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Complex Surface Representation and Machining Time Estimation Upon Three Types of End Mill Cutter

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Abstract-*The accuracy of data transition between CAD and CAM has been playing a great role in the product life cycle, and eventually, the product quality. As products complexity increased, the need to robust technique to data transition increased. On the other hand, Machining simulation facilitates deciding the process parameters. The aim of the present research is divided into two aims: first: building a free form surface and transforming its data accurately from CAD to CAM without any distortion. Second: study the milling process using different end cutters geometry and make a comparison between those in terms of machining time at a constant scallop height (s.h.). The study passed through three steps, first: A mathematical model and computer program had been built for non-uniform B-spline surface creation. The output points are stored in a format to be easily imported. Second: importing the data into manufacturing simulation program to emulate the milling process. Three types of milling tools with different end cutter had been used (flat, ball, and toroidal). Third, use a CIMCO edit package to estimate machining time for the three tools. A conclusion had been made that the surface data had been transformed accurately into the simulation process. Another conclusion was, with fixed (s.h.) the ball end mill takes more time than toroidal, which in turn takes more time than flat.*

Keywords*- data transition, non-uniform B-spline surface, milling process, machining time.*

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1. Introduction

Importing and exporting computer-aided design CAD data files have been a basic function of the computer-aided manufacturing CAM software now-days. The process of converting data format into another is referred to as data translation [1]. As of now, information trade gauges, for example, IGES and STEP give a special approach to interfacing among various CAD stages. This sharing of product data is key to the successful deployment of concurrent engineering. Furthermore, this practice mainly contributes to reducing product development time. Because of the substantial assortment of CAD frameworks in the market, design data trade among different CAD frameworks is irreplaceable [2]. A typical wellspring of the mistake to some extent records is accepting inadequate plans because of inexperienced or exhausted CAD designers. CAM translator may not be adequate for the specific CAD file format [1].

A literature survey for the researches concerning the line of the present research stated below:

Bey et al. automated the procreating of tool path using B- spline curves by specifying the minimum numbers of controls points that impact the best approximation to the various tool positions with a given accuracy [3].

Skoczylas et al. presented a different method utilized the calculation of standard work time of operations. A particularly imperative qualification was made between computing the total machining time and the real cutting time. Through the examination of various machined flat surfaces, the consequences of work time calculations from CATIA and the wrote numerical model were presented [4].

Redonnet et al. presented a study concerning optimizing the part machining direction permitting minimizing the machining time with respect to maximum instituted scallop height. Then, the optimization process is applied to an industrial part and measurements are applied to this part [5].

Oşan et al. analyzed the machining of complex surfaces with toroidal milling cutters as a comparison to spherical milling cutters. As rapprochement terms, surface roughness and machining time were considered. The objective was to demonstrate the advantage of the toroidal milling tool that could be substituted in case of spherical milling cuts to amend the machining time beside the surface quality [6].

In order to overcome the previously mentioned obstacles, and to gain the proposed surface geometry without any distortion (regardless of the complexity of the surface) innovatively technique will be adopted in this research. Manufacturing simulation for the complex surface using three types of milling end cut will be done based on a constant scallop height and the machining time will be estimated and will be used to compare between the three tools. By default, once the surface quality compared, an idea can be made of the tool suitable for processing these complex surfaces, for the time being, limiting them to 3-axis machining.

2. Construction of the Proposed Technique

For clarification, the structure of the proposed research could be divided into three stages. The first stage, concerning CAD, is the process of representing the geometry of the part. The second stage, concerning CAM, which is relating part manufacturing process simulation, and the third stage relating the machining time estimation. The details of these stages will be discussed in detail in the next sections.

I. Proposed part modeling

Freeform surfaces have been utilized in the design and manufacturing of molds, dies and aerodynamic parts, etc. in the proposed research, b- spline curve and surface will be used to represent the sculptured surface.

B-spline surfaces have been anxiously received as appropriate spline representation for complex surfaces in CAD [7]. The degree of a B-spline curve is not dependent on the number of control points. B-splines could have lower degree curves and still preserve a large number of control points. The control points could be moved without alteration of the shape of the whole curve. Also, provide piecewise polynomial segments that joint with some level of continuity in such a way that they achieve certain smoothness criteria [8]. The b-spline surface is a direct extension of b-spline curves.

