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Application of Curve Interpolation Algorithm in CAD/CAM to Remove the Blurring of Magnified Image

Yong-Joong Lee*
*Division of Automation System Engineering in Chang Won Polytechnic College

Abstract

This paper analyzes the problems that occurred in the magnification process for a fine input image and investigates a method to improve the problems. This paper applies a curve interpolation algorithm in CAD/CAM for the same test images with the existing image algorithm in order to improve the problems. As a result, the nearest neighbor interpolation, which is the most frequently applied algorithm for the existing image interpolation algorithm, shows that the identification of a magnified image is not possible. Therefore, this study examines an interpolation of gray-level data by applying a low-pass spatial filter and verifies that a bilinear interpolation presents a lack of property that accentuates the boundary of the image where the image is largely changed. The periodic B-spline interpolation algorithm used for curve interpolation in CAD/CAM can remove the blurring but shows a problem of obscuration, and the Ferguson's curve interpolation algorithm shows a more sharpened image than that of the periodic B-spline algorithm. For the future study, hereafter, this study will develop an interpolation algorithm that has an excellent improvement for the boundary of the image and continuous and flexible property by using the NURBS, Ferguson's complex surface, and Bezier surface used in CAD/CAM engineering based on the results of this study.

Key Word : magnification process. nearest neighbor. gray-level data. low-pass spatial filter. bilinear interpolation. CAD/CAM. NURBS, Ferguson's. Bezier.

I. Introduction

The shape recognition of a human being for the existing fixed shape is not performed by the principle that a retinal image is independent from the magnification, and a study that will improve an ability for the shape recognition through a number of methods has been processed [1]. In order to express a very fine input image in detail, the typical way is a magnification of the input image. However, a simple magnification of an input image applied by some arbitrary sample rates will cause a wrong region or boundary of the image, and then the recognition will fail. In the case of an automatic image inspection system, which inspects the quality of products and identifies whether or not they were passed, especially, is more serious [2, 3, 4].

Therefore, this study applies an image interpolation algorithm produced by the existing image processing algorithm and interpolation algorithm used in CAD/CAM in order to analyze the problems that occurred in the magnification process for a fine input image and investigate a method to improve the problems [5, 6]. It is known that an interpolation process changes an arbitrary sample rate to another sample rate, and an interpolation applied in image processing is a kind of estimation process of the intermediate value of a continuous signal from discrete samples that can usually be applied to the correction of spatial distortion when an image is magnified or reduced. There are various image interpolation methods used in the present, such as the nearest neighbor interpolation that mainly uses an image, which has a gray-level data and extracted outline, low-pass filtering that uses the characteristics of image frequency, and bilinear interpolation that applies to the interpolation of the gray-level data of the four pixels neighbored by the pixels of an input image. In addition, there are some algorithms used for the curve interpolation, such as a parametric B-spline that can interpolate by using a set of polynomial expressions, which connects the neighbored sampled data and Ferguson's curve that can be expressed by a unit curve and its end points for both end points, tangential vector, and parameters [7, 8, 9]. Especially, the non-periodic (open type: non-periodic) B-spline blending function among the parametric B-spline is changed by the position so that it can't be applied for the image interpolation due to the difficulties in calculation or correction for the curve. However, the periodic (closed type: periodic) B-spline blending function can be applied for the interpolation.

From the results of the experiment, the interpolation applied by the nearest neighbor interpolation among the present image interpolation methods is almost impossible to recognize the magnified image, and the bilinear interpolation shows a lack of property that accentuates the boundary of the image and other problems. In addition, the periodic B-spline algorithm can remove the blocks but shows a problem of obscuration, and the Ferguson's curve interpolation algorithm has merit because it presents a more sharpened image than that of the periodic B-spline algorithm. As a result, this study arranges the ideas on the magnification of image and compares and analyzes them through some tests. Moreover, this study constructs the basis for the development of an interpolation that has a good improvement for the boundary of image and flexibility. Furthermore, the results of this study can be applied to the process of production for the automatic vision inspection system with shape recognition for the magnified images of micro parts so that this will increase the quality and uniformity of products and devote a reduction of costs including the strengthening of the competitiveness of technology.

