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Research on Control Method of Machining Aspheric Surface Based on Numerical Control Interpolation Algorithm

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Abstract: According to the principle of high-order aspherical machining by numerical control Interpolation Algorithm, an open numerical control system was designed based on UMAC. In the composition of hardware, the function, features and variable applications of the servo axis card was introduced in detail, with the standard of the choice of man-machine interface illustrated. In software, the functions of the operating system, development tools and the dynamic link library were integrated, and the modular method was adopted to design the system management software and full-time control software. The innovativeness of the control system is displayed in the breakthrough in that the position control method in the traditional CNC numerical system controlling motion nodes by full-time rate control, the Hidden Markov model theory was introduced to realize ahead forecast compensation, enabling velocity to be controlled continuously, and therefore improve the accuracy of machining surface, and in the meantime this method can be expanded into all applications of speed servo, which improves the accuracy of locus control.

Keywords: Open numerical control, modularization, hidden markov model, forward forecast compensation, speed servo

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1. INTRODUCTION

The common way of aspherical machining with numerical control both home and abroad is by minute polyline approaching curve, for example, the American LODTM large-scale ultraprecise diamond lathe [1] , the German IPT Ultraprecision Lathe and the Japanese Toshiba Machinery Company's ULG-100A(H) ultraprecision numerical control diamond lathe [2] , the German Scheider Optical Machinery Company's ALG 100 size numerical control aspherical grinder, Top Optics Optech Company's numerical control aspherical grinder ASM100, the numerical control polishing lathe ASP200 and the British OAGM2500 large-scale ultraprecision grinder, etc. Although the whole surface accuracy can be ensured, the gained surface is not an optical surface. Sponsored by the National Natural Science Fund, the Science and Engineering University of Changchun has accomplished “the new principle of high-order aspherical machining with numerical control Interpolation Algorithm”, which not only realizes tangent aspherical machining, but also gains an aspherical curved surface with ultraprecision and continuous smoothness. The realization of this principle requires a control method of three axes interpolation linkage, of which one is a shaft of rotation and the other two are rectilinear moving axes, that is, with the rotation axis as the standard shaft, and the two rectilinear axes as driven axes, constituting the mode of electronic cam linkage control; as for the individual axis, to determine the section point is to determine the distance of each section. As the time base is different, the speed of each section is different, and the PVT control mode of cubic spline interpolation is adopted; The error compensation of PVT control uses the error compensation list [3] , and in rate interpolation, the rate of the next moment compared with the current moment may increase or decrease. Due to the particularity of the controlling of tangent high-order aspherical machining, the variation of speed must keep monotonicity to ensure the gradual rotation of tangent, which requires error compensation that must have the characteristics of being updated full-time and have forward-looking. This system introduces Hidden Markov model for forward-looking forecast, which is often adopted in mode identification. This way of control cannot adopt the position control method of the traditional CNC numerical control system to control the speed full-time of the motion node’s moving, so an open numerical control system based on UMAC is designed as shown in figure 1. The system supports the secondary development and expansion by users, and can run the rate interpolation algorithm defined by users themselves.

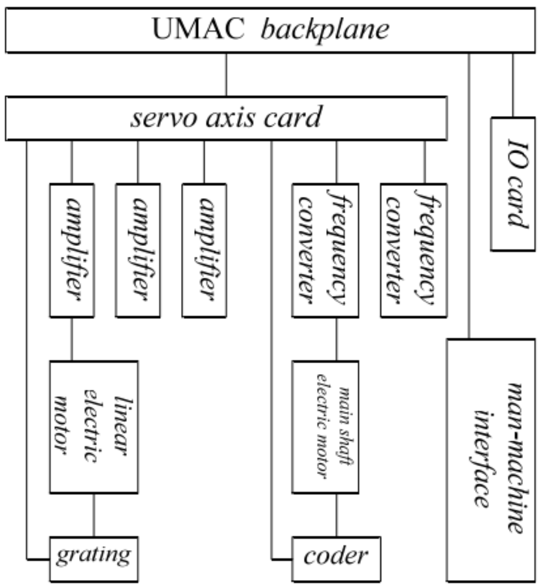


Fig.1. Open Numerical System Based on UMAC

2. COMPOSITION OF HARDWARE OF THE SYSTEM

The UMAC (Universal Motion and Automation Controller) motion controller is a type of professional controller with a built-in I/O, power module and a complete case. In the meantime, this type of controller possesses complete communication means of high-speed USB, Ethernet or MACRO (optical fiber) and so on communicating with the main computer. The distribution and installation of the 3U-structured UMAC controller is quite simple, which is configured into a highly flexible and powerful machine controlling system according to application.

