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# Implicit Surface Representation of Three-Dimensional Face from Kinect Sensor

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**Abstract**

Kinect sensor has two output data which are produced from red green blue (RGB) sensor and depth sensor, it is called color image and depth map, respectively. Although this device's prices are cheapest than the other devices for three-dimensional (3D) reconstruction, we need extra work for reconstruct a smooth 3D data and also have semantic meaning. It happened because the depth map, which has been produced from depth sensor usually have a coarse and empty value. Consequently, it can be make artifact and holes on the surface, when we reconstruct it to 3D directly. In this paper, we present a method for solving this problem by using implicit surface representation. The key idea for represent implicit surface is by using radial basis function (RBF) and to avoid the trivial solution that the implicit function is zero everywhere, we need to defined on-surface point and off-surface point. Based on our simulation results using captured face as an input, we can produce smooth 3D face and fill the holes on the 3D face surface, since RBF is good for interpolation and holes filling. Modified anisotropic diffusion is used to produced smoothed surface.

**Key Words** : Implicit surface, Radial basis function, Three-dimensional face, Kinect sensor.

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## 1. Introduction

In this decades, electronic devices which has relation with graphics such as smartphone, television, 3D scanner and other device has been growth rapidly. We also known that the printer device has been development to the 3D printer. This condition contributes to the research on computer graphics field which is also growth rapidly. We could make an avatar for virtual reality games or we could make a model which is represent our self and then we can print it using 3D printer, where this work has been performed[1]. In computer graphics area, this research called surface reconstruction and reconstruct a surfaces that have semantic meaning results are a challenge for researcher.

Surface reconstruction could be more difficult if the device for data acquisition produces noisy data and many holes. This condition will be happen if we used the cheapest device for 3D data acquisition like Kinect sensor. Kinect sensor can capture 30 images per second and this device has specification range for the depth, which is between 1.2m to 3.5m. Kinect sensor could produce many holes when we take the depth map data from the distance less than 1.2m. Although we captured the depth map in the spesification range, the raw data that we get are still contain a lot of noise. The holes could be filled by using some methods such as volumetric diffusion, neighborhood method, or interpolation method likes RBF interpolation.

At the first time RBF was introduced by Powell, he provided an algorithm with a restart procedure that takes account of the objective function automatically [2]. Broomhead and Lowe have done the development from Powell's researchthe relationship between learning in adaptive layered networks and the fitting of data with high

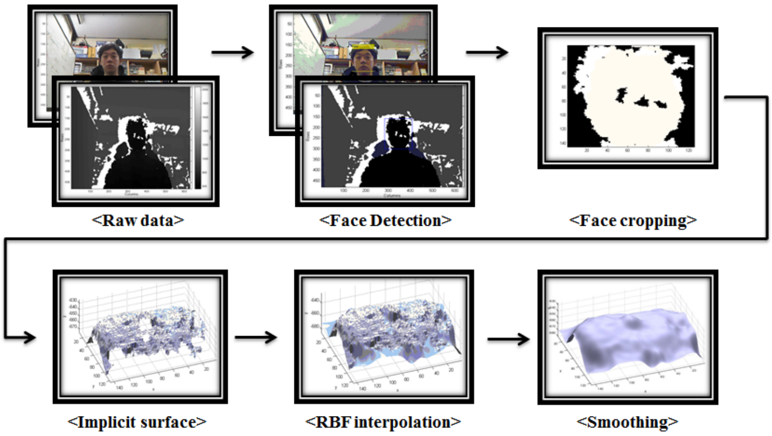


Fig. 1. Framework.

dimensional surfaces [3]. Surface interpolation for medical imaging using RBF method is proposed [4].

RBF is also has been proposed for interpolating implicit surface from scattered surface data [5]. In this paper we present 3D face representation using RBF and Kinect sensor with the distance is less than 1.2m.

This research makes the following contributions:

1. Providing a filling holes method for the 3D surface
2. Providing a smoothing method for 3D surface

The organization of this paper is as follows. Section 1 introduces surface reconstruction and previous research using RBF interpolation. In Section 2, data acquisition and preprocessing are presented in detail. In Section 3, we describe the implicit surface. Section 4 introduces smoothing of 3D surface. Section 5 presents the experiments and results. Finally, we present our conclusions in Section 6.