A mathematical model for derivation b-spline Curve equation for five control points (n=4) and of degree K=3 in order to verify C_2 continuity. The steps of derivation the equation will be stated below in detailed:

1) Calculate the limits of $0 \le u \le 3$.
2) Find the number of segments T= [t_0, t_1, t_2, t_3, t_4, t_5, t_6, t_7].
3) Find the values of segments T=[0,0,0,1,2,3,3,3].
4) First k=1 then use the following equation

$$N_{i,1}(u)=\begin{cases} 1 & if \quad ti \le u \le ti+1 \\ 0 & otherwise \end{cases} [8] \qquad (1)$$

5) When k >1, then use the following equation

$$N_{i,k}(u)=\frac{u-t_i}{t_{i+k-1}-t_i}N_{i,k-1}(u)+\frac{t_{i+k}-u}{t_{i+k}-t_{i+1}}N_{i+1,k-1}(u) \quad [8]\ (2)$$

6) $$P_T(u)=\sum_{i=0}^{n} N_{i,k}(u)p_i \qquad (3)$$

After using the steps from (1) to(6) the final derivative equation of b-spline for k=3 and n=4 is as follows:

$$P_1(u)=(1-2u+u^2)p_0+(2u-1.5u^2)p_1+(0.5u^2)p_2 \quad (4)$$

$0 \le u < 1$

$$p_1(u)=\begin{pmatrix} u^2 & u & 1 \end{pmatrix}*\begin{pmatrix} 1 & -1.5 & 0.5 \\ -2 & 2 & 0 \\ 1 & 0 & 0 \end{pmatrix}*\begin{pmatrix} p_0 \\ p_1 \\ p_2 \end{pmatrix}$$

$$p_2(u)=(2-2u+0.5u^2)p_1+(-1.5+3u-u^2)p_2+(0.5u^2-u+0.5)p_3 \quad (5)$$

$1 \le u < 2$

$$p_2(u)=\begin{pmatrix} u^2 & u & 1 \end{pmatrix}*\begin{pmatrix} 0.5 & -1 & 0.5 \\ -2 & 3 & -1 \\ 2 & -1.5 & 0.5 \end{pmatrix}*\begin{pmatrix} p_1 \\ p_2 \\ p_3 \end{pmatrix}$$

$$p_3(u)=(4.5-3u+0.5u^2)p_2+(-7.5+7u-1.5u^2)p_3+(u^2-4u+4)p_4 \quad (6)$$

$2 \le u \le 3$

$$p_3(u)=\begin{pmatrix} u^2 & u & 1 \end{pmatrix}*\begin{pmatrix} 0.5 & -1.5 & 1 \\ -3 & 7 & -4 \\ 4.5 & -7.5 & 4 \end{pmatrix}*\begin{pmatrix} p_2 \\ p_3 \\ p_4 \end{pmatrix}$$

II. Non-Uniform B-Spline Surface Generation

The simple extension for free-form surfaces from two-dimensional curves is by incorporating another parameter (v).the b-spline surface can be defined by the following general equation [4]:

$$P_T(u,v)=\sum_{i=0}^{n}\sum_{j=0}^{m} N_{i,k}(u)N_{j,l}(v)p_{i,j} \qquad (7)$$

Where: $N_{i,k}$ and $N_{j,l}$ the b-spline basis functions, $p_{i,j}$ are the control points of the characterized surface.

As mentioned previously, the non-uniform b-spline curve consists of three segments .Consequently, the b-spline surface consists of (3*3) patches. Each patch equation depends on the segments equations that generate it. Relations that are between patches and segments are shown in Figure 1.

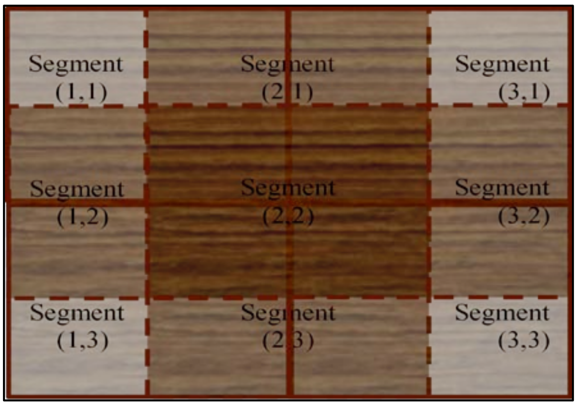


Figure 1: Relations between patches and segments (author)

After the mathematical model is derived, a computer program will be written using (MATLAB 2013 a) program in order to represent the b-spline surface easily. The flow chart of the model is shown in Figure 2).

