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***Research paper***

# 3D Hole Filling Based on Voxel with Weighted Neighbours Interpolation

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## Abstract

Reconstruction is a very important part of 3D visualization. A common reconstruction method is bin filling. Bin filling produces 3D image based on the 2D image and its position. But bin filling process still left empty voxels. That is the reason we do the 3D Hole Filling Based On Voxel With Weighted Neighbours Interpolation. To estimate the empty voxel's value, in this research the authors do the hole filling process by weighted neighbours interpolation method. To do the interpolation, the empty voxels should be labeled. Then from each of them, the distance of the surrounding non-empty voxels to the empty one are computed. Then certain radius is used as a threshold. The surrounding voxels within the threshold distance are considered as neighbours. Then the value of the empty voxels is determined by the weighted value of the neighbours' voxel. The method we propose has a high accuracy, as evidenced by a small error value is 11,24373 (from the scale 0 up to 255)

***Keywords***: *image reconstruction, hole filling, weighted neighbours interpolation*

## 1. Introduction

The main procedures in obtaining 3 dimensional volume of a two dimensional frame consists of two processes, image acquisition and position information, and 3D volume reconstruction [1]. The basic algorithm of three-dimensional volume reconstruction process consists of two stages, namely Bin-filling and Hole-filling [2]. Bin filling reconstruct 3D space based on 2D image and its coordinate. However, these methods still left empty voxels (holes) at some coordinates. Hole occurs because of the coordinates are not covered by bin filling, so that produce voxels that do not have any information or value. If the value of the hole is left empty, then it could be a problem on the next process.

This research proposed a weighted neighbours interpolation to determine the holes. The main supremacy of this method than the others method is, this method have a unique weight value for each neighbour. This research will do the interpolation based on weighted neighbours.

First thing to do is finding the hole. If the hole is found, then calculated the value of the radius of the neighbours. Radius here mean distance between hole and the neighbour. Then the neighbours are selected based on the radius. if the radius of the neighbour do not exceed the maximum, then the neighbour will be used. If not, then the neighbour is not used [6].

Then the weight of each neighbour have to be determined. Value of the neighbours and its weights used to calculate the value of the hole.

## 2. Literature Review

To determine the value of intensity of hole, a variety of approaches have been developed previously. McCann [3] and Nelson et al [4] have proposed a method to measure the holes. They measure the holes by the average value of its neighbours.

In the other research, Hottier and Collet Billon [5] also proposed a different method. Hottier and Collet Billon measure the value of the hole by the result of interpolation of two closest voxels in the transverse direction. Not only that, Hottier and Collet Billon also ensure that the value of the two closest voxels that used is not empty.

Next, in his study about imaging of the human spine, Purnama [6] proposed a new method that called Olympic Method. First, he sort the neighbours of the hole. After the nighbours are sorted, then some upper and lower neighbour values are removed. Last step, he average the sorted-removed neighbours value, and put it as the value of the hole.

On further research, Dewi [7] improved the Olympic Method of Purnama. She improved the Olympic Method by modified the range value of the neighbour using the average of the range width of all empty voxels. She also adjust the wight value that corresponds with the value between the average and range width values.

This research proposed a weighted neighbours interpolation to determine the holes / empty voxels. The main supremacy of this method than the others method is, this method have a unique weight value for each neighbour (every neighbour have its own unique weight). This research will do the interpolation based on weighted neighbours.

# 3. Methodology

Reconstruction is an important part in visualization system. Bin filling is a common method for reconstruction. Bin filling reconstruct 3D space based on 2D image and its coordinate. However, these methods still left empty voxels (holes) at some coordinates. It is very important to predict the value of these holes. One of the way is by interpolation.

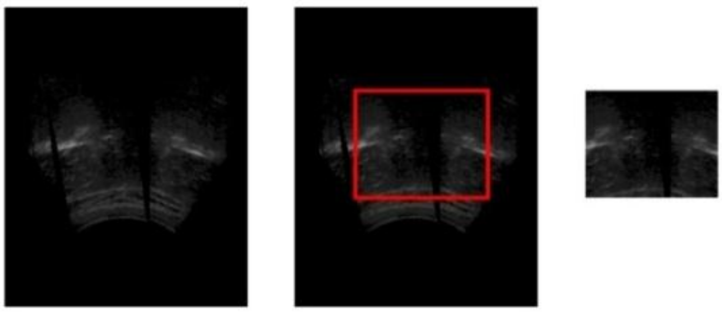
This research propose the interpolation based on weighted neighbours. This method will predict the value of the hole based on its neighbours. The difference is, this method count the weight of the neighbours first, then use it to predict the value of hole. So each neighbour has a unique weight.