2.1 Servo Axis Card

UMAC CPU+OPT-5E3 is a serial product of the UMAC plane card, which is a closely-structured , economical yet profitable serial product designed into OEM for embedding application system. While providing complete function of the UMAC plane and card, it has a tiny structure, more complete function and more convenient expandability, including the CPU of 80 MHz DSP56303 , STRAM of 128k x 24 digits used for compiling and storage program, STRAM of 128 x 24 digits used for user's data and flash memory of 1M x 8 digits used for user's backup and firmware, being adaptable to the servo system, the stack connection of the I/O accessory board and the back board connection of the UBUS bus. The board card adopts PID/trap/feedforward servo algorithm. At most it supports 32-axis motion control, with the optional analog amount of ±10V in output, direct PWM; the built-in coder input can choose direct binary counting or Gray code feedback, laser interferometer feedback, analog quantity feedback, Sinusoidal coder feedback, 4096 subdivided input feedback, SSI coder input, 16-bit rotary transformer input and MLDTs feedback input; the industrial bus supports Device Net or Profitus, etc.

The UMAC CPU+OPT-5E3 board card has four variables of I, P, Q and M, and the user can arrange according to the system configured by him. The names of variables is composed of the corresponding letter followed by 0-1023, and different types of variable occupy each of its address. Among them variable I is used for initiation and parameter setting, and each variable has its fixed definition; Variable P is the universal user's variable in UMAC, with the accuracy of variable of 48-bit floating-point number, which is the universal global variable in the user's UMAC programming and calculating. Variable Q is the universal variable in the frame of axes in users' UMAC programming and calculating. In multi-frame of axes, variable Q can be used for management. The physical address of variable Q is different in different frame of axes, and the same variable Q can be used to visit different physical memory address; Variable M is used to visit UMAC memory and the address pointer at the point of I/O. Variable Q is not defined beforehand, and users have to give the definition by themselves. Having been defined, it will be stored in the backup battery RAM or the flash memory, so it only requires one time definition by online instruction.

2.2 Man-machine Interface

The man-machine interface has to reliably finish the collection of data full time, full-time processing and full-time control in the course of production, which is the critical constituent in observation, control and management, and therefore Panel PC 677B is chosen, which is furnished with 2.16-GHz Intel Core 2 Duo T7400 double core processor and Intel 945GM Express chip set. The integrated Intel GMA950 graphic accelerator can achieve high-speed graphic processing. The memory can be upgraded to 4 GB, and the hard disc can be upgraded to 160 GB, able to be equipped with a CD-ROM drive. In order to improve the availability of the system and the security of data, Panel PC 677B adopts the optional antihunt double hard disc module used as RAID1 mirror image disk operating system, and supported by random RAID controller. In order to reduce maintenance and improve error tolerance, and to make it work without hard disc, Panel PC is furnished with two drive slots, into which flash memory card can be inserted---of which one has an external interface. Via two PCI interfaces, or one PCI interface and one PCI express x4 interface, a powerful expansion card can be integrated, say the expansion card for graphic processing. Either of the two products integrates two 7-section programmable display screen and two LED indicators, which can display BIOS powering up and fast diagnosis of running state, and can even diagnose the internal state of software’s application program. And Panel PC 677B possesses the capacity of connection to the Ethernet of -10/100/1000 megabit/s, being able to work together, one can adopt random Profibus interface, one can use DVI-I interface, four high-speed USB-2.0 port and the power of 24 V DC or 120/230 V AC. If the optional remote control tool kit is used, the running unit can be installed in the place 30 meters away from the PC. Once there is power failure, the 128KB SRAM powered by batteries can ensure the security of date controlled by WinAC. The operating system can adopt Windows 2000, Windows XP Professional MUI or Windows XP Embedded.

