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Application and Execution of CNCbCAD&CAPP Technology in INC

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Abstract - **This paper is based on a new philosophy of CNC (Computer Numerical Control), which is named as INC (Integrated Numerical Control or Intelligent Numerical Control). CNCbCAD&CAPP (CNC technology based on CAD&CAPP) is one of the most important key techniques used in INC. First this paper has a brief introduction of INC and describes the important characteristics of INC. Second it introduces and analyses the one of INC's three key technologies: CNC technology based on CAD&CAPP, which has mended general CNC system to fit CAD&CAPP. It mainly includes establishing a new INC standard with a STEP (Standard for the Exchange of Product Model Data) extension, expression based features, embedded technology, real-time Linux technology and so on. It focuses on discussing the application and execution of them further. Finally, a case in Linux platform is given to illustrate how to realize CNC based on CAD&CAPP in engineering area.**

I. INTRODUCTION

There is a trend that advanced manufacturing technologies are to be developed to include numeralization, precision, uttermost, automatization, integration, latticing, intelligentization and green production technologies [1]. Global competition and rapidly changing customer requirements result in great changes in production style and configuration of manufacturing organization. Increasingly, traditional centralized and sequential manufacturing planning, scheduling, and control mechanisms are being found insufficient to respond to highly dynamic variations in product development. With the advent of Internet and distributed computing technologies, product design and manufacturing are increasingly distributed. Therefore, collaborative manufacturing is to be required to develop and produce high quality products faster and cheaper.

Nowadays there is a rich literature in CNC (Computer Numerical Control) area. From the original CNC concept to latter-day ONC and DNC, there has been a long research history in this field. First we have a brief comparison and analysis on them as follows:

ONC is the abbreviation of Open Numerical Control, which is similar to OAC (Open Architecture Control). When NC is developed to be used in the distributed controlling and FMS (Flexible Manufacture System) environment, further it needs to communicate with CAD/CAPP/CAM (Computer-Aided Design/Computer-Aided Process Planning/Computer-aided Manufacturing) system, the original NC oriented to a single machine was being found insufficient to satisfy the new requirements. It was necessary that NC should be transferred to have an open architecture [2]. Open means NC has a unified external standard controller interface, which comprises an extensible man-machine interface, standard drive interfaces and etc. There are three authoritative open architecture controller standard specifications in the world: OMAC (Open Modular Architecture Controller), OSEC (Open System Environment for Controller) and OSACA (Open System Architecture for control within Automation). Compared to the traditional CNC, ONC is open [2][3].

DNC is the abbreviation of Direct Numerical control. In a wide sense, it means Distributed Numerical Control. DNC was conceived originally as a means of cost-effective program storage and machine control [4]. Therefore the system must be integrated with part programming so that programs can be directly transferred between the storage medium and the machine. DNC use a central computer to hold numerous component programs, and when required these are fed to individual machine tool controllers along a real-time two-way communications network. One DNC central computer can service a variety of dissimilar machines, and if the facility is arranged in cellular form it can store data on production needs, tool wear and machined down-time. This information can be used by management for improved decision making. It integrates communication, control, plan and management together, maybe includes CAD, CAPP and CAM. It aims at controlling a group of NC machines effective, or further controlling a whole factory. It can be seen as a kind of Distributed Manufacturing.

And here we make an introduction of a new concept of INC. What is INC? It can be seen as a cost-effective integrated theory oriented to manufacturing. In this paper, a brief introduction of INC is presented, followed by introducing the architecture and its three key technologies. And then we emphasizes on discussing CNC technology based on CAD&CAPP(CNCbCAD&CAPP) including interface technology with a STEP (Standard for the Exchange of Product Model Data) extension, embedded system and microcontroller technology, real-time Linux technology, etc. We also focus on giving a case to illustrate how to apply the technologies in engineering area. Finally, predictions are made on what INC and CNCbCAD&CAPP might to be in future years.