Interpolation start by finding the holes / empty voxels, then calculate the distance value of the neighbours (voxel around the hole). Distance here is distance between hole and the neighbour. Then the neighbours are selected based on the radius. if the radius of the neighbour do not exceed the maximum, then the neighbour will be used. If not, then the neighbour is not used.

First we have to determine the weight of each neighbour. Last, value of the neighbours and its weights used to calculate the value of the hole.

## 3.1. Normalization

The data that used in this research were 428 pieces of two dimensional medical images. But from that image 428, only 195 are usable. This happens because the other image does not provide a complete information about the object.



a b c

**Fig 1:** Image cropping area(a)Before cropping image(b)Cropping area(c)Image result

The size of two dimensional image data is 332 x 259 pixel. But we do cropping to this image. Because we assume that there are some part of the image that unused in interpolation process. Cropping process produces a new image with the size 115 x 141 pixel. Comparison between uncropped image, cropping image area, and the image result of cropping are contained in Figure 1.

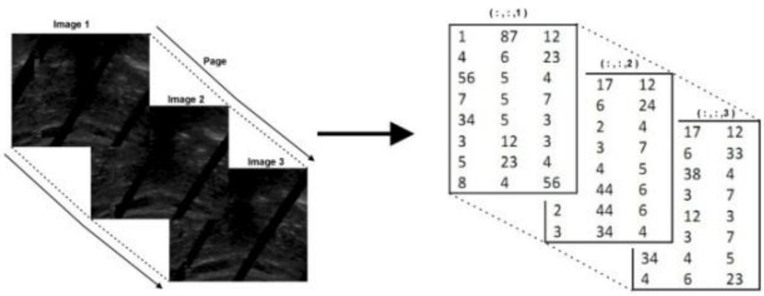



**Fig 2:** Converting a set of image data to be a three dimensional array

After the normalization process is finished, then the image data are being converted to be a three dimensional array. The value of intensity of the image are being checked for each coordinate. Then that values are stored as a 3 dimensional array (Figure 2).

## 3.2. Find the Holes

First step of interpolation process is find the hole. But must be understood first about what is hole (empty voxel) in this research. Hole in this research is the voxels that have no information or value. It is different between hole and zero voxel. Hole is voxel that have no value of intensity. While zero voxel is a voxel that have a value of intensity, but the value is 0. In the figure 3, the zero voxel marked by green square, and the hole (empty voxel) marked by red square.

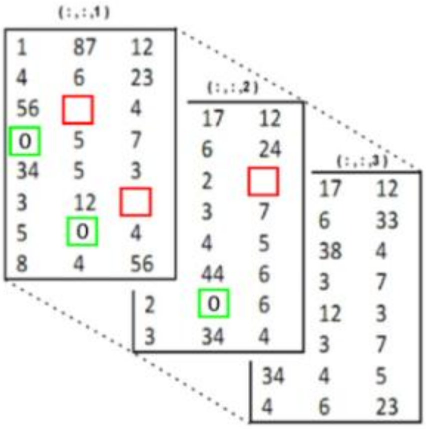



**Fig 3:** Holes (marked by red square) and zeros voxel (marked by green square)

In this research we generate random holes using the program. So that the coordinate position of the holes are random, and patternless.

To find the hole, in this research do searching for each three dimensional array element. When a voxel that have no value is found, so it will be decide as a hole. And then the coordinate of the holes are stored to be used in the next process.

Measure The Distance

After find the hole position, then need to measure the distance. Distance in this research mean the distance between the coordinate of neighbour voxel with the hole. In the next process, the distance will be the main parameter to determine the neighbour voxel is used or not in the interpolation process.

For example, there are a hole (I_h) and a non-empty voxel (I_1). The coordinate of the hole is x_h, y_h, and z_h , while the coordinate of the voxel is x_1, y_1, and z_1. To do the interpolation, first step is measure the distance (d) between hole (I_h) and voxel (I_1). To measure the distance between hole and the non-empty voxel, used Euclidian distance Equation (Formula 1).

$$d_1 = \sqrt{(x_1 - x_h)^2 + (y_1 - y_h)^2 + (Z_1 - Z_h)^2} \quad (1)$$

$d_1$= Distance between hole ($I_h$) and the non-empty voxel ($I_1$)
$x_1$= Voxel's coordinate ($I_1$) at x axes
$x_h$= Hole's coordinate ($I_h$) at x axes
$y_1$= Voxel's coordinate ($I_1$) at y axes
$y_h$= Hole's coordinate ($I_h$) at y axes
$Z_1$= Voxel's coordinate ($I_1$) at z axes
$Z_h$= Hole's coordinate ($I_h$) at z axes

### 3.3. Determine the Radius

In fact, there are so many neighbours around the hole that will be predicted. When all the points are calculated, it will make the interpolation process becomes increasingly long and heavy. And the neighbours that further from the hole often have less or unsignificant impact. Because of that reason, this research use range of radius to select the neighbours that will be used in interpolation process.

