# Numerical Control with Surface Driven Interpolation

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**Abstract:**
A conventional method, used for machining of sculptured surfaces, is that a CAM system generates a large amount of small line segment data and an NC interpolates between the lines. Recently, in order to reduce NC data and to obtain fine surfaces, an NC with the function of NURBS interpolation has been developed. However, since both systems depend on the data that a CAM system generates, the quality of machined surfaces is dependent on the data. Some problems are caused when an NC interpolates the data. This paper discusses such problems from the viewpoint of the relation between a CAM and an NC. Then, an NC with the function of surface driven interpolation is proposed as an ideal system. The conceptual idea, an implementation method and a prototype are introduced. Finally, the merits of the method are discussed and the result of an actual machining is introduced.
Keyword CNC, CAM, interpolation, numerical control, surface machining

## 1. Introduction

The conventional way of machining sculptured surfaces is shown in Figure 1(a): a CAM system generating a large amount of tool paths and an NC machining of sculptured surfaces using the tool paths. Commercial CAM systems generate tool paths as lines, arcs or spline curves such as NURBS (Non Uniformed Rational B-Spline) curves.

The conventional way has the following drawbacks : A commercial CAM system generates NC data using an individual algorithm respectively for machining sculptured surfaces. Sometimes it generates illegal NC data. For example, a certain CAM system may generate NC data with a slight step even where the surface is smooth. In this case, a numerical control has to perform a reduction process so as to recognize the illegal part and remove it. If a CAM system generates NC data with a slight gap, a numerical control has to fill the gap. A tolerance control may cause NC data without a corner position. Although an NC system can compensate such illegal NC data to some extent, the transaction failure may cause scratches on a surface. It is also difficult for an NC to guarantee an excellent compensation for each CAM system.

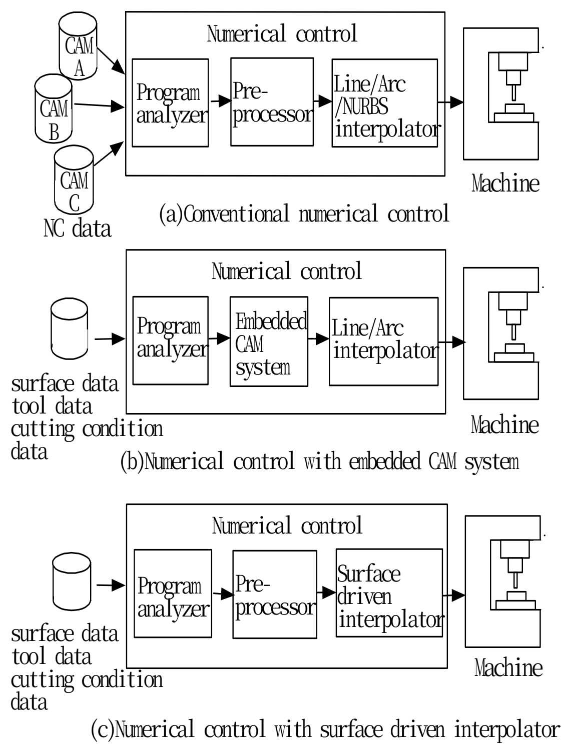



Fig.1. Three types of numerical control

A next type of NC system, shown in Figure 1(b), can eliminate such drawbacks that different CAMs cause [1]. Such a type of NC system has an embedded CAM system that can absorb the differences between the CAMs. And, since it does not generate a large amount of NC data, this type of NC system does not need a large storage. In addition, machining conditions can be suitably adjusted for various situations. Since this type of NC generates NC data in real time, an operator can change the machining condition freely when he is machining. It only combines a CAM function with an interpolation function but it is difficult to machine at high speed. The CAM part generates a number of small segments to guarantee a given tolerance. The smaller the tolerance becomes, the smaller the segment become and it is difficult for the interpolation part to transact small segments. This causes the speed to slow down.

The reason why such problems are caused is that a numerical control does not have the fundamental function of machining surfaces, but it has the functions of machining of line, arc and NURBS segments. So far, the function of machining of surfaces was obtained bycombination with a CAM system.

In this paper, a numerical control with surface driven interpolation is proposed, which interpolates directly from the given surface data without the combination with CAM system. The construction of the numerical control to realize this, the internal algorithm and the machining results are described. The development of numerical control from "point" to "curve" is realized by NURBS interpolation. This paper also shows that the evolution from "curve" to "surface" can be realized by surface driven interpolation [2].

## 2. Numerical control with surface driven interpolation

### 2.1 The structure of an NC with surface driven interpolation

Figure 2 shows the structure of a numerical control with surface driven interpolation, which consists of a block of data input, a block of surface evaluation and a block of surface driven interpolation. The block of data input gets surface data, a machining mode, a kind of tool and feed speed. The block of surface evaluation evaluates the condition of a surface and stores the results before interpolation. The interpolation block consists of three parts, namely a surface condition monitor, a speed controller and a position calculator with a collision detector.