## 2. Data acquisition and preprocessing

Our framework shown on figure 1 which have data acquisition step, preprocessing step, implicit surface, and smoothing step. In this section, we describe about data acquisition and preprocessing step in detail.

### 2.1 Data acquisition

Assume a person sit in front of the device for data acquisition. We used the kinect sensor as a device for data acquisition. It produces good depth map data when the distance between the person and the sensor are in the range 1.2–3.5m but in our system, we used the distance less than 1.2m.

We capture the RGB image and depth map from the person one time. The size of the RGB image and depth map are same. We used 480×640 as the size of the RGB image and depth map which is represent rows and column of image, respectively. The RGB image consist three channels (red, green, and blue channel) which have 8 bits in each channel or equal to 0-255 for represent a color. Depth map consist 11 bits which is represent the distance between the object to the kinect. This values represent on millimeter.

### 2.2 Preprocessing

We have two raw data, the RGB image and depth map. Because the focus of this research is about the face, so we need determined the position of the face. Because of this reason, we need algorithm for face detection. Face detection will be implement on the RGB image, it is caused the RGB image has an information more useful than depth map.

Viola and Jones [6] has been finished outstanding result of their research. They made an algorithm for detection the face. In their research, they made three contribution. First contribution is integral image. Integral image is image representation which allows the features used by their detector to be computed very quickly. Second contribution is simple and efficient classifiers. They used AdaBoost learning algorithm for selecting a small number of critical visual feature from very large set of potential feature. The last contribution is a method for combining classifiers in a “cascade” which allows background regions of the image to be quickly discarded while spending more computation on promising face-like regions. Because of this reason, we used viola-jones face detection in our research. We used this method to RGB image.

After we determined face position and region from RGB image, we should determined face position and region from depth map. Since we did not perform camera calibration before, we could not alignment between face position and region from RGB image to depth map directly. We should extend the box size which is represent face position and region from the output of face detection. Then we can crop the depth map.

The cropped depth map that obtained from the previous step is not only contains face, background or the other object are also included in this image. To eliminate this problem, we perform some preprocessing step. First, we compute minimum value from cropped depth map. This value represent the nose, where nose is the object that has nearest distance with kinect sensor. The second step is estimate the distance range of the face. We observed this distance range and we conclude that the distance which represent the face are between minimum value of cropped depth map to 50mm further away. Since the smallest value resulting from the depth map will highly affect in the 3D reconstruction, even though zero value, so we implement not a number in the third step. Not a number will be represent not face, and it will be combine to the previous step. The last step is generate point cloud from previous step that it represents geometry. This point cloud represented as $v(x,y,z)$,where $(x,y)$ represent cartesian coordinate and $z$ is represent the value from depth map which has correlation with $(x,y)$.

## 3. Implicit surface

In this section, we present implicit surface representation. Following Carr et al [7], implicit surface representation is made by using RBF. Briefly, implicit surface representation is an approach to model the surface implicitly with a function $f(v)$.If a surface consist of all the points and satisfy the equation $f(v)=0$, it could be said that $f$ implicitly defines the surface. Two important things in this step are constructing signed-distance function and fitting an RBF to the resulting distance function.

### 3.1 Fitting an implicit function to a surface

The problem in this section is how to find a function $f$ which implicitly defines a surface and satisfies the equation $f(v)=0$. This result will be zeros in all of points because points $v$ will be lying on the surface. To avoid this condition, we should add some point called off-surface point and are given non-zero value.

The new problem is how to generate the off-surface point and what is the value will be corresponding to the off-surface point. Following [7] the off-surface point will be given positive sign if that point is on outside of the surface, and will be given negative sign if that point is on the inside of the surface. Off-surface point could be generate by calculate surface normals. In the other word, off-surface point is the surface normals. Now we have on-surface points which is represent surface points and off-surface points which is represent surface normals. By using on-surface points and off-surface points, we could find the implicit function using approach for interpolation problem.

