

## Design and Modeling of Tool Trajectory in $C^0$ Continuity Concept by Importing the IGES Neutral File

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### Abstract

A common task in geometric modeling is to interpolate a sequence of points or derivatives, sampled from a curve, with a parametric polynomial or spline curve. To do this the first step is to choose parameter values corresponding to the interpolation points. In a parametric environment, user can completely define a geometric feature with some parameters. This paper has an aim to generate a smooth tool trajectory spline for machining a workpiece. With the spline technique MATLAB program has been proposed for simulation of cutter contact points in the trajectory. The author has gone through  $C^0$  continuity concept and at last the simulated result has been shown by MATLAB program in its output.

Keywords :- Spline, Approximation technique, C++, IGES, MATLAB

### 1. Introduction

Process planning is one of the functions for the manufacturing that determines which processes and parameters are to be used to product a part from its initial form to a final form predetermined in an engineering drawing. The input to the system will be a two- or three-dimensional computer-aided design (CAD) model. In milling operation, a tool moves along the tool path at cutter contact point (CC) linearly, that is a curved surface is approximated by a series of straight line segments. The length of each line segment between CC points is called a forward step. In this paper, we propose a new methodology that generates tool path for free-form curve.

The cubic Bezier curve can be represented by four control points. Higher degree of the curve requires more control points. Degree of the curve is equal to one value less than the order of the curve. The cutter contact points are generated through MATLAB program and its simulation of trajectory declaration has been shown in the output of the proposed program.

Parametric curves are extensively being applied in CAD design of a wide range of industries to represent the complex parts such as automotive, aerospace and dies/molds. However, most conventional CNC systems only provide linear/circular interpolators. Inevitably, there is a big gap between CAD design and CNC machining. In order to make up this gap, the traditional method is to divide the curves into a huge number of small linear segments, then input these segments to CNC systems. Inside CNC system, the linear interpolator conducts interpolation calculation and generates reference positions to drive the servo system of machine tool to finish machining movement.

Many related references on NC machining can be found in different application. During the last years, much progress has been made to use high-level geometric primitives, such as spline curves, directly for NC machining [1],[2]. In general, the trajectory of the tool is defined as the Cartesian space path of the tool relative to the workpiece [3],[4]. Any physical object can be viewed as a collection of points in Euclidean space. This is the basis for mathematical models of physical objects. Curve based surface creation technique is a challengeable topic now a days. Despite some promising results from space filling curve method, to be practically useful, more work on the machine dynamics and the surface finish is yet to be done [3],[4],[5],[6].

As in most CAM literatures, the cutter location (CL) path represents the trajectory of the cutter centre for a particular tool path [6], [7], [8], [9]. The most frequently used tool path generation methods in CNC machining of free-form surfaces use planar curves [8],[9],[10],[11],[12]. A new approach has been developed based on using Bezier curves as the seed function for the path planning algorithm as an alternative to cubic splines. The resulting path is manipulated by the control points of the bounding polygon [13].

In modern commercial CAD and systems, a wide variety of part shapes for dies and molds are usually represented in parametric curves (or surfaces) like the Bezier curve, B-spline, and NURBS [14]. However, conventional CNC machines only provide line or circular interpolators. In order to perform the machining of molds, the shapes and desired tool paths designed using CAD/CAM systems are typically approximated with very small line or circular segments. These line segments are further processed by post processors to produce straight-line G-codes which constitute the commands needed to control the machine. In the CNC system, these linear G-codes are fed into the interpolator that makes a linear motion for the curve. Linear NC segments are perhaps still the best NC representation form that is used to generate NC tool paths for digital CAD models because of the tool path generation speed and accuracy.

## 2. Initial Graphics Exchange Specification (IGES) :

The Initial Graphics Exchange Specification (IGES) is a file format which defines a vendor neutral data format that allows the digital exchange of information among Computer-aided design (CAD) systems. The official name of IGES is “Digital Representation for Communication of Product Definition Data”, first published in January, 1980 by the U.S. National Bureau of Standards as NBSIR 80-1978. Using IGES, a CAD user can exchange product data models in the form of wireframe, freeform surface or solid modeling representations. IGES supports the application related to traditional engineering drawings, models for analysis, and other manufacturing functions.

