

TOOL PATH GENERATION OF THREE DIMENSIONAL NC MACHINING SURFACES

توليد مسارات العدة القاطعة لتشغيل أسطح ثلاثية الأبعاد لماكينات التحكم الرقمي

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هذا البحث يقدم نظام هدفه توليد مسارات العدة القاطعة للأسطح ثلاثية الأبعاد للتشغيل على ماكينات تفرز التحكم الرقمي اتوماتيكيا بالربط مع استخدام الحاسب الآلي في الرسم . حيث أن برمجة ماكينات التحكم الرقمي للأسطح ثلاثية الأبعاد تعتبر من الصعب اتمامها بالأساليب اليدوية . وتكمن الصعوبة في استنتاج مسارات العدة القاطعة بطرق يدوية في كثرة بيانات الأسطح وضرورة استنتاجها على مرحلتين وهما مرحلة الاستقراب Roughing ومرحلة التشطيب Finishing . مرحلة الاستقراب تتم على مستويات متعددة وذلك تبعاً لأقصى عمق قطع مسموح به للعدة القاطعة . وفكرة البحث تبدأ بالتعامل مع الجزء المطلوب تشغيله ورسمه بأحد أنظمة CAD بأسلوب Wire Frame ويقوم البرنامج المصمم بعدة عمليات منها استخراج بيانات الأسطح المطلوب تشغيلها وهي عبارة عن احداثيات ال nodes المختلفة للأسطح وتنظيم هذه البيانات بعد ترتيبها وتقسيمها الي مستويات منفصلة ثم التعرف من البيانات على طبيعة شكل السطح سواء كان الشكل يحتوي على Cavity أو سطح غير منتظم وتكوين مسارات العدة القاطعة لمرحلة الاستقراب على شكل Zigzag وتكوين الكود الخاص بها لماكينات التحكم الرقمي يتبعها بعد ذلك مرحلة التشطيب . ويتميز هذا النظام بالسرعة العالية مقارنة بالطرق اليدوية حيث يقوم بالتعرف على الشكل الهندسي للسطح المطلوب تشغيله دون تدخل من مستخدم البرنامج المصمم ويعتبر مفيد للكثير من التطبيقات في المصانع الصغيرة والمتوسطة في حجم الاستثمارات وكذلك في الأغراض التعليمية حيث أن الحزم التجارية باهظة الثمن وصعب الحصول عليها لكثير من القطاعات وقد تم تجريبه هذا النظام على العديد من المشغولات وقد أظهر نتائج جيدة .

ABSTRACT

The machining of complex products which have specific geometries and accurate dimensions is vital for industrial competition. This work presents a methodology for the automatic generation of tool paths required to machine Three-Dimensional (3-D) surfaces consisting of cavities or free form shapes. The proposed system starts with the creation of the wire frame drawing for the surface of the required mechanical component using a CAD system. Based on the created drawing, several procedures are performed to automate the tool path generation of a process plan which contains detailed information needed in the NC machining process. These procedures include

extracting the coordinates of surfaces nodes, arranging these databases to several cutting planes, and the self identification of the geometrical shape of the surface. The geometrical shape of the surface may consists of a cavity or free form shape. Based on the geometry of the surface, the proposed system generates the tool paths for both the roughing and finishing operation required to produce the required surface.

KEYWORDS: CAD/CAM, 3D-Machining, Machining surfaces, CNC, Process Planning

1. INTRODUCTION

The applications of computers in manufacturing automation assist to produce complicated parts in a more effective, efficient and error-free fashion [1]. A computer support as an aid to part programming was not required during the early period of NC use. With the increased use of NC systems and growth in complexity of parts to be machined, the part programmer was no longer able to calculate efficiently the required tool path. The machining in two-dimensional configurations requiring simple mathematical calculations compared with the machining in three-dimensional cutting planes. NC automatic programming for two-dimensional milling components have been successfully demonstrated in previous works [2,3].