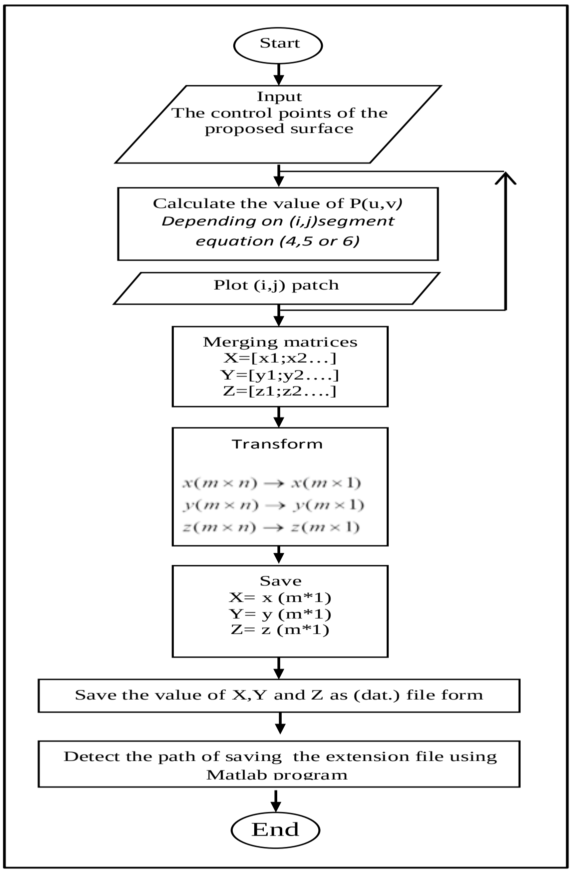


Figure 2: Flowchart of the proposed program.

III. Implementation process

When implementing the program by identifying the control points in three coordinates system, the patches of the surface will be generated as shown in figure (3). And it can be noticed that the proposed surface represents a complex surface because it combines concave and convex patches.

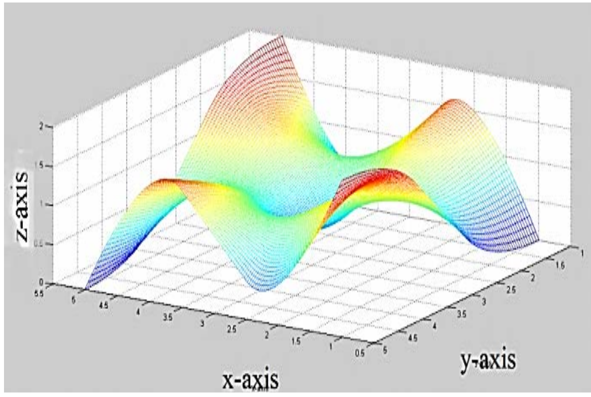


Figure 2: Non-uniform B-spline surface representation based on the proposed techniqu.

3. Manufacturing Process Simulation

In order to simulate the manufacturing process for the proposed case study, NX (UGS) program will be adopted. Where this program can read the surface of the proposed work by its points coordinate (x, y, and z) so, the surface points generated in the three coordinates system will be saved in the extension (.dat). These points are listed in the saved file as three columns which represent the value of x, y, and z coordinatessystem respectively.

I. Tool path generation

To generate the tool path, the geometry of the surface must be defined. Then, the CAM role should be started by defining the manufacturing process, machine type, (three or multi-axis), cutting tool geometry and dimensions and cutting process specifications. Then, the simulation process could begin for the specified surface resulting in the part program (G-code) using the post processor order.

II. Milling end nose cutting tools geometry

The cutter determination plays a critical role in an NC system. For example,influencingthe machining speeds, the surface quality, and the effectiveness of tool path generation. Flat, ball and toroidal end cutters are ordinarily utilized tools in free form surface machining [9]. CAD/CAM frameworks characterize the envelope of processing cutters by seven geometric parameters CUTTER/D, R, Rr, Rz, a, b, h. These seven geometric parameters are free of one another, however with geometric constraints to make mathematically feasible shapes [10]. The geometric parameters for the flat, ball and toroidal (bullnose) end mill are shown in Figure 4.

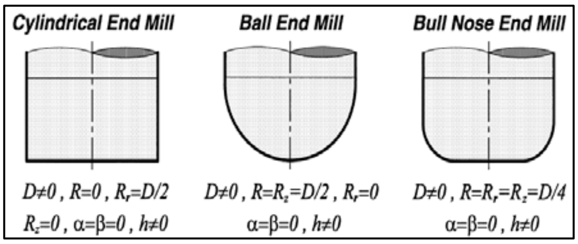


Figure 3: The end mill geometric parameters for the flat, ball and toroidal (bullnose) [10].

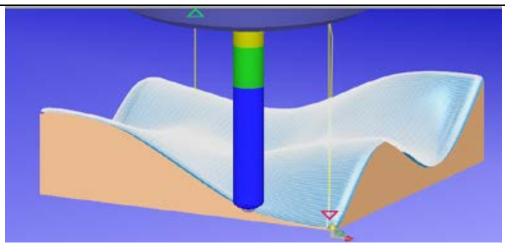
Ball End Mills have a spherical tip utilized in machine rounded details. It is always preferred to select the maximum allowable ball end mill size. For the same stopover, a bigger instrument will leave littler scallops, along these lines giving smoother results. Flat end cutter provides the best quality for plan surfaces.

