Evaluation of Applying Surface Simplification Techniques in Medical Volume Data

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ABSTRACT
Medical volume data such as MRI and CT images consist of a large number of voxels. Thus, the process of displaying, storing and transmission of medical volume data is a big challenge in the biomedical field. Applying surface simplification techniques to reduce the size occupied by medical images is considered as one of the most common approaches to overcome this challenge. However, not all of the surface simplification techniques are accurate enough to be used in the medical fields. This paper aims to evaluate the impact and the accuracy of applying the Uniform Mesh Resampling (UMR) technique and the Quadric Edge Collapse Decimation (QECD) technique. Moreover, this study investigates Poisson Surface Reconstruction (PSR) technique and sets experimentally the optimal offsetting value of this technique. Two real medical benchmark datasets are used in this study to evaluate the experimental work. The outcomes indicate clearly that the use of QECD as a surface simplification technique achieves competitive results when used with medical volume data.

General Terms
Biomedical Engineering, Computer Algorithms for Medical Images

Keywords
Medical Volume Data, Medical Images, Surface Simplification, Dice Coefficient, Stl Files

1. INTRODUCTION
1.1 Medical Volume Data
Volume data in medicine and medical volume images, such as Computed Tomography (CT) and Magnetic Resonance Imaging (MRI), play a key role in monitoring the progression of different diseases [4, 10]. These type of medical images help the physician to track the efficiency of medication and adapt protocols as needed [8].

Table 1. Average file sizes of various imaging modalities.

| Image type          | width x height | File size |
|---------------------|----------------|-----------|
| Digital radiography | 3000 x 3000    | ~18 MB    |
| Digital mammography | 3328 x 4096    | ~27 MB    |
| Computed radiography| 3520 x 4280    | ~30 MB    |

Medical volume data are ordered as a Cartesian grid named voxels. Since different imaging modalities need a large number of voxels to be electronically stored, this leads to make the following operations time-consuming and requires the need for high computational resources:

* Medical image registration
* Medical image segmentation
* Exploring and diagnosis of volume data on computers
* Transferring of medical volume images

Table 1, which is adapted from [3], tabulates the average size of files for images generated by different imaging modalities. It is noteworthy that the values presented in the third column of Table 1 are per image. Since there are dozens and even hundreds of images for each patient, then one stack of these medical images for one patient needs several gigabytes to be stored and processed.

The process of displaying and transferring of medical volume data (i.e., medical volume images) are considered a big challenge in the biomedical field [5]. One common solution of this challenge is the reducing of the file size of medical volume data. Reducing the size, which is normally performed by surface simplification, aims to generate, in smaller size, an approximation of the original volume image. The process of reduction the size using surface simplification techniques over medical data has the following attributes:

* It has a sufficiently significant effect on the speed of the processing particularly on low-end servers [7]
* It is a fundamental approach when computing resources (such as RAM, CPU and graphics card) are limited.
Fig. 1. Graphical illustration of Dice similarity coefficient.

Table 2. Description of datasets evaluated in our study.

| Form       | provider                              | Attributes                        |
|------------|---------------------------------------|-----------------------------------|
| Pelvis     | Able Software Corporation (USA)       | Mesh surface/ FileSize (Pelvis) =750KB (7625 vertices) |
| Knee       | The Biomedical 3-D Printing Community (embodi3D LLC) | Mesh surface/ Knee File-size =2665 KB (26651 vertices) |

Fig. 2. The datasets used in this study. (a): surface mesh represents real pelvis. (b): surface mesh represents real knee.

* It is employed to export three-dimensional medical data to manufacture physical biomodels [7].

1.2 Dice Similarity Coefficient

Dice Similarity Coefficient (DSC), which was presented in [4], is one of the most common similarity metrics that are utilized to evaluate between two images. It is basically calculated, as illustrated in Figure 1, by multiplying two by the area of overlap (i.e., intersection area) divided by the whole number of pixels (i.e., union area). DSC is one of the widely-accepted metrics used in the medical imaging community [12, 13] and therefore it will be used in this study for evaluation of the experiments.

The remaining of this paper is organized as follows: Section 2 describes the materials and datasets used in this study. Section 3 presents the experimental works, where Section 3.1 clarifies the effect of applying surface simplification techniques to reduce the size of medical images, and Section 3.2 presents the optimal setting of some parameters. Section 4 concludes this study and highlights the main contributions.

2. MATERIALS AND DATASETS

This section describes the two datasets that are employed in this study to demonstrate and evaluate the experimental work. The details, attributes and source of these datasets are illustrated in Table 2.
and the value of DSC in either the case of filling the slices or with no fill.