One of the most common features found on milling components are the surfaces including free form shapes. Such shapes as in stamping dies, molds, turbine blades, and automobile bodies are common place in modern design. In order to overcome difficulties associated with machining of such mechanical components, advanced CAD/CAM systems are required to automate process planning and machining control. Moreover, the level of automation in CNC programs provided by commercially packages is somewhat low. Therefore, an integrated approach for machining such surfaces, capable of meeting the requirements of high precision is essential to sustain the competitiveness of the industry.

This work presents an advanced CAD/CAM system which generates automatically the tool paths required to produce three-dimensional surfaces. The surface may

consists of a cavity or free form shape. The proposed system manage the databases available in the wire frame model diagrams which are useful for all the design and manufacturing activities. These databases are arranged, and analyzed to directly identify the shape of the surface, hence perform the necessary steps to produce the part including both the roughing and finishing operations. One of the main objectives of these procedures is to eliminate the human interventions and depends only on the geometric reasoning in selecting the method of cutting. The mechanical parts considered contain the most complex shape such as die stamps, cavities, and free form surfaces. The proposed system generates the necessary NC standard G-codes in addition to a postprocessor designed to extract special codes to be suitable for one specific machine to perform several components.

2. THE PROPOSED SYSTEM

In general, when machining a surface from a block of raw material, the metal is removed through two stages : 1) Rough cutting with a flat end mills, 2) Finish cutting with ball ended mills. In order to perform the cutting process by NC machine, the part programmer should involve three main tasks.

- 1) Selection of proper cutting tools for rough machining and finishing operations.
- 2) Determination of proper machining parameters for the NC part program
- 3) Creation of NC cutter paths for rough machining and finishing operations.

The selection of the proper cutting tools for rough machining may be based on the maximum metal removal and minimization of the machining time. These parameters affects also the selection of the cutting tools for finishing operation in addition to a geometric reasoning of the part to be produced. The determination of the proper machining conditions is an essential step in a good machining practice. One of the most essential part of CAM system is the manufacturing database which provides the ability to store the vast amount of data which are necessary to support the engineering analysis performed [2,3] by the systems. The advantages of these data are that the

recommended cutting conditions could be easily updated. The disadvantages of this method is the neglect to the machining variations resulting from the variations of the cutting forces, material hardness, tool wear, and other cutting parameters. Therefore, it is possible to formulate a dynamic model [4] to analyze the cutting variables and determine the optimum cutting parameters which may be varied to compensate the variation of the cutting performance.

To machine a surface, the material is removed through several paths because in many cases the required depth of cut exceeds the maximum permissible depth of cut of the cutting operation, then a finishing operations can be done in only one path. Each path of rough machining in the proposed system uses the stair method [5] which is illustrated in Fig. 1. In this Fig., the cutter moves in the direction parallel to the X-axis until it touches the other boundary of the surface or the end of the material block. Then the cutter follows the edge of the boundary to the next value of Y-axis in order to resume machining in the X-direction. The whole process is repeated until the material is removed from each cutting plane, and the height of the cutting plane depends on the cutter's permissible depth of cut. After the rough machining is done, finishing operations are performed to remove the material along the surface itself.

To automate the generation of tool paths for both roughing and finishing operations, the proposed system starts with the creation of the 3-D wire frame drawing using a CAD system. The CAD system used in the current study is AutoCAD. The required surface is created using the available 3-D commands in AutoCAD. The user of the proposed system should translate the required surfaces into a dxf file format. Then, the proposed system extracts the necessary database for the vertices which constitute the required surfaces. Fig. 2 shows the sequence followed by the proposed system.

3. 3-D SURFACE MACHINING EXAMPLES

Two examples are given here to verify the validity of the developed technique. The sequences followed in both examples are as follows:

- 1) Figs. 3.a and 4.a illustrate the part drawings of the final shape which results from the machining of a solid block. The surface of the block represents the Z-zero level, and the lower left corner of the surface represents the Zero Reference Point (ZRP) selected as X, Y=0.0.
- 2) The user starts by drawing a 3-D surfaces view using the available drawing commands presented in AutoCAD. The variables surfab1, and surfab2 should be selected according to the diameter of the cutter used, and the maximum available depth of cut. In the sample example 1 surfab1 and surfab2 selected as 12 for a cutter 10mm diameter, and maximum depth of cut=3mm.
- 3) After the user has finished the drawing, he must exchange the surfaces presented into a dxf file [6]. A part of this file for the surface presented in Fig. 3.a is shown in Fig. 5.
- 4) The proposed system translates the existing information extracted from the drawing into a database file. Fig. 6 represents a sample of the X, Y, and Z coordinates of the surface presented in Fig. 3.a.
- 5) The system determines the pocketing operation required for removing enough material for rough machining. The different cutting planes are determined from the Z values of the surfaces.
- 6) The proposed system identify the shape of the surface (free form or cavity), grafting the databases for the similar vertices obtained from the surface by determining the repeated vertices values, determine the direction of cuts

according to the Y-values to perform the stair cut method, and finally construct a database file which contains the two ended coordinates for the tool path pocketing operation. A sample of this file is shown in Fig. 7. Figs. 3.b, and 4.b represent the parts which would be removed from the raw material blocks of the two samples.

- 7) The proposed system generates the NC part program for these steps by assigning the G01 code from each node to another. Fig. 8 represents a sample of this file. Then, the NC code for the finishing operation is generated through the movements of the vertices of surfaces in the direction of the X-axis or the Y-axis as desired.
- 8) The proposed system contains a postprocessor to extract the NC format required for the Computer Aided Modeling Machine (PNC 3000) [7]. A sample of this file is presented in Fig. 9.

4. CONCLUSION

This paper presents an integrated approach to use the part CAD model to automatically generate a NC part program for both roughing, and finishing tool path operations for 3-D surfaces. The proposed system is useful to apply in the small to medium size of factories, and also for educational purposes instead of using one of the commercial packages which are frequently too expensive, and are not suitable for specific applications. The software developed is tested through several parts, and good results are obtained.

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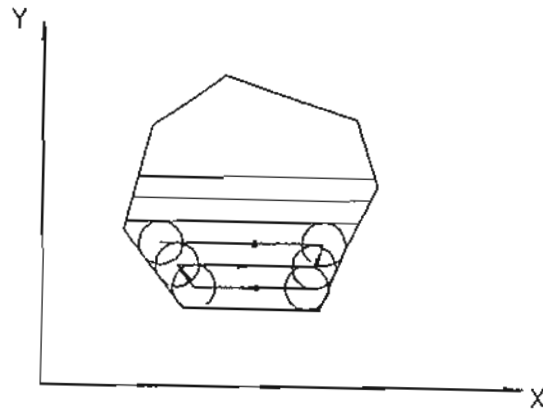