### 3.2 Radial basis function interpolation

The set of on-surface points and off-surface points that we have is the kind of a scattered data. For the interpolation problem, it is scattered data interpolation problem. To solve this problem, we approach with to used RBF. RBF function could be determined as follow:

$$RBF(v)=p(v)+\sum_{i=1}^{N}\lambda_i\phi|v-v_i| \quad (1)$$

where $p$ is a polynomial low degree and the basic function $\phi$ is a real valued function on $[0,\infty)$.The points $v_i$ are represented as a *center* of the RBF and $N$ is equal to the number of points $v$.

The existing basic function $\phi$ that often to use in the RBF are the gaussian (usually used in the neural network), thin-plate spline (usually for smoothing and need input two variable), multiquadric, biharmonic (Eq. 1), and triharmonic. In this research we used biharmonic basic function because we want to fit with three variables which represent the coordinate of the points $v$. Eq. 1 could be formulated as a linear system, and this linear system can be written as follows, and where $d$ is the value of surface normal and $c$ is polynomial coefficient.

After we determined the RBF interpolant, we can fit this interpolant to the surface which is generate based on grid representation, and the range of value $(x,y)$ on grid representation are from minimum to the max-

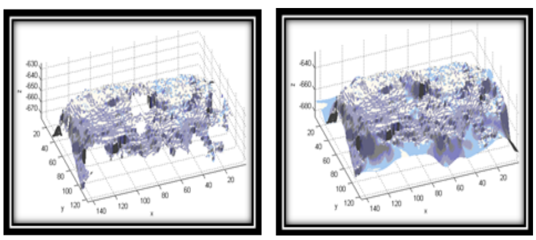

Fig. 2. 3D face before (left) and after (right) interpolation using RBF.

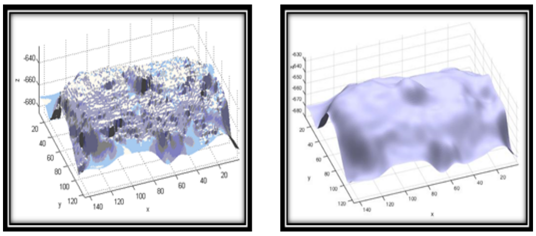

Fig. 3. 3D face before (left) and after (right) smoothing using modified anisotropic diffusion.

$$\begin{bmatrix} \phi_{11} & \phi_{12} & \cdots & \phi_{1N} & 1 & x_1 & y_1 & z_1 \\ \phi_{21} & \phi_{22} & \cdots & \phi_{2N} & 1 & x_2 & y_2 & z_2 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \phi_{N1} & \phi_{N2} & \cdots & \phi_{NN} & 1 & x_N & y_N & z_N \\ 1 & 1 & \cdots & 1 & 0 & 0 & 0 & 0 \\ x_1 & x_2 & \cdots & x_N & 0 & 0 & 0 & 0 \\ y_1 & y_2 & \cdots & y_N & 0 & 0 & 0 & 0 \\ z_1 & z_2 & \cdots & z_N & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_N \\ c_0 \\ c_1 \\ c_2 \\ c_3 \end{bmatrix} = \begin{bmatrix} d_1 \\ d_2 \\ \vdots \\ d_N \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (2)$$

imum value of each other. We can get new values of $z$ by using this procedure. Figure 2 shown the result of the interpolation using RBF. In this example, we used $N$ is equal to 26994.

## 4. Smoothing

Since the result from interpolation using RBF still coarse, we will perform smoothing in this step in order to get smooth surface. Suryo and co-worker [8] perform smoothing surface using modified anisotropic diffusion. In their work, the detect not a number (nan) and replace this value to the zero while perform anisotropic diffusion. We follow their work for our smoothing process.

Begin with the result from interpolation using RBF, we have the new points data about $v(x,y,z)$,we called this as $v_{rbf}(x_{rbf}, y_{rbf}, z_{rbf})$. $x_{rbf}$, $y_{rbf}$, and $z_{rbf}$ consist of 2D array, respectively. Because of $(x_{rbf},\ y_{rbf})$ represent value from mesh grid data and it is important to constructing triangle mesh, so we did not set this value as an input to smoothing process using modified anisotropic diffusion. The input for modified anisotropic diffusion that we set are only from $z_{rbf}$ values. So, the input for modified anisotropic diffusion are 2D array.