Toroidal end cutter combines the advantages of ball and plan end cutter and capable of leading high-performance machining.

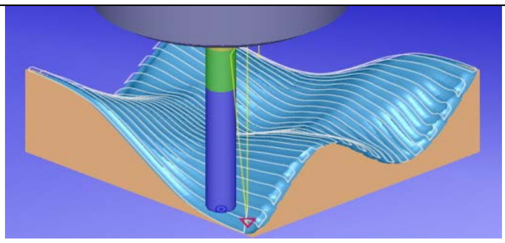
Table 1 depicts the geometric parameter for each type. The tool path will be selected in terms of constant scallop height. Machine speed =1000mm/min. The simulation process and the tool path could be shown in Figure 5 for the three tools.

Table 1: Geometric parameters for the three tools.

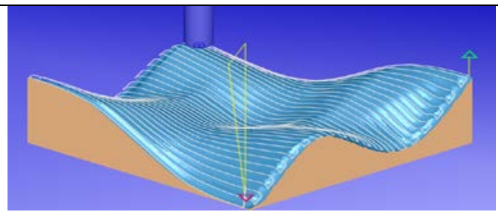
Type	Geometric parameters Ultimate load (kN)
Ball	R=Rz=1, Rr=0, α= 0, β=0
Toroidal	R=Rr=1, Rr=0.5, α= 0, β=0
Flat	R=Rz=0, Rr=1, α= 0, β=0



a-Ball end cut



b- Flat end cut



c- Toroidal end cut

Figure 4: Machining simulation process.

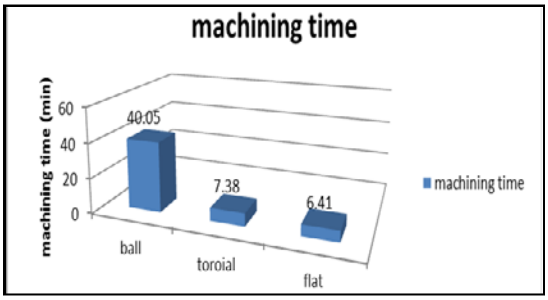
4. Estimating The Machining Time

The standard working times of technological operations area fundamental component in the business tasks of every enterprise. It is a mensuration for the production capacity, planning, schedule, or even economic calculating.

After G-code has been generated, the machining time could be estimated using CIMCO edit v5. CIMCO Edit gives a far-reaching set of editing tools that fulfill the needs of modern CNC program editing. By using the tool path statistics option, the program can calculate the machining time, cutting length, minimum and maximum x, y and z coordinates and other information. The time of tool change can be entered to be added. For the three mill end cut the machining time are shown in Table 2. Figure 6 depicts a chart to compare the machining time and cutting length for the three tools. It is obvious that the ball end cut takes the maximum machining time, then the toroidal and finally the flat. To maintain a constant scallop height the step over distance (in ball end case) should be decreased resulting in increasing the number of paths and cutting length and eventually increasing the machining time.

Table 2: Machining time and cutting length for the three types

Type	Machining time(min)	Cutting length(mm)
Ball	0:40:05	9945.1898
Toroidal	0:07:38	1837.92
Flat	0:06:41	1596.173



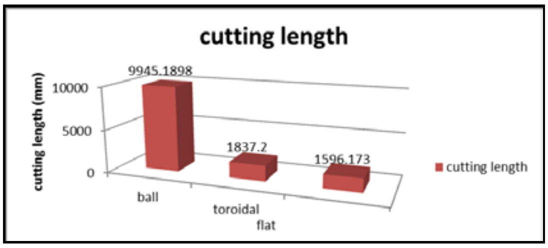


Figure 5: A comparison of machining time and cutting length between the three types of cutting tools

Most of the programs do not guarantee the accuracy and efficiency in data transforming between CAD and CAM, especially when the part has the complex surface design. In this research, a method had been adopted in order to avoid disfiguration the geometry of the-sculptured surface. The non-uniform b-spline surface had been built to represent the complex surface. The method approved its efficiency and the model correctly transformed to NX program without any deformation and the simulation process had been executed to emulate manufacturing the surface by using three different geometric end cutters. After that, the machining time had been estimated using CIMCO edit program. It could be concluded that when the goal is to get a constant scallop height, the maximum machining time was when using the ball end cutter then the toroidal and finally the flat .This was because when steady scallop height was required, the step over distance should be reduced and the cutting length distance would increase and consequently, the machining time increased. In order to enhance the study, it is recommended for future work to do practical experiments to measure and compare the simulated and real results.

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