II. Main Subjects

1. Image interpolation by the existing method

For the transformation of an arbitrary pixel (x, y) of an input image to the pixel of an output image (x_n, y_n), the spatial relationship between the two pixels can be expressed by Eq. (1).

$$x_n = ax, \; y_n = ay \qquad (1)$$

where a, b are the factors of the direction of x and y respectively. In addition, the pixels of an input image p, q, and r are mapped to the pixels of an output image p', q', and r' respectively in case of the magnification of an input image as shown in Figure 1.

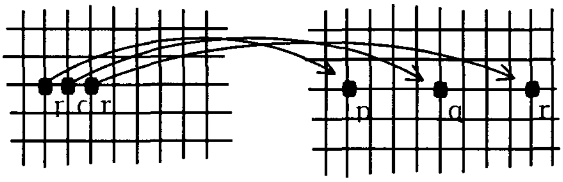
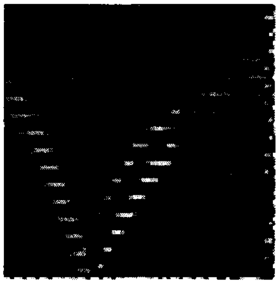


Figure 1. Magnification of an input image

For the actual magnification of images, however, it is a more serious problem whether or not the results were verified can only be considered by the outline or other feature points without the processing of the whole gray-level data for an input image to get the fast figuration in case of the automatic image inspection system. As shown in Figure 2 (a), the original image is filtered by a 3x3 convolution gradient operator and reduced by 1/4 as presented in Figure 2 (b). And then, it is almost impossible to recognize the image if it is restored by its orignal size as presented in Figure 2 (c). This is because that the mapped pixels p', q', and r' can't decide the values of gray-level for the neighbored pixels between p' and q', or q' and r' for the magnification rate by integer like $a = b = 4$ for a and b so that these blocks can be produced by the decrease of the continuity for the gray-level data of mapped pixels [10].

(a) Image of a gradient outline

(b) Reduced by 1/4 for the image (a)



(c) Restoration image for the image (a)

Figure 2. Reduction and restoration of the image

As expressed by Eq. (2), the blocks are also presented for the nearest neighbor interpolation applied for the gray-level data of the neighbored pixels that are similar to the previously mentioned results.

$$x_n = (x_{float}+0.5), \; y_n = (y_{float}+0.5) \qquad (2)$$

On the other hand, the low-pass spatial filter uses the characteristics of image frequency that show a different luminosity of an image from a low frequency, which shows a slow change of luminosity to a high frequency, which has a fast change of luminosity. The convolution mask for the low-pass filter can be formed by 9 coefficients as presented in Table 1.

Table 1. Convolution mask

1/9 (x-1, y-1)	1/9 (x, y-1)	1/9 (x+1, y-1)
1/9 (x-1, y)	1/9 (x, y)	1/9 (x+1, y)
1/9 (x-1, y+1)	1/9 (x, y+1)	1/9 (x+1, y+1)

Table 1 presents that the centered pixel and neighbored 8 pixels can be applied by the averaging process for the convolution mask and gray-level data of the pixels,

$$O(x_n, y_n) = \frac{1}{9} I[(x-1, y-1) + (x, y-1) + (x+1, y-1) + (x-1, y) + (x, y) + (x+1, y) + (x-1, y+1) + (x, y+1) + (x+1, y+1)] \quad (3)$$

where $O(x_n, y_n)$ is the output image, and $I(x, y)$ is the input image. The fastest frequency in the image can interpolate the magnified image by reducing the property of high frequency as shown in Figure 3 because the gray-level data, which is rapidly changed from 255 to 0, will exist as an edge or point in one or two pixels and strengthening the property of low frequency only.