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II. INTRODUCTION OF INC

A. *Conception of INC*

INC [5], proposed by Manufacturing Grid Resource Group of CIMS & Robot Centre of Shanghai University, China, in a narrow sense is the abbreviation of Integrated Numerical Control. It means that abstracting some functions of traditional CIMS (Computer Integrated Manufacturing System), such as CAD, CAPP, CAM, into a series of modules, which makes the application be divided into a group of tasks frame. The tasks frames could be decomposed into detailed sub-functions. Every function module is a practical module oriented to manufacturing, such as code explaining, interpolation and PLC control. The function modules are organized and integrated into the bigger parts modules with the tasks frame. And these parts modules are integrated into a concrete application CNC system finally with a unified user interface. The flow chart of INC is shown in figure 1

But different with some general CAD/CAPP/CAM integrated system, the focus of INC is the CNC module. Every foregoing module is the preparation of the CNC module. The other modules all work for the kernel module - CNC module. For example, CAD parts module, which is oriented to CNC module, is not same as the general CAD system. It excludes some advanced and complex functions of computer aided design, such as three-dimensional design and three-dimensional modelling, but includes some useful functions oriented to CNC, such as distilling of image outline, image binarization, image vectorization and so on.

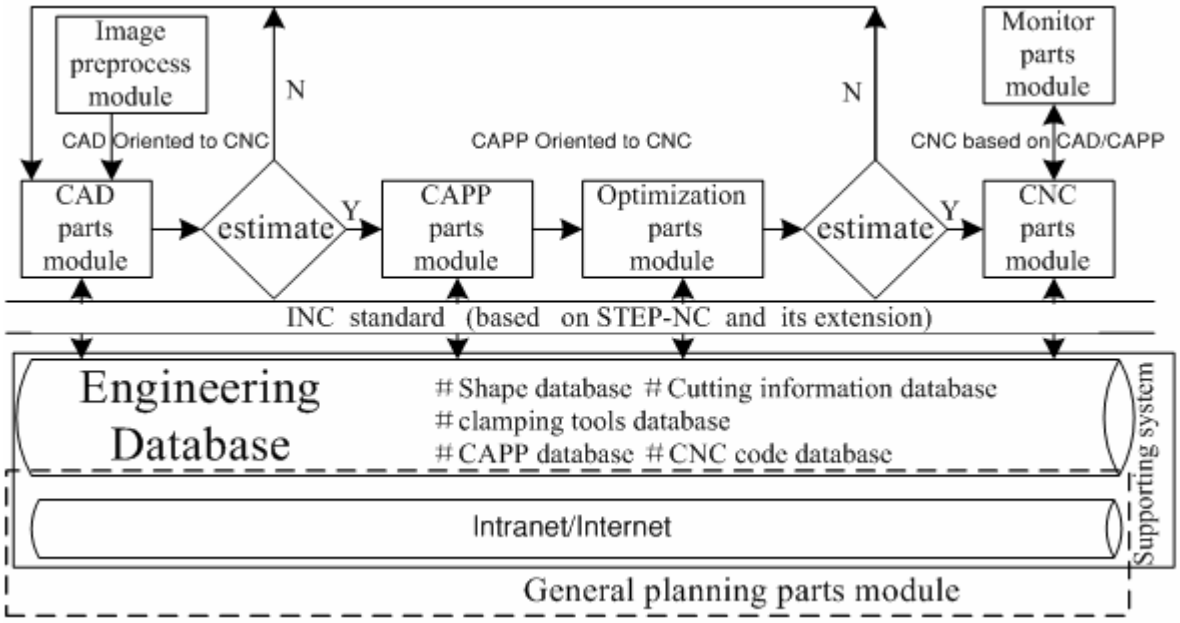

Figure. 1 Flow chart of INC

In a broad sense, INC is the abbreviation of Intelligent Numerical Control. It not only has the functions of INC in a narrow sense, but also has the function of collecting system information, monitoring system conditions to do self-adapting adjustment, recording historical information to analyse and synthetize, making decision, managing it own expert database and etc. It has the extra expert system and information collecting system than INC in a narrow sense. It also has the function of remote control. And in this updated model, we have tried to build an INC standard to do the data exchange work. The INC standard is based on the STEP-NC and has extended the STEP-NC. It has extended the feature-based expression to the control area.