An IGES file is composed of 80-character ASCII records. One of the unique features of the IGES standard is that it was the first ANSI Standard to be documented using itself. Since Version 4.0, all of the technical illustrations for the printed version of the standard have been generated from IGES files. Beginning with IGES version-5.2, the most recent ANSI approved version-5.3 is utilized as a starting platform for technique development in this research work. This IGES file is used here as a digital representation of freeform curve and surface data and it is an input part for IGES reader software to filter the entity index.

The file is divided into 5 sections: Start, Global, Directory Entry, Parameter Data, and Terminate indicated by the characters S, G, D, P, or T in column 73. The characteristics and geometric information for an entity is split between two sections; one in a two record, fixed-length format (the Directory Entry Section), the other in a multiple record, comma delimited format (the Parameter Data Section), as can be seen in a more human-readable representation of the file.

A spline curve is a curve composed of two or more segments where each segment is defined by its own polynomial. To create a spline the user specifies three or more points for the spline to interpolate. The CAD system then automatically sets up the right equations to calculate the tangents at all points and then stores the spline in the database as a number of consecutive polynomial segments. The exact way to calculate tangents can differ between systems. The spline data forms of the corresponding IGES entities in the following ways:

**Degree :-** The IGES parametric spline entities have their degree fixed at 3, but the degree in these data structures is arbitrary (up to a limit of 12). The IGES rational Bspline entities are already of arbitrary degree.

**Dimension :-** All the present IGES spline entities have coefficients with dimension fixed at 3, but the dimension in these data structures is arbitrary.

**Rational :-** The IGES parametric spline entities are not rational, but the IGES rational B-spline entities, of course a rational.

### 3. Curves in Computer Aided Design

Modern CAD-systems usually include a number of different ways to create and manipulate curves of several different types. Curves are also very often created indirectly by the system as the result of more complex modeling operations.

**Polynomial curve:** This is the general way to create a curve. Depending on the required kind of polynomial curve the designer wants to create, it will have to define a number of data that controls the shape of the curve. Splines, Bezier curves and NURBS are all polynomial curves. Different polynomial curve types have different mathematical representation as well as different geometrical properties.

**Offset curve:** An offset curve is a curve that is defined by the size of its offset distance to another curve. Offset curves are very important when modeling objects of constant thickness and to generate tool paths for numerically controlled machines. Offset curves are best represented by their offset distance and a reference to the original curve ( Fig.-1(a)).

#### Intersect curve

Intersect curves are curves defined by the intersection of two surfaces. Intersect curves can be defined directly by intersecting one surface with another or indirectly as the result of an operation between two solid bodies or a solid and a surface. Intersect curves can be used to define some interesting part of an object but are also often used to define a part of a surface to remove by trimming. Intersect curves are usually computed as a set of points along the curve. For practical purposes these points are then often interpolated (splined) to a continuous curve and stored in the database as such.

**Silhouette curve:** This curve is defined by the visible edge of a surface as viewed from a specific direction. Computation and storage is similar to the intersect curve.

**Geodesic curve:** In mathematics, particularly differential geometry, a geodesic is a generalization of the notion of a "straight line" to "curved spaces". This curve represents the shortest possible path between two points on a surface. Computation and storage is similar to the intersect curve.

**Planar curves:** Most curves can be planar. This means that they lie entirely in one plane and can be described in terms of 2-dimensional coordinates X and Y only. Some curves, like conics are planar by definition but most curves need not be planar in all cases.

**Non planar curves:** Many curves need not be planar. The spline for example may very well twist out of the plane and become truly 3-dimensional.

Due to the different mathematical representation of the curves described above they are not always compatible with each other or with surface geometry. In one system for example it may not be possible to create an offset curve if the original curve is not a polynomial curve. In other systems it may not be possible to define a surface if the limiting curves are not polynomial.