Fig. 1. Stair method for tool path of a plane

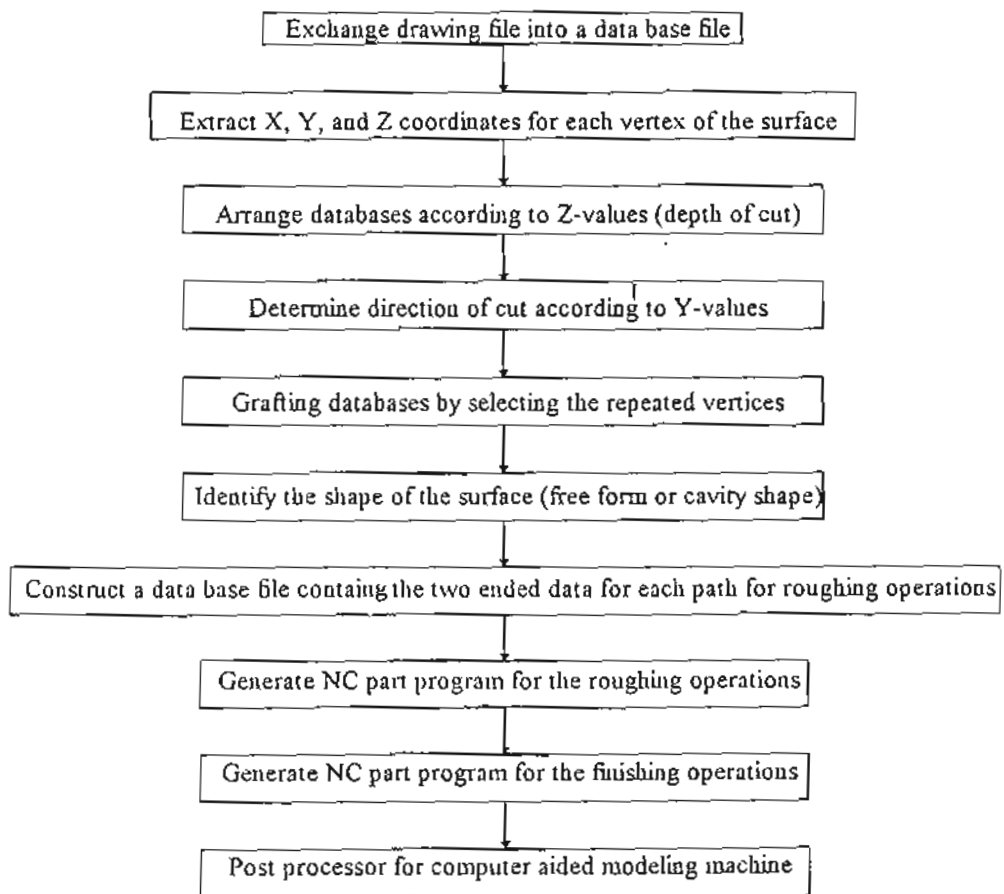


Fig. 2. System sequence block diagram

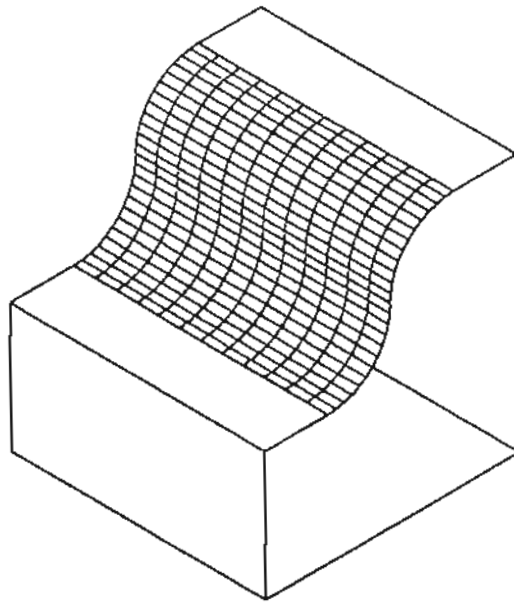


Fig. 3.a Representation of a workpart I

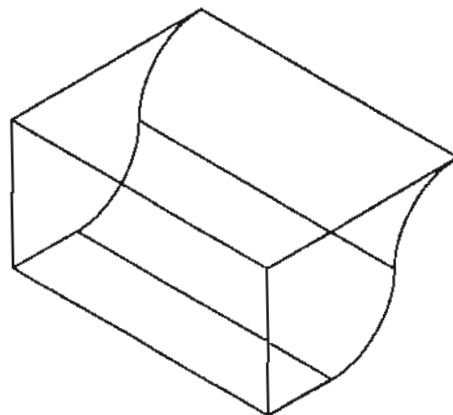


Fig. 3.b Part removed from workpart I

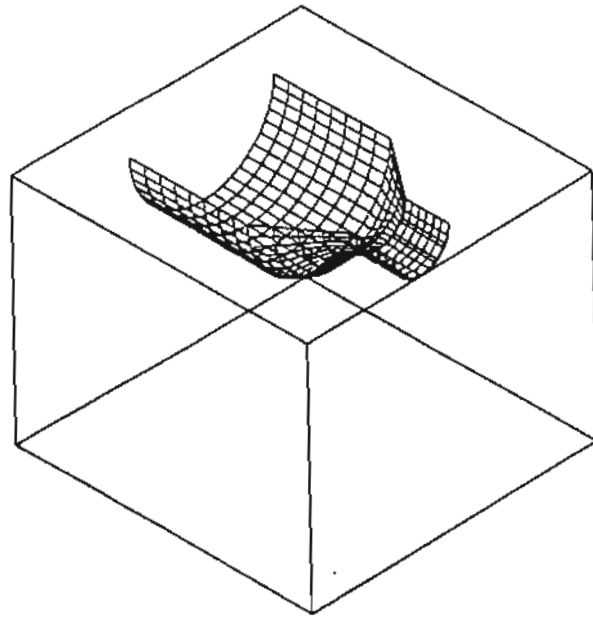


Fig. 4.a Representation of a workpart Π

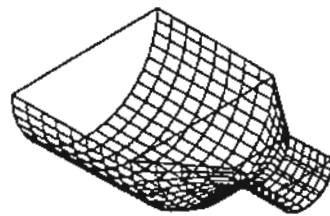


Fig.4.b Part removed from workpart Π

0
SECTION
2
ENTITIES
0
POLYLINE
8
L1
66
1
10
0.0
20
0.0
30
0.0
70
16
71
13
72
13
0
VERTEX
8
L1
10
75.0
20
0.0
30
0.0
70
64
0
VERTEX
8
L1
10
71.736845
20
0.0
30
-0.213878
70
64
0

G	X	Y	Z
INC	71.736845	0.000000	-0.213878
INC	71.736845	8.333333	-0.213878
INC	71.736845	16.666667	-0.213878
INC	71.736845	25.000000	-0.213878
INC	71.736845	33.333333	-0.213878
INC	71.736845	41.666667	-0.213878
INC	71.736845	50.000000	-0.213878
INC	71.736845	58.333333	-0.213878
INC	71.736845	66.666667	-0.213878
INC	71.736845	75.000000	-0.213878
INC	71.736845	83.333333	-0.213878
INC	71.736845	91.666667	-0.213878
INC	71.736845	100.000000	-0.213878