This research use the range of radius as a selector of neighbours. neighbours which are within range radius, will be given weight and then used in the interpolation process. While the neighbours that are outside the range / radius set, will be considered to have no influence on the hole.

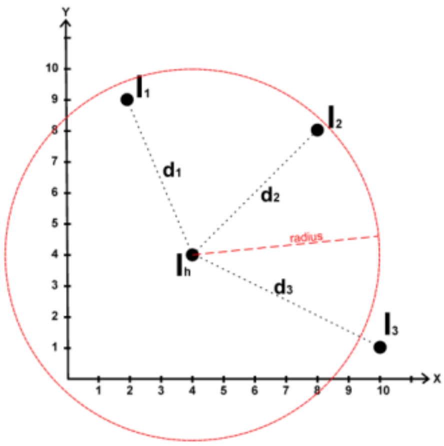



**Fig 4:** Select the neighbours based on radius (red circle).

For example, there are a hole (I_h) and three non-empty voxel (I_1,I_2, and I_3) (Figure 4). The distance from I_1,I_2, and I_3 to the hole is d_1,d_2, and d_3. And the radius is marked by the red circle. Then the distance of voxel are being checked one by one. Each distance s being compared with the radius. If the distance value is less than radius (example : I_1 and I_2), so the voxel is used as the neighbour (used in the interpolation process). But if the distance value is more than the radius (example : I_3), the voxel are rejected as the neighbour.

### 3.3. Determine the weight of each neighbour

Neighbours used for the interpolation has a distance that is different (Figure 5). So the impact of the neighbours to the hole are also different. This is the reason of this research to give unique weight for each neighbour. The weight are determined based on its distance value. the value of the distance is inversely proportional to the weight given to neighbour. The greater the distance value, the smaller the weight given. Conversely, the smaller the distance value given greater weight.

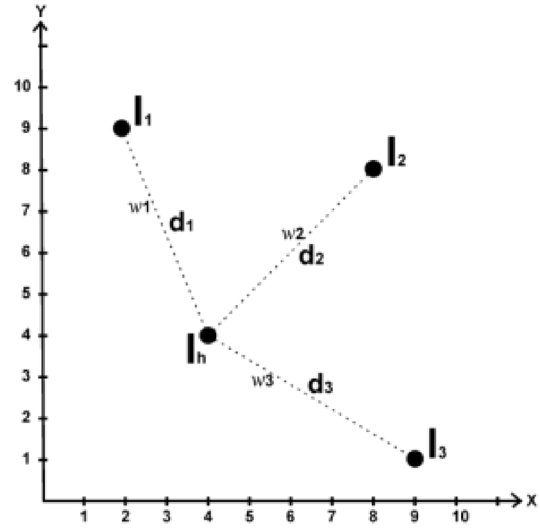



**Fig 5:** Weight of neighbours (w_1) (w_2)(w_3) based on radius.

This research want to give the weight that inversely proportional with its distance, so the authors divide the number 1 with the distance value (1/d). Not only divide 1 with the distance value, this research also squaring the distance value (1/d^2 ). The squaring will increase the distance of the value between each weight. Then the authors divide it by the square of the sum of all weights to keep the proportionality of the weight. Complete formula for calculating the weights is the formula 2.

$$w_a = \frac{\left(\frac{1}{{d_a}^2}\right)}{\sum_{i=1}^{n} \frac{1}{{d_i}^2}} \quad (2)$$

$w_a$ = Weight of the neighbour a
$d_a$ = Distance of the neighbour a
$d_i$ = Distance of the neighbour i
$n$ = Number of neighbour

### 3.4. Interpolation

Now the neighbours are being selected already, along with the weight value. The final step is to do the interpolation process, which predicts the value of empty voxels (holes). The value of the hole predicted (interpolated) based on the value of its neighbours and weight of its neighbours. To do the interpolation based on the weighting, we use the formula number 3.

$$I_h = \sum_{i=1}^{n} I_i . w_i \quad (3)$$

$I_h$ = Value of hole (empty voxel)
$I_i$ = Value of the neighbour i
$w_i$ = Weight of the neighbour i
$n$ = Number of neighbour

## 4. Result and Discussion

The data used in this research were 195 pieces of 2 dimensional image with a size of 115 x 141 (yield normalization). The result of the normalized 2 dimensional image data then converted into a 3 dimensional array form.