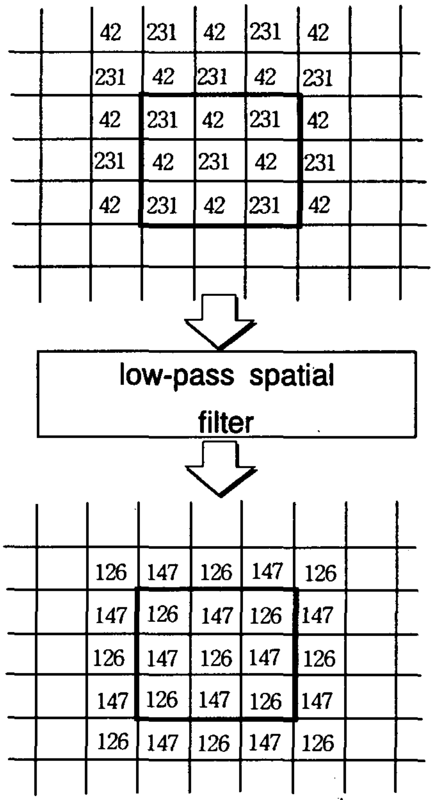


Figure 3. Low-pass spatial filter

Therefore, the characteristics of the low-pass filter that has the 3x3 group with the constant gray-level data will not change the pixel values. That is, the spatial frequency becomes 0, and it means that the gray-level data for the pixels within the section is not changed. However, this result has a weak point because the continuity will decrease due to neglecting the characteristics of image for each section.

On the other hand, the bilinear interpolation can be applied for the gray-level data of the four pixels neighbored by the pixel of an input image (x, y) as shown in Figure 4.

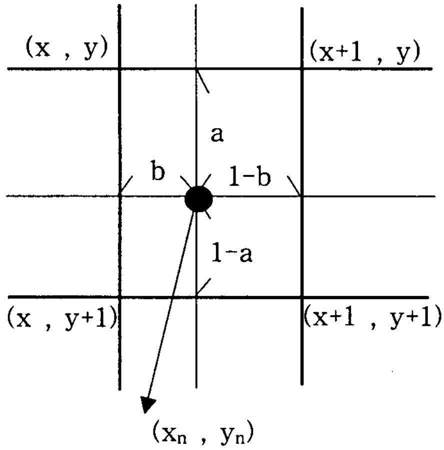


Figure 4. Bilinear interpolation

$$O(x_n, y_n) = (1-a)(1-b)I(x,y) + (1-a)bI(x,y+1) + a(1-b)I(x+1,y) + abI(x+1,y+1) \quad (4)$$

where a, b are the weighted data of $x_{float} - floor(x)$, $y_{float} - floor(y)$ respectively. It is considered that the method has a lack of property that accentuates the boundary of the image where the image is largely changed by following the considerations of the characteristics of the view angles of human beings because these are formed by the directional structure that will be affected by the nearest pixel among the four neighbored pixels of what the pixel is to be interpolated.

2. Application of curve interpolation algorithm in CAD/CAM for the image interpolation

Generally, a typical way to express the shape in CAD/CAM engineering are parametric and non-parametric equations. A non-parametric equation has merit because it can easily be analyzed by dividing the equation as a positive and negative function but is subordinated when the equation of shape is transferred into a coordinate system. In addition, it has a weak point that the expression of a shape is difficult if the coordinate is changed. Moreover, the expression is impossible if a curve or surface included in the shape are not in a plane and have a boundary [14]. However, a parametric equation can simply express a shape using a single parameter, which is a type of vector. Especially, it can be easily applied to the development of a program for the soften surface processing in CAM. Therefore, a parametric equation is usually used to interpolate a curve and surface in CAD/CAM engineering, and the minimum order of polynomial that guarantees the location and inclination between the two neighbored sampled data (first order differential continuous) and continuity of curvature (second order differential continuous) is the 3rd order polynomial. A parametric B-spline curve interpolates curve using a set of polynomial, which connects the neighbored sampled data and divides it as a non-periodic and periodic one. In addition, the equation can be expressed by Eq. (5) if the sampled date is Q_i.

$$R(u) = \sum_{i=0}^{n} Q_i N_{i,k}(M) \quad (5)$$

where $N_{i,k}(u)$ is the Bernstein blending function of B-spline and has a circulative property, which can be defined by the Cox-Deboor algorithm as follows.