INC	68.529524	0.000000	-0.851854
INC	68.529524	8.333333	-0.851854
INC	68.529524	16.666667	-0.851854
INC	68.529524	25.000000	-0.851854
INC	68.529524	33.333333	-0.851854
INC	68.529524	41.666667	-0.851854
INC	68.529524	50.000000	-0.851854
INC	68.529524	58.333333	-0.851854
INC	68.529524	66.666667	-0.851854
INC	68.529524	75.000000	-0.851854
INC	68.529524	83.333333	-0.851854
INC	68.529524	91.666667	-0.851854
INC	68.529524	100.000000	-0.851854
INC	65.432914	0.000000	-1.903012
INC	65.432914	8.333333	-1.903012
INC	65.432914	16.666667	-1.903012
INC	65.432914	25.000000	-1.903012
INC	65.432914	33.333333	-1.903012
INC	65.432914	41.666667	-1.903012
INC	65.432914	50.000000	-1.903012
INC	65.432914	58.333333	-1.903012
INC	65.432914	66.666667	-1.903012
INC	65.432914	75.000000	-1.903012
INC	65.432914	83.333333	-1.903012
INC	65.432914	91.666667	-1.903012
INC	65.432914	100.000000	-1.903012
INC	62.500000	0.000000	-3.349365
INC	62.500000	8.333333	-3.349365
INC	62.500000	16.666667	-3.349365
INC	62.500000	25.000000	-3.349365
INC	62.500000	33.333333	-3.349365
INC	62.500000	41.666667	-3.349365
INC	62.500000	50.000000	-3.349365

