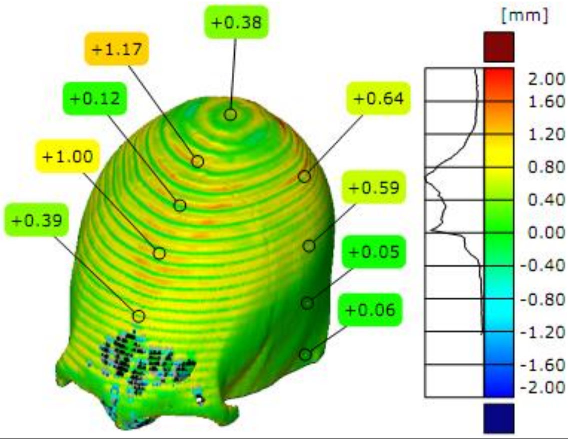
Model obtained using Lanczos resample filter



Mean value	**0.446 mm**
Standard deviation (SD)	**0.544 mm**

Fig. 3. Cranium model of third patient

Model obtained without using Lanczos resample filter	
Number of points	**438851**



Mean value	**0.513 mm**
Standard deviation (S.D)	**0.535 mm**

Fig. 4. Cranium model of the second patient obtained without using Lanczos resample filter

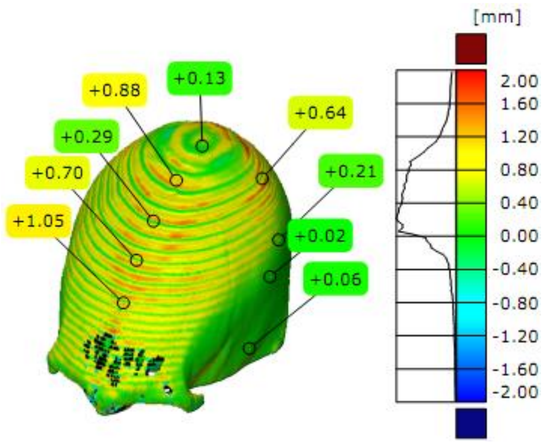
<table>
<tr><th colspan="2">Model obtained using Lanczos resample filter</th></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>Mean value</td><td>0.452 mm</td></tr>
<tr><td>Standard deviation (S.D)</td><td>0.500 mm</td></tr>
</table>

Fig. 5. Cranium model of the second patient obtained using Lanczos resample filter

<table>
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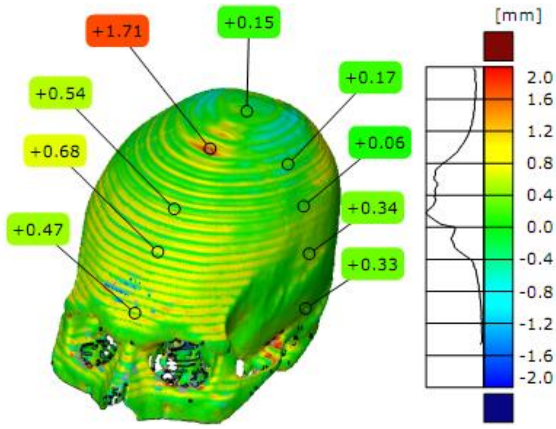
<tr><td>Number of points</td><td>446741</td></tr>
<tr><td colspan="2">
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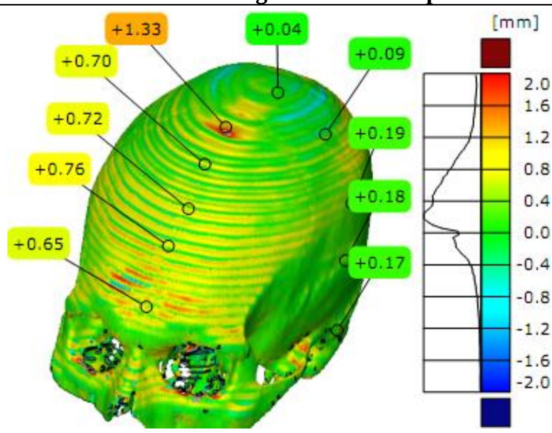
<tr><td>Mean value</td><td>0.422 mm</td></tr>
<tr><td>Standard deviation (S.D)</td><td>0.570 mm</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">Model obtained using Lanczos resample filter</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>Mean value</td><td>0.372 mm</td></tr>
<tr><td>Standard deviation (S.D)</td><td>0.527 mm</td></tr>
</table>

Fig. 6. Cranium model of third patient

4. Conclusion

This research showed that the spatial resolution, which is determined by the voxel size, has a huge impact on the accuracy of reconstruction of 3D models. The influence of a Lanczos resampling filter on the accuracy of cranium geometry was very similar for the three patients in this study. Changing the spatial resolution of the data, improved the accuracy of reconstruction of the cranium geometry. The presented research highlights new opportunities to control deviations in geometry reconstruction of the cranium at the stage of data processing and modeling.

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