To overcome this usually designer has to define a polynomial curve by approximating a curve which is not polynomial and use the approximate curve where the non polynomial curve did not work. Some systems do this automatically. It should have be note that for uncontrolled use of this functionality may impose problems with accuracy in later stages of the design work.

#### 4. Approximation curves and its application to tool path generation

##### Bezier Curves

P. Bezier used an approximation technique in UNISERF software to define the outer panels of several Renault cars is named later as Bezier curve. The shape of Bezier curve is controlled by its defining points only. If the position of any point changes then the total Bezier curve will change globally. Bezier curve will not allow any addition of control point without altering the degree of the curve, i.e. Bezier curve with (n+1) control points always possesses n<sup>th</sup> degree curve. The mechanism behind is that additional degree of freedom does not exist in Bernstein polynomial concept to provide flexibility in the degree of the resulting Bezier curve.

Bezier curve is defined by the following polynomial of degree n. (n+1) control points.

$$P(u) = \sum_{i=0}^n P_i B_{i,n}(u) \dots\dots\dots (1)$$

Where,  $0 \leq u \leq 1$  and  $B_{i,n}$  are Bernstein blending function.

$$B_{i,n}(u) = \frac{n!}{i!(n-i)!} u^i (1-u)^{n-i} \dots\dots\dots (2)$$

##### NURBS parametric curves

A NURBS curve is briefly defined by the user by means of so called “control points”. These points can be regarded as vertices in a polygon, the “control polygon”. The curve does not necessarily interpolate the point (which is the case for an ordinary spline-curve). Normally the NURBS-curve is given such parameters that actually make it interpolate the first and last point. The intermediate points operate as magnets on the curve ( fig.-2). The control points are represented by “Pi”. Other parameters that control the shape of the curve is: the degree of the curve, the weights of the control points and the knot vector.

For given knot vector  $U = \{u_0, u_1, u_2, \dots, \dots, u_{n+p+1}\}$ , weight vector  $W = \{w_0, w_1, \dots, \dots, w_n\}$  and control points ‘ $P_i$ ’,  $0 \leq i \leq n$ , the p<sup>th</sup> degree NURBS curve  $C(u) = \{x(u), y(u), z(u)\}$  is defined by :

$$C(u) = \frac{\sum_{i=0}^n N_{i,p}(u) W_i P_i}{\sum_{i=0}^n N_{i,p}(u) W_i} \dots\dots\dots (3)$$

Where, (n+1) is the number of control points and ‘p’ is the degree of the curve,  $N_{i,p}(u)$  is the p<sup>th</sup> degree B-spline basis function defined on the non-uniform knot vector U.

$$N_{i,0}(u) = \begin{cases} 1 & \text{if } u_i \leq u < u_{i+1} \\ 0 & \text{Otherwise} \end{cases} \dots\dots\dots (4)$$

$$N_{i,p}(u) = \frac{u-u_i}{u_{i+p}-u_i} N_{i,p-1}(u) + \frac{u_{i+p+1}-u}{u_{i+p+1}-u_{i+1}} N_{i+1,p-1}(u) \dots\dots\dots (5)$$

Note-  $\frac{0}{0} = 0$

Where,  $u_i, u_{i+1} \in U = \{a, \dots, a, u_{p+1}, \dots, u_{m-p-1}, b, \dots, b\}$ ,

Some fundamental computer-aided design tools are used in the implementation of a NURBS curve, including knot insertion, knot refinement, knot removal and degree reduction. A designer can use these tools to change the knot distribution and obtain the desired shape.

As the imported .igs file consists of all weight values equal to one with same knot span, so, the NURBS technique can be followed through Bezier curve technique for further processing. Here, there is no necessity of reformation or modification of design required. So, the design of freeform curve so exported from CATIA-V5 platform is now introduced into the customized program prepared for this research work. After processing as per the logic given in DEV C++ program of IGES reader, control points, knot sequence, weight sequence have been extracted from the imported .igs file. Now these approximated data are the raw material for MATLAB program of this work. The simulated output conforms the smoothness of tool trajectory with cutter contact points. A certain assumption indicates out that a fixed numbers of control points have been assigned for a defined degree of spline that will give 21 cutter contact points in the trajectory. The proposed total generation process is very smooth and easy to handle the designed software.