$$\begin{cases} N_{i,1}(u) = \begin{cases} 1 : t_i < u < t_{i+1} \\ 0 : \text{그 외의 경우} \end{cases} \\ N_{i,k}(u) = \dfrac{(u-t_i)N_{i,k-1}(u)}{t_{i+k-1}-t_i} + \dfrac{(t_{i+k}-u)N_{i+1,k-1}(u)}{t_{i+k}-t_{i+1}} \end{cases} \tag{6}$$

where k expresses the $(k-1)$th order polynomial, and t_i is a vector. For $k=5$ and $n=5$, the B-spline curve can be presented as follows [14].

$$N_{0,4}(u)=\frac{1}{2}u\,(1-u)[(4-3u)N_{2,1}(u)+(2-u)^2N_{3,1}(u)] \tag{7}$$

$$N_{1,4}(u)=\frac{1}{2}[(-4u^3+6u^2)N_{2,1}(u)+(u^4-2u^3-8u^2+15u-6)N_{3,1}(u) + (u^3+4u^2-21u+18)N_{4,1}(u)] \tag{8}$$

$$N_{2,4}(u)=\frac{1}{2}u[u^2N_{2,1}+(-2u^2+6u-3)N_{3,1}(u)+(3-u)^2N_{4,1}(u)] + \frac{1}{6}(3-u)(u-1)[(u-1)N_{3,1}(u)+(3-u)N_{4,1}(u)] \tag{9}$$

$$N_{3,4}(u)=\frac{1}{6}\{u(u-1)[(u-1)N_{3,1}(u)+(3-u)N_{4,1}(u)] + (4-u)[(u-2)N_{4,1}(u)+(4-u)N_{5,1}(u)]\} + \frac{1}{2}(3-u)[(u-3)^2N_{5,1}(u)] \tag{10}$$

. . . .

$$N_{4,4}(u)=\frac{1}{2}\{(u-1)[(u-3)^2N_{5,1}(u)]+(3-u)[(u-3)^2N_{5,1}(u)]\} \tag{11}$$

Therefore, the relationship between the $(k-1)$th polynomial of the blending function of the non-periodic B-spline and the knot vector according to the arrangement of the processes of Eqs. (7) to (11) can be shown in Table 2.

Table 2. Knot vectors of the blending function

k	t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
1	0	1	2	3	4	5	6	6	6
2	0	0	1	2	3	4	5	5	5
3	0	0	0	1	2	3	4	4	4
4	0	0	0	0	1	2	3	3	3

As presented in Table 2, the blending function of the non-periodic B-spline stresses a non-periodic property for the changes of the locations but is hard to apply for the image interpolation due to the difficulties in the calculation and correction of curves. In order to improve these problems, a periodic B-spline can obtain a periodic property in the arbitrary sections as follows, because the knot vector becomes $t_i = i-4$ for $k=5$.

⓪area : $N_{i+0,1}$
　　$N_{i+0,2}$
①area : $N_{i+1,1}$　　$N_{i+0,3}$
　　$N_{i+1,2}$　　$N_{i+0,4}$
②area : $N_{i+2,1}$　　$N_{i+1,3}$
　　$N_{i+2,2}$　　$N_{i+1,4}$
③area : $N_{i+3,1}$　　$N_{i+2,3}$
　　$N_{i+3,2}$　　$N_{i+2,4}$
④area : $N_{i+4,1}$　　$N_{i+3,3}$
　　$N_{i+4,2}$　　$N_{i+3,4}$
⑤area : $N_{i+5,1}$　　$N_{i+4,3}$
　　$N_{i+5,2}$
⑥area : $N_{i+6,1}$

(12)

Therefore, the blending function of the periodic B-spline produced by Eq. (12) can be expressed as follows.