It is obvious from Table 3 that there is a positive correlation between the file size and the value of DSC. This is reasonable since reducing the size by performing surface-simplification will lead to lose some details in the generated form, and consequently will decrease the value of the DSC metric. However, it can be observed from Table 3 that even when the size is reduced to be 20% of the original size, the DSC gives 90.13% and 98.41% for the pelvis and Knee datasets, respectively.

Table 3. Evaluating DSC on different size-reduced versions (surface-simplified). (using QECD approach)

| Case# | Percent | F-Size | Vertices | faces | DSC |
|-------|---------|--------|----------|-------|-----|
| Pelvis |         |        |          |       |     |
| 1     | Same    | 750    | 7,630    | 15,400| 1.0000 |
| 2     | 90%     | 675    | 6,860    | 13,820| 0.9970 |
| 3     | 80%     | 600    | 6,100    | 12,280| 0.9990 |
| 4     | 70%     | 525    | 5,330    | 10,800| 0.9771 |
| 5     | 60%     | 450    | 4,560    | 9,220 | 0.9620 |
| 6     | 50%     | 375    | 3,800    | 7,680 | 0.9390 |
| 7     | 40%     | 300    | 3,041    | 6,151 | 0.9240 |
| 8     | 30%     | 225    | 2,270    | 4,666 | 0.9150 |
| 9     | 20%     | 150    | 1,510    | 3,081 | 0.9020 |
| 10    | 10%     | 75     | 750      | 1,540 | 0.8740 |
| 11    | 1%      | 8      | 74       | 160   | 0.6097 |

Knee

| Case# | Percent | F-Size | Vertices | faces | DSC |
|-------|---------|--------|----------|-------|-----|
| 12    | Same    | 2,670  | 26,660   | 53,320| 1.0000 |
| 13    | 90%     | 2,350  | 23,990   | 47,990| 0.9987 |
| 14    | 80%     | 2,140  | 21,325   | 42,661| 0.9970 |
| 15    | 70%     | 1,830  | 18,660   | 37,325| 0.9950 |
| 16    | 60%     | 1,570  | 15,990   | 31,990| 0.9930 |
| 17    | 50%     | 1,340  | 13,331   | 26,662| 0.9911 |
| 18    | 40%     | 1,051  | 10,664   | 21,331| 0.9891 |
| 19    | 30%     | 787    | 7,996    | 15,999| 0.9872 |
| 20    | 20%     | 527    | 5,331    | 10,671| 0.9852 |
| 21    | 10%     | 263    | 2,662    | 5,337 | 0.9821 |
| 22    | 1%      | 27     | 263      | 537   | 0.9521 |

Table 4. Evaluating DSC on different size-reduced versions (surface-simplified). (using UMR approach)

| Case# | Percent | F-Size | Vertices | faces | DSC |
|-------|---------|--------|----------|-------|-----|
| Pelvis |         |        |          |       |     |
| 1     | Same    | 750    | 7,630    | 15,400| 1.0000 |
| 2     | 90%     | 675    | 6,860    | 13,820| 0.9970 |
| 3     | 80%     | 600    | 6,100    | 12,280| 0.9990 |
| 4     | 70%     | 525    | 5,330    | 10,800| 0.9771 |
| 5     | 60%     | 450    | 4,560    | 9,220 | 0.9620 |
| 6     | 50%     | 375    | 3,800    | 7,680 | 0.9390 |
| 7     | 40%     | 300    | 3,041    | 6,151 | 0.9240 |
| 8     | 30%     | 225    | 2,270    | 4,666 | 0.9150 |
| 9     | 20%     | 150    | 1,510    | 3,081 | 0.9020 |
| 10    | 10%     | 75     | 750      | 1,540 | 0.8740 |
| 11    | 1%      | 8      | 74       | 160   | 0.6097 |

Knee

| Case# | Percent | F-Size | Vertices | faces | DSC |
|-------|---------|--------|----------|-------|-----|
| 16    | Same    | 2,670  | 26,660   | 53,320| 1.0000 |
| 17    | 90%     | 2,350  | 23,990   | 47,990| 0.9987 |
| 18    | 80%     | 2,140  | 21,325   | 42,661| 0.9970 |
| 19    | 70%     | 1,830  | 18,660   | 37,325| 0.9950 |
| 20    | 60%     | 1,570  | 15,990   | 31,990| 0.9930 |
| 21    | 50%     | 1,340  | 13,331   | 26,662| 0.9911 |
| 22    | 40%     | 1,051  | 10,664   | 21,331| 0.9891 |
| 23    | 30%     | 787    | 7,996    | 15,999| 0.9872 |
| 24    | 20%     | 527    | 5,331    | 10,671| 0.9852 |
| 25    | 10%     | 263    | 2,662    | 5,337 | 0.9821 |
| 26    | 1%      | 27     | 263      | 537   | 0.9521 |

by the QECD algorithm is obvious. It is clear from Figure 4 that the relation between the DSC and the file size is more linear for QECD when it is compared with the UMR technique. This confirms again the advantages that can be gained when using the QECD in medical fields in order to reduce the size of meshes.