### 5. IGES file reader flow chart for data extraction

IGES file reader software will take the imported .igs all data and will read to store it in an array. The step will be forwarded in a row and column wise. The pointer will enter to the file to check the sections of the IGES file and will enter into the parametric section by matching with word 'P'. Then it will come to left side to extract the entity index. As per individual entity index logic, the required parametric data are extracted and stored in the output format named as "merge file". The required entity index along with their geometric data will be visualized in output format and become the raw data for downstream operation. In this research work, the flow chart of the designed software is limited to spline and surface. Fig.-5, represents the flow chart for IGES reader. If it is surface then two knot sequences are extracted. If the neutral file represents for a composite curve then the output will contain a sequence of curve as per design so concerned. A tricky point of  $C^0$  continuity helped here for the formulation of tool trajectory declaration.

A composite curve (Fig.-4 (a)) has been designed in CATIA-V5 with a concept of approximation freeform technique. Once everything gets optimized, it has been fixed by constraints. But drafting for this composite curve is not required. Only IGES file is enough for its detail description. From the imported .igs file control points are get filtered for individual curve and feed into proposed MATLAB program to give real geometry of loci of points that declare the trajectory. Simulated trajectory has been shown in figure-4 (b).

### 6. Conclusion

The proposed methodology and developed software to read the IGES file for special application is user friendly software. The output of the reader will help to downstream operation in manufacturing of freeform curve or surface on a prismatic raw material. Geometry of the .igs also helps for geometric representation of an object. Here, the author has designed the IGES reader software written in Dev C+ and with the output of this parametric data simulated tool path has been declared by MATLAB program. Finally it has been seen that the designed tool trajectory is matching with the output trajectory. This is very easy to use and accurate for real geometry generation for tool path representation. This methodology may also help for robot motion in a plane.

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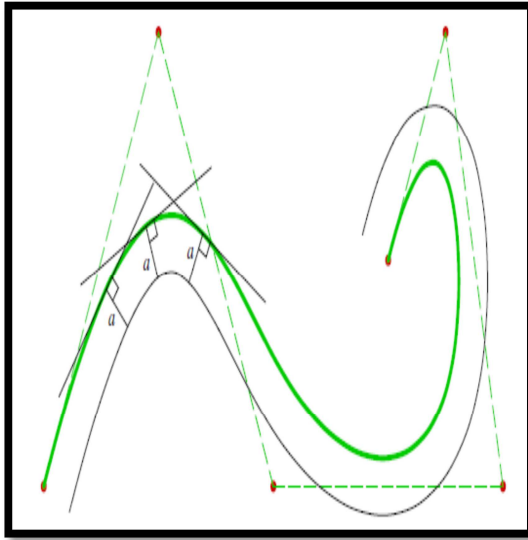