Fig. 5. A sample of DXF file for workpart I

Fig. 6. A sample of a database file contains data of each vertex of the surface

G	X	Y	X1	Y1	Z
INC	71.736845	0.000000	0.000000	0.000000	-0.213878
INC	71.736845	8.333333	0.000000	8.333333	-0.213878
INC	71.736845	16.666667	0.000000	16.666667	-0.213878
INC	71.736845	25.000000	0.000000	25.000000	-0.213878
INC	71.736845	33.333333	0.000000	33.333333	-0.213878
INC	71.736845	41.666667	0.000000	41.666667	-0.213878
INC	71.736845	50.000000	0.000000	50.000000	-0.213878
INC	71.736845	58.333333	0.000000	58.333333	-0.213878
INC	71.736845	66.666667	0.000000	66.666667	-0.213878
INC	71.736845	75.000000	0.000000	75.000000	-0.213878
INC	71.736845	83.333333	0.000000	83.333333	-0.213878
INC	71.736845	91.666667	0.000000	91.666667	-0.213878
INC	71.736845	100.000000	0.000000	100.000000	-0.213878
INC	68.529524	0.000000	0.000000	0.000000	-0.851854
INC	68.529524	8.333333	0.000000	8.333333	-0.851854
INC	68.529524	16.666667	0.000000	16.666667	-0.851854
INC	68.529524	25.000000	0.000000	25.000000	-0.851854
INC	68.529524	33.333333	0.000000	33.333333	-0.851854
INC	68.529524	41.666667	0.000000	41.666667	-0.851854
INC	68.529524	50.000000	0.000000	50.000000	-0.851854
INC	68.529524	58.333333	0.000000	58.333333	-0.851854
INC	68.529524	66.666667	0.000000	66.666667	-0.851854
INC	68.529524	75.000000	0.000000	75.000000	-0.851854
INC	68.529524	83.333333	0.000000	83.333333	-0.851854
INC	68.529524	91.666667	0.000000	91.666667	-0.851854
INC	68.529524	100.000000	0.000000	100.000000	-0.851854

Fig. 7. A sample of databases of the two ended of roughing operations.

```

G00 X 71.736845 Y 0.000000
G01 Z -0.213878
G01 X 0.000000 Y 0.000000
G01 X 0.000000 Y 8.333333
G01 X 71.736845 Y 8.333333
G01 X 71.736845 Y 16.666667
G01 X 0.000000 Y 16.666667
G01 X 0.000000 Y 25.000000
G01 X 71.736845 Y 25.000000
G01 X 71.736845 Y 33.333333
G01 X 0.000000 Y 33.333333
G01 X 0.000000 Y 41.666667
G01 X 71.736845 Y 41.666667
G01 X 71.736845 Y 50.000000
G01 X 0.000000 Y 50.000000

```

Fig. 8. A part of NC program (Standard Code) for workpart I

```

Z 7478.612200 , 8500.000000 , -326.315500
Z 2521.387800 , 8500.000000 , -326.315500
Z 2521.387800 , 8000.000000 , -326.315500
Z 7478.612200 , 8000.000000 , -326.315500
Z 7478.612200 , 7500.000000 , -326.315500
Z 2521.387800 , 7500.000000 , -326.315500
Z 2521.387800 , 7000.000000 , -326.315500
Z 7478.612200 , 7000.000000 , -326.315500
Z 7478.612200 , 6500.000000 , -326.315500
Z 2521.387800 , 6500.000000 , -326.315500
Z 2521.387800 , 6000.000000 , -326.315500
Z 7478.612200 , 6000.000000 , -326.315500
Z 7478.612200 , 5500.000000 , -326.315500
Z 2521.387800 , 5500.000000 , -326.315500
Z 2521.387800 , 5000.000000 , -326.315500
Z 7478.612200 , 5000.000000 , -326.315500
Z 7478.612200 , 4500.000000 , -326.315500
Z 2521.387800 , 4500.000000 , -326.315500
M 7414.814600 , 8500.000000
Z 7414.814600 , 8500.000000 , -647.047600
Z 2585.185400 , 8500.000000 , -647.047600
Z 2585.185400 , 8000.000000 , -647.047600
Z 7414.814600 , 8000.000000 , -647.047600
Z 7414.814600 , 7500.000000 , -647.047600

```

Fig. 9. A part of a postprocessor program (CAMM) designed for workpart II.

```

DO WHILE Z=P .AND. Y<=MI .AND. .NOT. EOF()
REPLACE G WITH "REP"
SKIP
ENDDO
CASE P1=P .AND. V1=V .AND. M>M1
MA=M
PRO="DEC"
DO WHILE Z=P .AND. Y<MA
SKIP -1
REPLACE G WITH PRO
SKIP
REPLACE G WITH PRO
MA=Y
SKIP
ENDDO
DO WHILE Z=P .AND. Y>=MA
REPLACE G WITH "REP"
SKIP
ENDDO
CASE Z #P
LOOP

```

Fig. 10. A part of the software program