From the concept of INC, we can see the differences between INC and DNC. DNC integrates communication, control, plan and management together, maybe includes CAD, CAPP and CAM in some degree. But it aims at controlling a group of NC machines effective, or further controlling a whole factory. It can be seen as a kind of Distributed Manufacturing. Instead, the heart of INC is NC. It aims at manufacturing. All its work is for its last task: NC manufacturing. Its CAD parts module and its CAPP module, which are oriented to CNC module, are not same as the general CAD system. It has a good CSCW (Computer Supported Collaborative Work) performance and can be seen as a good application case of parallel engineering. Contrasted to Distributed Manufacturing, it is a kind of Collaborative Manufacturing. And it is a more cost-effective approach to realize CIMS than DNC. Theoretically, it can realize CAD/CAPP/CAM in a CNC machine. INC also absorbed the open attribute of ONC. It realizes the openness using the new INC standard in the software layer, and using the embedded technology in the hardware layer. It is integrated and is open as ONC in the same time.

B. *Key techniques of INC*

Because INC is an integrated and intelligent CNC, its key technologies not only include the technique of CNC, but also include extra integration and intelligentization technology. And we conclude there are three kernel technologies should be

considered: CAD technology oriented CNC (CADoCNC), CAPP technology oriented to CNC (CAPPoCNC) and CNC technology based on CAD&CAPP (CNCbCAD&CAPP).

CADoCNC [6] includes image preprocessing technology, intelligent identification technology, image vector quantization (VQ) technology and CAD/CAPP integration technology, etc.

CAPPoCNC [7] includes nesting optimization technology, motion expression based on Characteristics, interactive CAD &CAPP technology based on engineering database and fuzzy information expression and evaluation technology, etc.

CNCbCAD&CAPP includes building a new INC standard with a STEP-NC [8] extension, expression based features, embedded system and microcontroller technology, real-time Linux technology and so on.

And about system monitoring parts module and general planning parts module, they may involve signal processing technology, MIS (Management Information System) technology and some other relative technologies.

In this paper, we emphasize on discussion and study of CNCbCAD&CAPP (CNC technology based on CAD&CAPP used in INC) in the next pages.

III. Discussion of CNCbCAD&cAPP

In the traditional CAD/CAPP/CAM manufacturing process, CNC can only get data from CAD&CAPP, but it can't feedback data to CAD&CAPP. There is no two-way communication between CNC and CAD&CAPP. For general CNC controller is made of SCM (Single Chip Micyoco), it hasn't a good extensible and configurable characteristic. Now we apply newly STEP technology and embedded system technology into INC, and it mainly comprises interface technology with an INC standard, embedded system and technology, real-time technology, embedded GUI (Graphical User Interface) technology and so on.

A. Expression Based on Features

The significance of the "feature" concept, or rather its implication and implementation in design and manufacturing domain, has long been recognized. Most of the contemporary CAD/CAM systems have all adopted the feature-based design approach. On the CNC side, feature-based machining still remains as a much-anticipated reality. Central to the concept of feature-based machining is effectively that of "task-oriented" as opposed to the "method-oriented" CNC programming. G-code documents CNC machining instructions, which are rigid and machine dependent. STEP-NC, on the other hand, brings task-related information to a CNC machine. In STEP-NC, the feature-based machining concept is embedded in a well-established hierarchy of workingstep supertypes and subtypes. It breaks down every machining operation into steps required to perform the operation. These steps include actions to be taken for each of the machining features defined. In other words, the "workingstep"-based structure replaces the axis motion and tool operation command sets as in G-code. STEP-NC provides a feature-based and object-oriented data model for CNCs. It is systematically detailed with a structured data model that incorporates the component geometry through feature-based programming [9][10].

STEP-NC data model is formed on the base of STEP (ISO6893) about three-dimensional geometric model. Manufacturing technology and information is added to it to substitute the traditional G-code (ISO 6893). At present, the international standard ISO14649 comprises general principles (ISO 14649-1), universal data model (ISO 14649-10), CNC milling model (ISO 14649-11) and milling tools (ISO 14649-111), etc. The standard adopts EXPRESS (ISO 10303-11) language to define the data interface of milling and cutting operations of CNC in detail [11][12].