3. SOFTWARE FUNCTION OF THE SYSTEM

The control system software in the numerical control system employs the way of modularization in its design of the two parts of system management software and full-time control software, in which management software consists of system management, man-machine interface, etc.; full-time control software is made up of locus control, servo control, etc. WindowsXp is chosen as the operating system, which is the key segment to the development of the software of the open numerical control system. The software of the open numerical system can be regarded as a kind of application software running on the universal operating system, which is different from other application software in that it is a typical full-time multitask control system. Essentially, it is the adoption of the full-time multitask operating system that can ensure full time of the numerical control system. In addition, the operating system should possess substantial resources of both soft and hard ware and powerful management ability to provide the developers with good development environment. The software of the whole open numerical control system being developed on the platform of the open WindowsXp in the language of VC++, UMAC can perform all the strong full-time task in the numerical control system, such as position control, interpolation, rate processing, the PLC task, decoding interpretation and cutter compensation etc, and therefore the focus of the development of numerical control software lies in the communication between UMAC motion control card and the man-machine interface and the realization of some non-high full-time tasks like the compilation of the software of the upper system operation, dispatching and management, failure diagnosis, parameter input, program editing. As UMAC provides a high useful open software package, when exchanging information with communications, it only need to call the corresponding functional function in the function library to exchange information with communications, so the development of the heavy communication drive development is spared, and it is unnecessary to deal with UMAC hardware directly, hence the function of numerical control system can easily be achieved by VC++. In the operating system of WindowsXp, with VC++ as the development tool, adopting the object-oriented compilation, making good use of the function in the dynamic link library of the UMAC motion control card, the open numerical system software is developed, and the basic function of the numerical control system is fulfilled. The specific functions that can be fulfilled include: the friendly man-machine interface of WindowsXp style, preprocessing of system initiation, decoding of the numerical control program, automatic and manual machining, origin regression, monitoring of the lathe state, coordinate positions and the full-time display of the main shaft's rotation rate, configuration of dynamic parametrization of the system, the built-in PLC function, etc.

4. ALGORITHM OF RATE CONTROL ERROR COMPENSATION

Mode usually refers to the sequence of event that happens in accordance with a certain order, which reflects the correlation between the events in the sequence. The Markov assumes that the current state is only related to some of the previous states, which greatly simplifies the mode. Although it may lead to error in forecasting, this kind of error is usually acceptable. If the present state in the Markov mode is only related to n previous states, then it is called n sequence mode. Usually the Markov process is not enough, because it does not employ other conditions. A mode does not necessarily exit on the surface, but rather it is very likely to exist beneath some phenomena. Nevertheless, there are some relations between phenomena and modes, which constitutes the Hidden Mode of Markov [4] . The subject that the Hidden Markov Mode studies is a sequence of data, in which each value is called an observational symbol. The theory of HMM holds that another sequence hides behind a sequence, and this sequence represents a series of states, each symbol occurring in a certain state, and the transition of symbols and states being modeled by the probability model, yet the state sequence being invisible and hidden behind the symbol HMM. The state of the HMM is uncertain or invisible, only to be shown through the observation of the random course of sequence, and the observed events and states are not one-to-one correspondent, but rather related through a set of probability distribution. The HMM is a double random process, consisting of two parts:

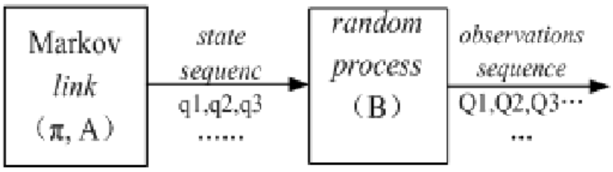


Fig.2 .The sketch map of composition of HMM

The mode of the HMM can be described in three sets (H, A,B):

1) H= (hi) is the initialization vector;

2) A = (aij) is the state transition matrix, which is a conditional probability, whose row sum is 1;

3) B = (bij) is the observational state matrix;

Main aspects of study of the HMM in application:

1) Starting with a section of observational sequence and the given model, finding out the optimum state sequence in the model is called the question of decoding;

2) Starting with a section of observational sequence, finding out the model is called the question of learning;

3) For an undetermined observational sequence, finding out a best model from the several learned models is called the question of identification [4] .

The HMM and the revolution Interpolation Algorithm correspond to each other in rate control process in high-order aspherical machining of optical components, i.e., the sequence in the HMM corresponds to the theoretical fragment in rate forward-looking control, each position error (the difference between the actual position feedback value and the theoretical position calculation) corresponds to an observable state matrix of the HMM, resulting in position error which hides rate error (the difference between the rate set in each section and the actual running rate), and this rate error corresponds to a state transition matrix of the HMM. Position error occurs on rate error, but the rate error is unobservable, which hides behind position error, only to be reflected via observation of the observable state matrices. The observed position error and rate error are related through a set of probabilities calculated by the HMM, that is to say, the observed current position error is related to the unobservable rate error through probability distribution, and therefore the probability result got by the HMM can compensate the sectional rate got by theoretical calculation. The actual research shows that it is entirely feasible to introduce the HMM in the control of high-order aspherical machining to reduce rate control error. A HMM and a observations sequence are given, and the most probable hidden state sequence is calculated, using the Vitebi algorithm to do decoding calculation, whose advantage consists not only in surveying the relation between the two observational states before and after, but in surveying the overall observational sequence, gaining an optimum result of a complete sequence.