Fig.- 1 (a) Offset curve

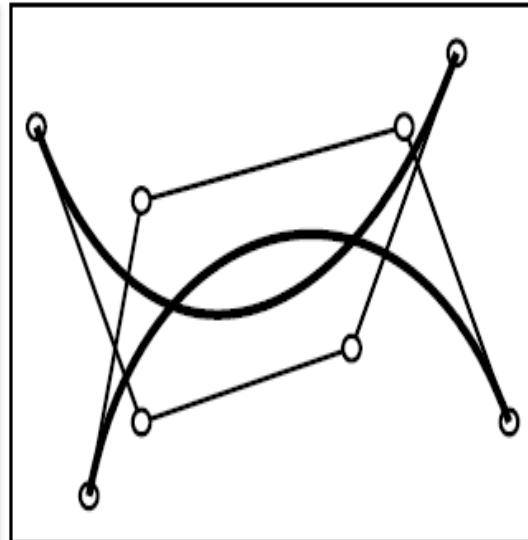


Fig.-1 (b) Intersecting curves

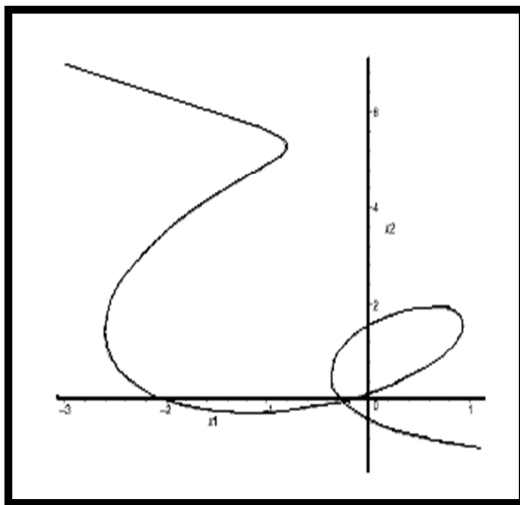


Fig.-1 (c) Silhouette curve

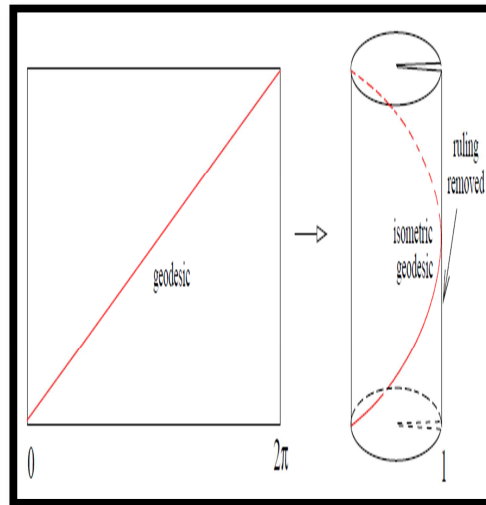


Fig.-1 (d) Geodesic curve



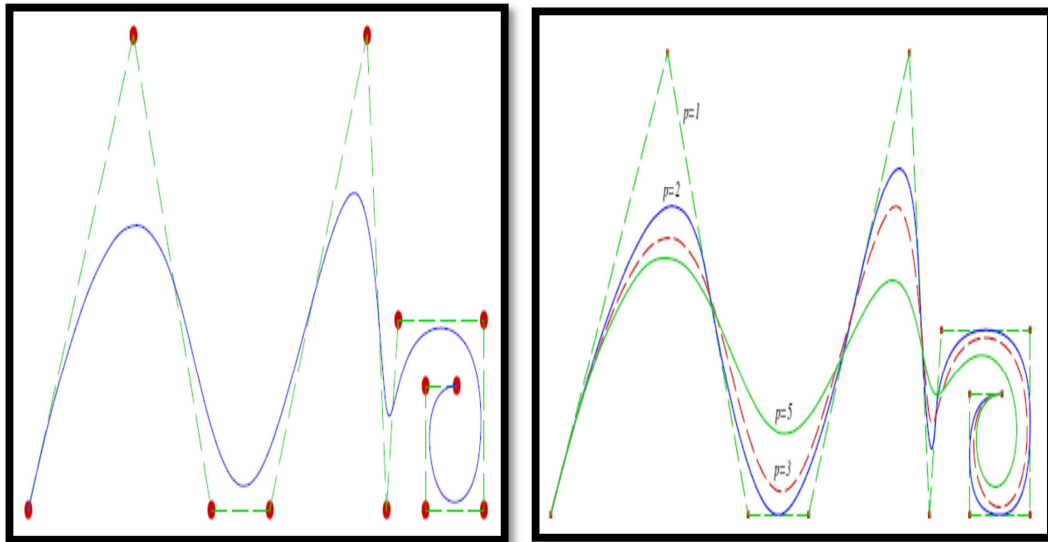


Fig.-2: A NURBS curve with control polygon (left) ; NURBS curves with different degree (Right).