![Fig. 4. QECD vs. UMR.](image-url)
3.2 Part (II): Specifying experimentally the Best Offsetting Value in Poisson Surface Reconstruction Approach

Poisson Surface Reconstruction Technique (PSR) has an essential parameter named Correction-value or Offsetting-value $\alpha$. Determining the optimal value of this parameter is time-consuming for many researchers and prone to uncertainty. The aim of the experimental work in this part is to find experimentally the optimal surface offsetting value $\alpha$ of the iso-surface threshold of the PSR technique. The impact of setting different values of $\alpha$ is evaluated and the effect of that on the value of DSC. Table 5 tabulates the value of DSC using different values of the $\alpha$.

Table 5. The DSC of various values of $\alpha$.

| Case # | $\alpha$ | FSize | Vertices | faces | DSC   |
|--------|---------|-------|----------|-------|-------|
| Pelvis | 1       | Same  | 750      | 7,630 | 15,400 | 1.0000 |
|        | 2       | 0.25  | 851      | 8,602 | 17,201 | 0.5742 |
|        | 3       | 0.50  | 792      | 7,995 | 15,991 | 0.7433 |
|        | 4       | 0.75  | 721      | 7,289 | 14,579 | 0.8331 |
|        | 5       | 0.875 | 691      | 6,957 | 13,917 | 0.8411 |
|        | 6       | 1.00  | 640      | 6,530 | 13,060 | 0.8413 |
|        | 7       | 1.25  | 567      | 5,760 | 11,501 | 0.7512 |
|        | 8       | 1.50  | 461      | 4,710 | 9,391  | 0.6032 |
|        | 9       | 1.75  | 331      | 3,373 | 6,661  | 0.4150 |
|        | 10      | 2.00  | 197      | 1,998 | 3,971  | 0.2302 |

Knee

| Case # | $\alpha$ | FSize | Vertices | faces | DSC   |
|--------|---------|-------|----------|-------|-------|
| 12     | Same    | 2,670 | 26,660   | 53,320| 1.0000 |
| 13     | 0.25    | 456   | 4,664    | 9,324 | 0.7478 |
| 14     | 0.50    | 442   | 4,518    | 9,032 | 0.8318 |
| 15     | 0.75    | 429   | 4,392    | 8,784 | 0.9069 |
| 16     | 0.875   | 427   | 4,362    | 8,724 | 0.9324 |
| 17     | 1.00    | 426   | 4,356    | 8,712 | 0.9424 |
| 18     | 1.25    | 415   | 4,240    | 8,480 | 0.8892 |
| 19     | 1.50    | 386   | 3,946    | 7,888 | 0.7943 |
| 20     | 1.75    | 341   | 3,485    | 6,970 | 0.6570 |
| 21     | 2.00    | 235   | 2,401    | 4,794 | 0.4516 |

Figure 5 plots, for the PSR technique, the value of DSC for diverse values of $\alpha$. The value at which parameter $\alpha$ amounts to the largest DSC possible value $\alpha$ is illustrated using red ellipses in Figure 5. It is clear from Figure 5 that selecting a value for $\alpha$ in the interval [0.90 - 01.00] is the optimal selection to keep the quality of the reduced mesh close to the quality of the original one.

4. CONCLUSION

This paper discussed and evaluated the effect of applying surface simplification techniques over medical volume images. The paper presented two contributions. The first one, it compares between two of the common surface simplification techniques and evaluates the quality of the generated reduced versions. The evaluation is performed using the DSC as it is considered one of the widely-accepted metrics used for medical images. The results indicated clearly that the Quadric Edge Collapse Decimation (QECD) technique exceeds the Uniform Mesh Resampling (UMR) technique in terms of accuracy. The second contribution that this study presented is the setting of the $\alpha$ parameter. The Offsetting-value $\alpha$ is an essential parameter that should be correctly tuned as a preprocessing step for the Poisson Surface Reconstruction Technique (PSR).

The outcomes of this study confirm the feasibility of using surface simplification techniques, particularly the QECD technique, to store, display, and transmit medical volume data.

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