The surface-monitoring part generates the speed needed to satisfy a given tolerance and allowable acceleration. The interpolation part calculates a next point Fdt apart from a current position by using a given speed F (dt is sampling time). The collision detector is used to avoid a collision between tool and surface. Interpolation points are transferred into each servo amplifier in real time. Position calculation is important to realize the proposed numerical control. An algorithm to realize that should have the following properties.

1. Fast calculation to guarantee sampling time
2. Robustness and safety for direct machining
3. High precision to guarantee the minimum unit of an NC

A boundary sphere method has been developed [3]. In this method, surfaces are divided into boundary spheres that are represented by a hierarchal tree structure beforehand. First, search leaf spheres that may collide with a tool. Then, mesh points are generated on the part of surface that is included in each sphere and a tool position is calculated by comparing the tool with the mesh points. After applying the algorithm to a CAM system, it was found that this algorithm was fast and precise. Therefore we applied it to the proposed NC.

Simple application of the same module as the CAM system does not give a fine surface. Figure 3 shows tool paths that a general CAM system generates using tolerance control, and ideal tool paths that the proposed NC has to generate. The former paths are generated so that an error may be within a given tolerance “t”. However, since the length of the paths is

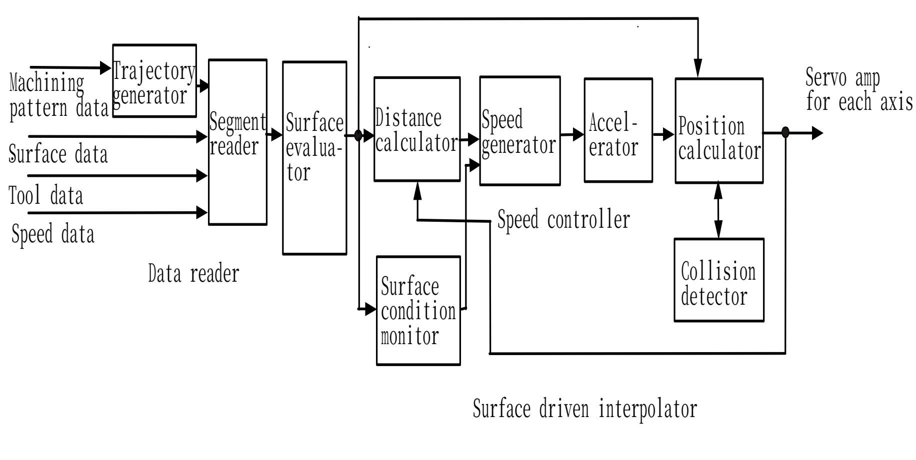



Fig.2. The structure of a numerical control with surface driven interpolation

uneven, it is difficult to drive a machine directly using these paths. The tolerance, which a CAM operator necessarily has to set, is only needed for the algorithm in a CAM system. It is important to recognize that sampling time determines geometric precision. From this, it follows that it is necessary for an NC to generate interpolated points so that a machine can move smoothly as shown in Figure 3(b). The algorithm was investigated to determine whether it is suitable for real time machining and whether the precision is within the sub-micron range.

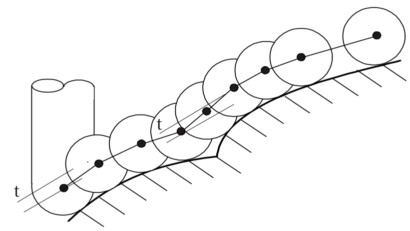
## 2.2 Interpolation point generation

It is necessary to control a tool machine smoothly so as not to add any vibration or shock to it. Conventional speed control is classified into two types, namely speed control before interpolation and speed control after interpolation.

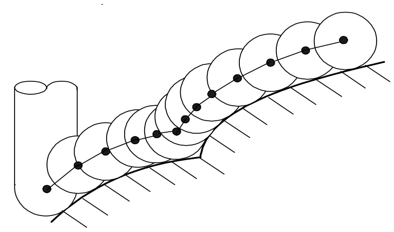
Speed control before interpolation controls the set speed, which is an input to the interpolation part. Although this system structure becomes complex, the precision is good. Speed control after interpolation uses a filter for the speed reference after interpolation. Although the system structure is simple, the precision is not good. In this study, we have selected speed control before interpolation in order to achieve high precision. Therefore, we propose a speed control directly and geometrically from surface information without any filter.