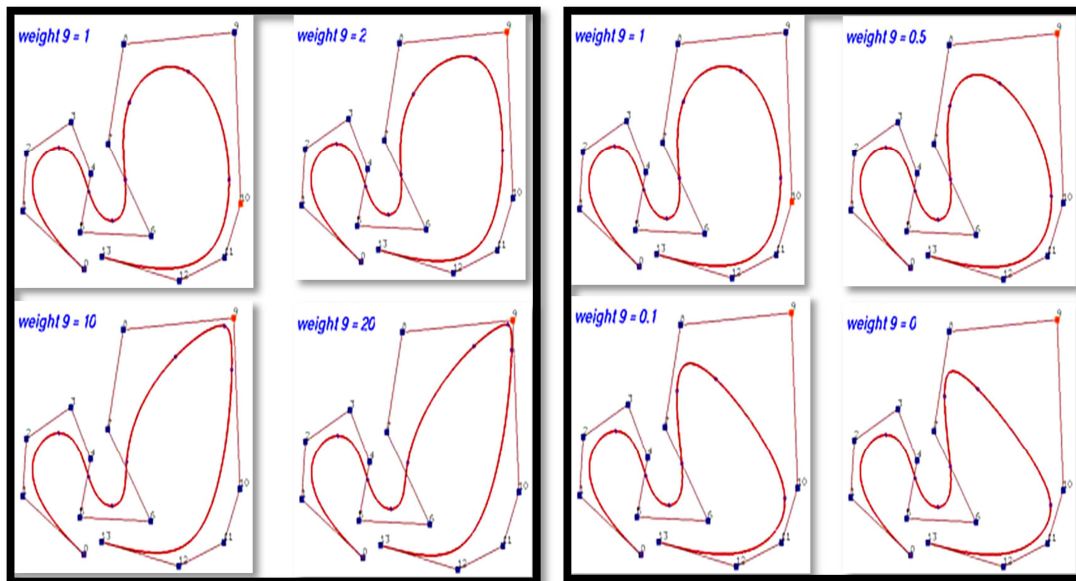


Fig.- 3 : Modifying Weights: increasing the value of  $w_i$  will pull the curve toward control point  $P_i$  (Left); Modifying Weights: decreasing the value of  $w_i$  will push the curve away from control point  $P_i$  (Right)

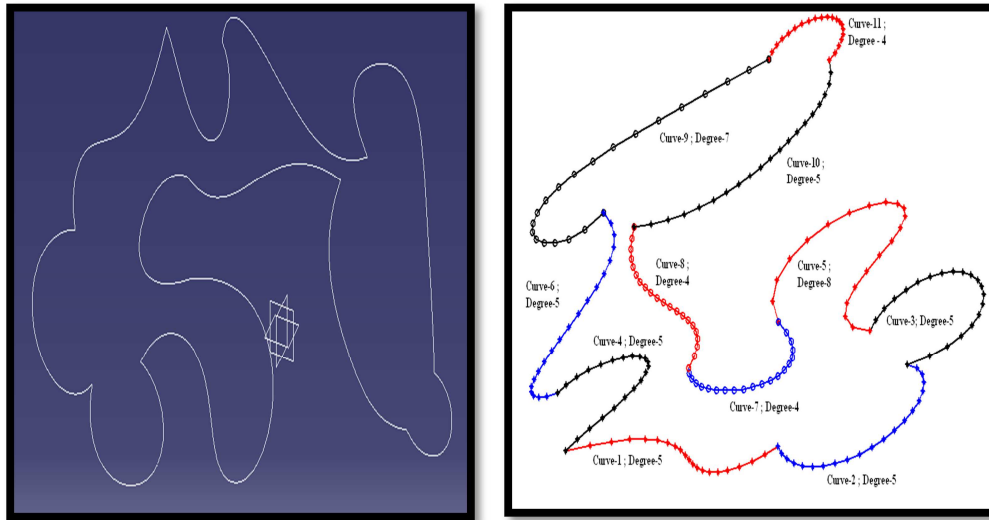


Fig.-4 (a) Complicated drawing for milling operation consists of composite curve (Left) ; (b) Simulated tool path in 2D plane, generated by MATLAB program.



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