$$N_{0,4}=\frac{1}{3}[(u+4)N_{0,3}(u)+(-u)N_{1,3}(u)] \tag{13}$$

$$\Rightarrow \begin{cases} ◎\ area: \frac{1}{6}(u^3+12u^2+48u+64) \\ ①\ area: -\frac{1}{6}(u^3+10^2+32u+32) \\ ②\ area: \frac{1}{6}(u^3+3u^2+3u) \\ ③\ area: \frac{1}{6}(u^3+u^2) \end{cases}$$

$$N_{1,4}=\frac{1}{3}[(u+3)N_{1,3}(u)+(1-u)N_{2,3}(u)] \quad (14)$$

$$\Rightarrow\begin{cases} ① \ area: \frac{1}{6}(u^3+9u^2+27u+27) \\ ② \ area: -\frac{1}{6}(3u^3+15u^2+21u+5) \\ ③ \ area: \frac{1}{6}(u^3-4u^2-6u+1) \\ ④ \ area: \frac{1}{6}(-u^3+3u^2-3u+1) \end{cases}$$

$$N_{2,4}=\frac{1}{3}[(u+2)N_{2,3}(u)+(2-u)N_{3,3}(u)] \quad (15)$$

$$\Rightarrow\begin{cases} ② \ area: -\frac{1}{6}(2u^3-4u^2+4u) \\ ③ \ area: \frac{1}{6}(u^3+6u^2+12u+8) \\ ④ \ area: \frac{1}{6}(3u^3-6u^2+4) \\ ⑤ \ area: -\frac{1}{6}(u^3-6u^2+8u-8) \end{cases}$$

$$N_{3,4}=\frac{1}{3}[(u+2)N_{3,3}(u)+(2-u)N_{4,3}(u)] \quad (16)$$

$$\Rightarrow\begin{cases} ③ \ area: \frac{1}{6}(u^3+4u^2+5u+2) \\ ④ \ area: -\frac{1}{6}(3u^3+4u^2-u-6) \\ ⑤ \ area: -\frac{1}{6}(2u^3-9u^2+11u-14) \\ ⑥ \ area: -\frac{1}{6}(u^3-7u^2+21u-18) \end{cases}$$

On the other hand, the Ferguson's curve consists of a blending function expressed by the tangential vectors and parameters as follows.

$$R(u)=(2u^3-3u^2+1)R(0)+(-2^3+3^2)R(1)+(u^3-2u^2+u)R_u(0) + (u^3-u^2)R_u(1) \quad (17)$$

where $R(0)$ and $R(1)$ are the start and end point vector of the unit curve, $R_u(0)$ and $R_u(1)$ are the start and end point vector of the tangential line. These curve interpolation algorithms produced from the field of CAD/CAM engineering can be applied as follows to keep the local properties in accordance with the application of image interpolation [10, 11]

Setting an input image $I(x, y)$

↓

Creation of a new coordinate system for the output image $O(x_n, y_n)$ by the same magnification rate as presented in Eq. (1)

↓

Setting a range for the neighbored pixels based on the pixels, which are to be interpolated, and then interpolate for the vertical and horizontal direction

- Setting the weighted sample points as follows when the blending function of the periodic B-spline of Eqs. (13) to (16) are applied.

$$N_{0,4}(u) + N_{1,4}(u) + N_{2,4}(u) + N_{3,4}(u) = 1$$

- For applying the Ferguson's curve as presented in Eq. (17), it is necessary to consider that a line or tangle will occur according to the dimension of the tangential line.

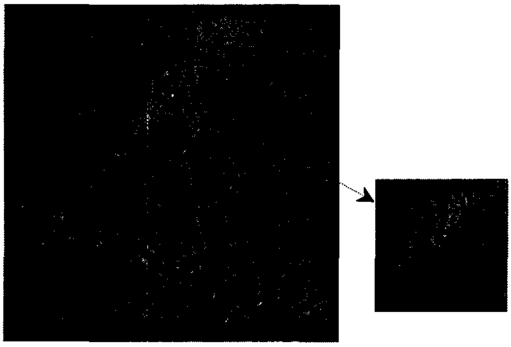
↓

Adjusts the exceeds of the negative or maximum gray-level pixel data after the calculation and returns it to $O(x_n, y_n)$

Figure 5. Application of the curve interpolation algorithm used in CAD/CAM

III. Test and considerations

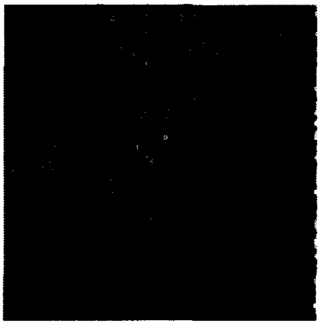
The objective of this study is to analyze the problems for the implementation of a system that will identify fast, whether or not it was passed by using an outline. The test image was selected by an M.R.I picture for the inspection of a blood vessel as shown in Figure. The inspection is processed by the magnification of the suspicious region of a patient by the doctor in charge as marked in Figure 6 (a) like the image shown in Figure 5 (b) in order to inspect more precisely.