This smoothing process begin with calculating finite differences of each neighborhood pixel, this process need a 2D matrix mask with the size is 3×3 for each matrix. By using this matrix, calculating finite differences could be determined by performing convolution between $z_{rbf}$ and 2D matrix. 2D matrix shown in Eq. 3

$$\begin{aligned} M_1 &= \begin{bmatrix} 0 & 1 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{bmatrix}, M_2 = \begin{bmatrix} 0 & 0 & 1 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{bmatrix}, M_3 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & -1 & 1 \\ 0 & 0 & 0 \end{bmatrix}, \\ M_4 &= \begin{bmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, M_5 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 1 & 0 \end{bmatrix}, M_6 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & -1 & 0 \\ 1 & 0 & 0 \end{bmatrix}, \\ M_7 &= \begin{bmatrix} 0 & 0 & 0 \\ 1 & -1 & 0 \\ 0 & 0 & 0 \end{bmatrix}, M_8 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{bmatrix}. \end{aligned} \quad (3)$$

Eq. 4 shown about the convolution between 2D matrix mask and $z_{rbf}$,

$$\begin{aligned} &CZ_1 = Z_{rbf} * M_1, CZ_2 = Z_{rbf} * M_2, CZ_3 = Z_{rbf} * M_3, \\ &CZ_4 = Z_{rbf} * M_4, CZ_5 = Z_{rbf} * M_5, CZ_6 = Z_{rbf} * M_6, \\ &CZ_7 = Z_{rbf} * M_7, CZ_8 = Z_{rbf} * M_8 \end{aligned} \quad (4)$$

$CZ$ is the convolution result.

After this we determined the convolution result, the next step for smoothing process is calculating partial differential equation by using Eq. 5,

$$PDE = D\_coef \cdot \sum_{i=1}^{8} \frac{1}{1 + \left( \frac{CZ_i}{\sigma} \right)^2} \cdot CZ_i \quad (5)$$

where $D\_coef$ is equal to 0.2 and $\sigma$ is equal to 10.

The last step for smoothing process are replace nan with the zero in the $PDE$, after this we can determined

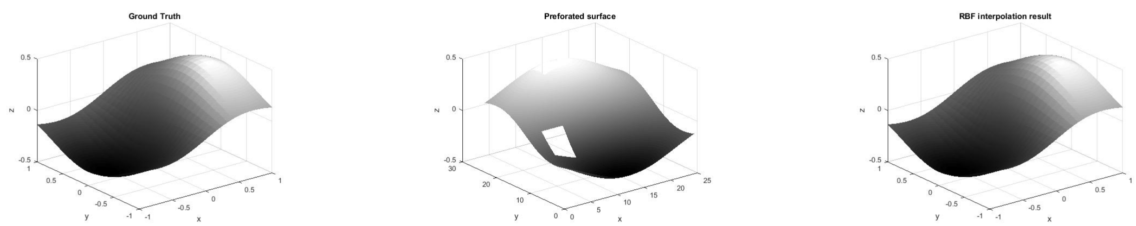


Fig. 4. (Left) Ground truth data, (Center) example of preforated surface and (Right) result of RBF interpolation.

new value from $z_{rbf}$ by using Eq. 6.

$$z_{rbf} = z_{rbf} + PDE \tag{6}$$

this process (Eq. 4 to Eq. 6) will be repeated until the number of iterations. In this example, the number of iterations that we used is 10 iterations. Figure 3 shown the comparison of 3D face before smoothing and after smoothing.

## 5. Experiment

In our experiment, we used three different people and each person has four different data. All the data contains many holes and noisy. By using the data, we perform testing procedure to determine the performance of our algorithm. We can see that holes in the 3D face could be filled by using RBF. By performing RBF and modified anisotropic diffusion, we can get smooth surface and also the holes could be filled.

Since we did not have ground truth data, we could not know the performance of RBF interpolation. In this section, we will calculate the performance of RBF interpolation using RMSE. The ground truth data generated based on our simulation and artificial holes will be embedded in to the ground truth data, it will become new data called perforated surface. This perforated surface will be set to be the input of RBF interpolation, and we will calculate the RMSE between the result of RBF interpolation and the ground truth data. Figure 4 illustrated the ground truth data, example of preforated surface and the result of RBF interpolation.