Figure 4 shows the method of surface evaluation and speed control. The surface evaluation method looks beforehand forward at the surface condition along a given trajectory segment. It then calculates the appropriate speed and memorizes it for the given segment. Defining a set speed as Fm, clamp speeds such as from Fa to Ff must be set from a position A to a position F as shown in Figure 4. The part of surface driven interpolation controls feed speed based on the obtained clamp speeds. Since each clamp speed should be strictly kept constant at each position, the feed speed has to be changed beforehand. So, the NC monitors the distance from the current position to the destination and guarantees each clamp speed. Such a process is performed in the distance calculation part and the surface condition part of the monitor.

A feed speed is determined from a set speed, override, emergency stop, etc. Put the current speed of a machine as Fcur. After that, the distance L to the next clamp point is calculated. From the distance and the next clamp speed, acceleration mode such as speed-up, speed-down, constant-speed is selected. In the case of speed-down, feed speed is specified according to the distance L. If F is equal to Fcur, the speed is kept constant. If F < Fcur, speed-down is selected by acceleration Acc. If F > Fcur, speed-up is selected by acceleration Acc. Using the obtained speed, Fdt is calculated and the correspondent pulses are transferred to a servo system. When the tool goes beyond the clamp point, a clamp point is renewed. Such a procedure is performed in a sampling time. To calculate a next interpolation point Fdt apart from a current interpolation point, an iterative calculation is performed.




ath generation by tolerance control



(b)Ideal path generation

Fig.3. Path generation

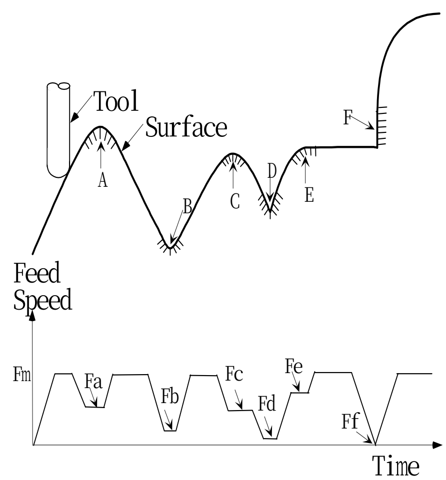



Fig.4. Surface evaluation and speed control

## 3. Machining Result

To prove the proposed numerical control, we used a personal computer (Pentium2 333MHz), a numerical control (Mitsubishi MELDAS M64) and a machining center (MAZAK FJV-20) as the prototype system. The numerical control was modified so that interpolation points generated by the

PC can be transferred to the servo amplifier directly.

Figure 5 shows the results of the interpolation points. We can see a fine speed control at the discontinuous part. In order to machine such a part precisely, the tool speed should be slowed down. The proposed NC can interpolate such a part because the system has surface information and can interpolate in real time. It is difficult for a conventional NC system to do such a control.

Figure 6 shows an example of machining result. Speed control has been performed correctly and fine surface finishes have been obtained.

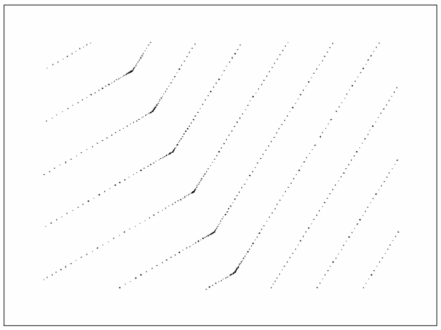


Fig.5 Example of interpolation

Fig.6 Machining result

## 4. Conclusion

In this paper, we have investigated and analyzed the problems of conventional numerical control , and have proposed a numerical control method with surface driven interpolation to resolve them. The concepts, the structure of the numerical control and the algorithm have been discussed. We have also evaluated a machining result with a prototype system. From these results the following conclusions were obtained:

(1) The proposed system gives effective machining by tight coupling of CAM and NC and by discarding an ineffective tolerance control.
(2) It is not necessary to tune certain parameters of a conventional NC to obtain fine machining, because the proposed method does not need a recognition process inside an NC system.
(3) High precision machining has been realized even at a discontinuous part, because the system has the information of surface geometry and can generate interpolated positions at high precision even at low speed.
(4) Since the system does not depend on NC data, which commercial CAM systems generate, the problem caused by illegal NC data is absent.
(5) The fineness of machining of surfaces has been proved with an actual cutting.

One may conclude that the shift from curve interpolation to surface interpolation is appropriate for the generation of interpolating points that are needed for the machining of any given geometry.

## References


1. K.Kato, M.Oshima and H.Maruyama, The DDI-CNC for Machining Sculptured Surfaces, IECON '84, (1984) 551-555.
2. K.Kato, K.Iriguchi, N.Takahahi: Numerical Control using Surface Driven Interpolation, The Journal of JSPE, Vol.66, No.12, (2000) 1879-1884(in Japanese).
3. K.Iriguchi, K.Kato, M.Oshima, Real time Tool Path Generation for 5-Axis Control machining, Proceedings of the IMACS/SICE 95-100 (1992).