The study subject of the compensation algorithm is a theoretical fragmentation sequence in a rate servo course. The difference between the feedback of each actual position of the sequence and the calculation of the theoretical position is the result that can be got through position detection, which is called observational symbol. Behind the sequence another sequence is hidden, i.e., the difference between the rate set in each section and the actual running rate. This sequence represents a series of states. The state set of rate error can be divided into three state of {equal, greater than, smaller than}, and the state transition matrix A shown in Table 1 is obtained by means of experimental statistics.

TABLE I
The State Transition Matrix

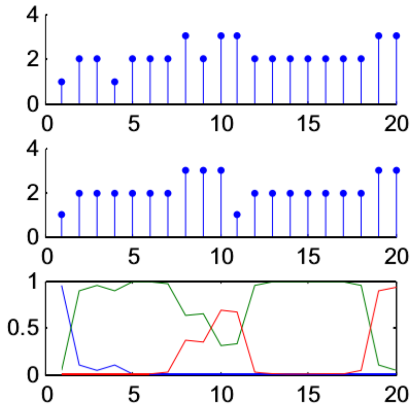
Rate Error	equal	greater than	smaller than
equal	0.8	0.1	0.1
greater than	0.1	0.8	0.1
smaller than	0.1	0.1	0.8

If the rate servo process considers position error in the meantime, then two sets of state can be gained, i.e. observations' set (position error) and "hidden" set of state (rate error). Employing these two sets of state, the future set rate value is forecasted by an algorithm. For this purpose, the Hidden Markov Mode can be used to describe it. It can be seen from Table 2 that beneath the observational state hides the change of actual state, and its probability relation can be represented by Pr (position error/rate error), whose observational state matrix is B, which conforms more to the following rate values set according to the calculation on the basis of observations. A Hidden Markov Model and an observation sequence are given; the most probable hidden state sequence is calculated, doing the decoding calculation by the Vitebi algorithm. The advantage of the Vitebi algorithm lies not only in surveying the relation between the two observational states before and after, but also in surveying the whole observational sequence and gaining the "most seeming" result.

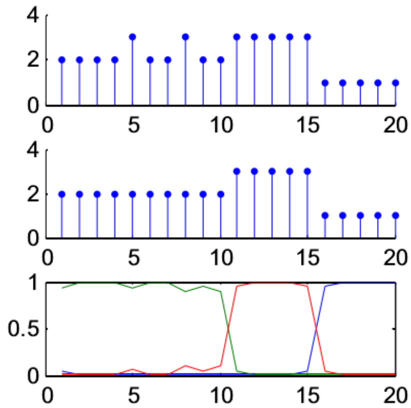
TABLE II
The observational state matrix

Position error-> Rate error	equal	bigger than	smaller than
equal	0.6	0.2	0.2
bigger than	0.2	0.6	0.2
smaller than	0.2	0.2	0.6

Figure 3(a), (b) are the simulation results of different random position errors and rate errors. In the first two charts of the two sets of charts, the coordinate “1” in axis Y symbolizes “equal”, “2” symbolizes “bigger than”, and “3” symbolizes “smaller than”; in the bottom chart axis Y represents probability value; axis represents the number of random sequences.



(a)



(b)

Fig.3. Simulation Results of Errors

It can be seen from Figure 3 (a) that the three sub-charts are respectively position error state chart (above), rate error state chart (middle), the probability graph (below) of equality, bigger, smaller of position error and rate error. When position error and rate error have the same state, that is, the position error in the above chart and the rate error in the middle chart take the same value in the same random point, it means that the probability value in the state takes the maximum value in the random point. By simulation verification [5], the position error and rate error of the 1st point are equal, i.e., their values are both “1”, and from the bottom chart it can be seen that by comparison of the three state probabilities of the first point, “equal” has the maximum probability of 0.95, and for the next point, rate can be set at a theoretical calculation, being unnecessary to compensation. Figure 3 (b) is the verification of Figure 3 (a), which the reader can put to the proof by himself.

5. CONCLUSION

The hardware and design of the open numerical system base on UMAC solves effectively the control of high-order aspherical machining by means of tangent. Especially when the HMM was introduced, the forward-looking forecast compensation of rate interpolation error was solved. For numerical control servo system, the surface machined is continuous smooth with great accuracy, and efficiency improved. The application of the HMM to motion control technique has good prospects for generalization to other rate servo system with similar conditions, for example, in the course of the large radar antenna tracking the rotation rate of antenna can be controlled continuously and well, and tracking accuracy can be improved. This is a breakthrough in speed tracking with high accuracy, and therefore can facilitate further development of automatic control.

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