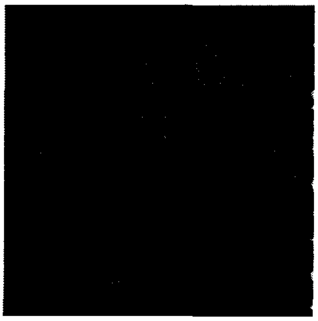
(a)Original image (b) Separated image of the suspicious region

Figure 6. M.R.I Image for the inspection of blood vessel

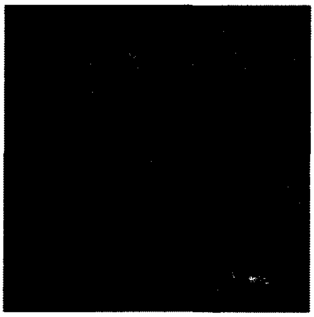
For the results of the magnification of the image shown in Figure 7, Figure (a) applied by the nearest neighbor interpolation algorithm is not possible to recognize the image due to the severe mosaic. Figure (b) applied by the low-pass spatial filter shows the interpolated image with a mid-gray-level data due to the weakness of high frequency, which exist as an edge or point but is also hard to recognize the image because of the blurring. Finally, Figure (c) applied by the bilinear interpolation algorithm presents the first interpolated image with 3 pixels per each pixel that shows a better image than those of (a) and (b), but it has a problem in that the thick blood vessel presented by the plane region shows the blurring too.



(a) Nearest neighbor interpolation



(b) Low-pass spatial interpolation



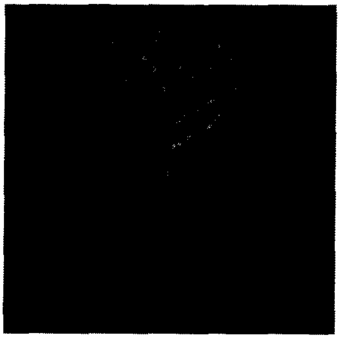
(c) Bilinear interpolation

Figure 7. Results of the image interpolation

Figure 8 presents the application of a curve interpolation algorithm used in

CAD/CAM. Figure (a) illustrates the application of the periodic B-spline in which the blocks are removed by the interpolation with a mid-gray-level data as same as the low-pass spatial filter, but it shows a problem of blurring around the suspicious region. Figure (b) shows the Ferguson's curve where the parameter of Eq. (13) is fixed by -0.5. It is verified that the results present a more sharpened image than that of the periodic B-spline applied by the 3rd order polynomial because the interpolated curve is changed from being slow to the rapid state according to the increase of parameter.

(a) B-spline



(b) Ferguson's curve

Figure 8. Results of the application of a curve interpolation algorithm used in CAD/CAM

III. Conclusions

This paper analyzes the problems that occurred in the magnification process for a fine input image and applies the existing image interpolation algorithm and curve interpolation algorithm used in CAD/CAM to investigate a method to improve the problems. The results of the comparison and analysis for the experimental image interpolation algorithm presented above are as follows.

(1) The interpolation applied by the nearest neighbor interpolation algorithm is almost impossible to recognize the image.
(2) The low-pass spatial filter can be interpolated by the mid-gray-level data.
(3) The bilinear interpolation algorithm has a lack of property that accentuates the boundary of an image where the image is largely changed.
(4) The periodic B-spline can remove the blocks but shows the blurring.
(5) The Ferguson's curve presents a more sharpened image than that of the periodic B-spline.

For the future study, we will develop an interpolation algorithm that has an excellent improvement for the boundary of image and a continuous and flexible property for the magnified images by using the NURBS, Ferguson's complex surface, Bezier surface, and various other things used in CAD/CAM engineering based on the results of the comparison and examination of this study.

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