RMSE calculated from 5 preforated surfaces with different number of holes. Table 1 shows the result of RMSE. Based on Table 1, RBF interpolation can be used to fill the hole and this method produces little error. The example result of the testing process is illustrated in the right-most of Figure 4.

Table 1. Result of RMSE from preforated surface

| Name | Number of holes | RMSE |
|---|---|---|
| Preforated_surface_1 | 1 | 0.00056 |
| Preforated_surface_2 | 2 | 0.00081 |
| Preforated_surface_3 | 3 | 0.00053 |
| Preforated_surface_4 | 4 | 0.00051 |
| Preforated_surface_5 | 5 | 0.00055 |
| Preforated_surface_6 | 6 | 0.00022 |
| Preforated_surface_7 | 7 | 0.00014 |
| Preforated_surface_8 | 8 | 0.0003 |
| Preforated_surface_9 | 9 | 0.00024 |
| Preforated_surface_10 | 10 | 0.00024 |

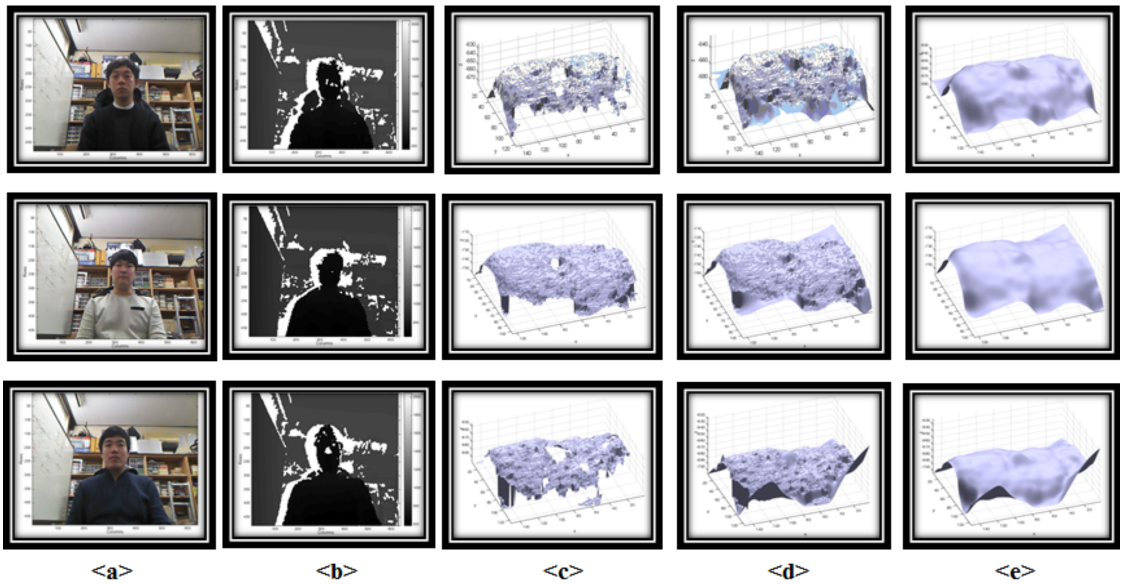


Fig. 5. 〈a〉 is raw data of RGB image, 〈b〉 is raw data of depth map, 〈c〉 is 3D face contains holes and coarse surface, 〈d〉 is the result of RBF interpolation, and 〈e〉 is smoothing result using modified anisotropic diffusion.

## 6. Conclusions

This paper presents a method to filled the holes and produces smooth result with the single input data (single RGB and single depth map). For fill the holes, we should determined about implicit surface, and this problem could be solved by using RBF interpolation, since this problem is kind of scattered data problem.

For avoid trivial solution problem which is zero everywhere, signed-distance function should be determined. Modified anisotropic diffusion can be used to produce smooth surface. Based on the simulation to produce smooth surface. Based on the simulation from artificial data, RBF is one of robust method for scattered data interpolation problem.

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