There is no hole in the first three dimensional array data. So this research use the random function to generate the of the holes (empty voxels). Number of holes generated in this research are varied, ranging from 50%, 60%, 70%, 80% up to 90% of all data. While the value of the range radius are also varied from 10, 20, 30, and 40 and also 50.

(a) (b) (c)

**Fig 6.** Data image without holes (a), data image with generated holes (b), Interpolation result image (c)

Examples of image data without holes and image data with generated holes are shown in figure 6. But the image shown in Figure 6 is only one frame of many existing 3-dimensional frame.

First, measure the distance of non-empty voxels around the hole by formula 1. Then the neighbours are selected based on the comparison between distance value and radius value. This step will select the chosen neighbour and the rejected neighbour. Then the weight of each neighbour are determined based on its distance value.

Interpolation process based on weighted neighbours is then do on the second image data (three dimensional array data with generated holes). The second image data is the data that has been modified by added some generated holes. But the size of the second image data is not change, still 115 x 141 pixel. But the value of the new data is different with the first, because the new data is added by holes.

The result of the interpolation is shown in figure 6 c. Physically, we can see that the interpolation result image (figure 6 c) is similar to the data image without holes (figure 6 a), its mean that the interpolation method succeeded in measure the value of the hole, resulting in images (figure 6 c) that are similar to the data image without holes (figure 6 a).

To see the accuracy of the methods that used, this research do count the average of the absolute value of reduction between the interpolated data (figure 6 c) with the original data (figure 6 a) as the error. Error value of each data are being calculated and showed in the table I. the errors of this research use scale 1 – 255 adapt with the range of the voxel intensity value. While the delta (Δ) is the absolute difference between current error with the previous error. The delta value are counted to measure the consistency of the method.

In this research, the interpolation is done with the radius value 10, 20, 30, 40, and 50. For each value of radius, will be paired with the hole value of 50%, 60%, 70%, 80% and 90%. Hole value here means the number of the hole that generated in this research. Then the average of error are being counted.

**Table 1:** Error Value of Each Radius Given

| Radius | Hole | Error | Δ |
|---|---|---|---|
| 10 | 50% up to 90% | 9,73148 | 0,00000 |
| 20 | 50% up to 90% | 10,65566 | 0,92418 |
| 30 | 50% up to 90% | 11,35816 | 0,70250 |
| 40 | 50% up to 90% | 11,96356 | 0,60540 |
| 50 | 50% up to 90% | 12,50978 | 0,54622 |
| Average | | 11,243728 | 0,55566 |

Based on the results of the experiment (Table I), we know that the average error value for all radius is 11,243728. The smallest error found in the value of radius 10, with the error value is 9,73148. While the biggest error is in the value of radius 50, with the error value is 12,50978. Then, the average of delta value is 0,55566. Its mean that in every change of radius value, will affect to the error value about 0,55566.

An increase in the value of error is directly proportional to the increase in the value of the radius. The increase in the value of error also directly proportional to the increase in the value of the hole number.

Next, the experimental setting is changed to observe the impact of the hole value to the error. The interpolation is done with the hole value 50%, 60%, 70%, 80%, and 90%. Hole value here means the number of the hole that generated in this research. For each value of holes, will be paired with the radius value of 10, 20, 30, 40 and 50. Then the average of error are being counted.

**Table 2:** Error Value of Each Hole Given

| Radius | Hole | Error | Δ |
|---|---|---|---|
| 10 up to 50 | 50% | 9,37530 | 0,00000 |
| 10 up to 50 | 60% | 10,18630 | 0,81100 |
| 10 up to 50 | 70% | 11,10402 | 0,91772 |
| 10 up to 50 | 80% | 12,16784 | 1,06382 |
| 10 up to 50 | 90% | 13,38518 | 1,21734 |
| Average | | 11,24373 | 0,801976 |

Based on the results in the table II, the average error value for all variation of hole is 11,24373. The smallest error we ge ist in the value of hole 50%, with the error value is 9,37530. Then the biggest error is found in the value of hole 90%, with the error value is 13,38518. Then, the average of delta value is 0,55566. Its mean that in every change of radius value, will affect to the error value about 0,801976.

An increase in the value of error is directly proportional to the increase in the value of the hole number. The increase in the value of error also directly proportional to the increase in the value of the radius.

## 5. Conclusion

This paper is used to propose a method to fill the hole in the three dimensional space by a representative value. The conclusions for this research are as follows:

1. The method we propose has a high accuracy, as evidenced by a small error value is 11,24373 (from the scale 0 up to 255).

2. Our method is also quite stable, as evidenced by the average margin of error for each radius changes only at 0.55566 and 0.801976 for each hole number changes.

3. An increase in the value of error is directly proportional to the increase in the value of the hole number. The increase in the value of error also directly proportional to the increase in the value of the radius.

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