We also can use this method to express other elements in the manufacturing process. And to expand it to the control phase and make the whole process have a unified specification, we used this method into the process of building the standard of INC, which are also based on the stand of STEP-NC, and expressed in the same language EXPRESS with STEP.

B. Establishing INC standard with a STEP extension

The extension part of INC standard indicates the information related to manufacturing, but the information is not been defined in STEP-NC, such as some controlling characteristics, e.g. motion, interpolation, acceleration and deceleration and so on. INC has normalize them to be expressed in the same format with the standard of STEP-NC.

It has extends STEP to express the motion and control features, such as the last passage described. This method has the positive meaning than original STEP-NC as follows:

1) It has extended the method based on features to the phase of control, which meets the requirement to accomplish interpolation and control of characteristic level.

2) It makes the whole process (from translation to plan, and to control) more fluent and flexible, which forms the base of dynamic decision and control.

C. Embedded system technology

SCM is widely used in traditional CNC. But with the development of science and technology of computer, SCM has been found that it can not meet the requirement of more and more integrated and multifunctional and modularized CNC system. And embedded controller has been the trend of CNC development in the future.

Compared to other embedded systems, Linux is not only free, but also is an open-source project. As a customizable platform Linux is supposed to be a popular system of the embedded product by many companies. Considering embedded Linux is open-source, good network-supporting, steady and safe and some other merits, we prefer to adopt embedded Linux as the embedded system solution in INC.

We have divided INC tasks to two categories: real-time task and nonreal-time task. Nonreal-time task interact with kernel through OS API (Application Programming Interface). And we use an embedded GUI above the kernel and nonreal-time application to facilitate users to operate. There are three popular embedded GUI solutions in the present: Qt-embedded, Microwindows and MiniGUI. We choose MiniGUI for its small kernel and good Chinese support attributes. And for

real-time tasks, they have different interplay style with kernel. We talk about it in next paragraph in detail.

D. Real-time Linux technology

The rapid development of Linux is for its applications have good compatibility of POSIX, but the architecture of Linux is a typical time-share design.

Although Linux is a single-kernel time-share OS, it has absolute advantage than other real-time embedded system for it has a better development environment and running environment. And some research organizations has developed different Linux real-time edition to make Linux used conveniently in real-time environment.

At the present, the real-time Linux solutions can be divided two categories. The first is to modify the original kernel adding or correcting some codes of original edition to make the kernel has a foreseeing capability. The second is to use a hybrid structure. It needs to write a new extra real-time OS kernel to handle real-time tasks. It is generally called dual-kernel architecture [13].

We can choose the first manner to modify the kernel. But if response time need to be less-than 1ms, hard real-time is recommended. We need to use the dual-kernel architecture in the condition. When using the real-time kernel, the CNC function modules could be divided into two layers. The NC threads functions module such as PLC control and Interpolation have a high priority level, and the others have a lower priority level.

And CADbCAD&CAPP includes some other technologies also, such as programming of device drive, kinetic control technology and so on. But they are not as distinguished as the above three, so we don't introduce them here.

IV. APPLICATION OF CNCBCAD&CAPP

We have done researches on INC upon Windows, Linux and embedded Linux platform. Here we depict working process of INC under the Linux-based and Embedded Linux environment as an example. All the researches and development of Linux-based INC system were based on AWJ (Abrasive Water Jet) cutting machine. AWJ cutting machine is a patented product of Shanghai University JiRen Co ltd & Shanghai University of China. AWJ cutting machine cuts components by water mixed abrasive via high-pressure tube. We explain how to realize narrow-sense INC based on this.

Now first we got a pattern of a digital photo as top left part of figure 2. It is a finished product of a kind of ceramic tile.

As it is shown in figure 2, we can see how image preprocessing course goes on. It is an important point of INC, it can convert engineering pattern to editable vector file. In the second part, we get a grayscale binarized image; in the third part, we denoise the image, and then we debur the edge, finally we got a clear outline.

After VQ process, we get a standard dxf file, and we import it into our CAD/CAPP module, as it is shown in figure 3.

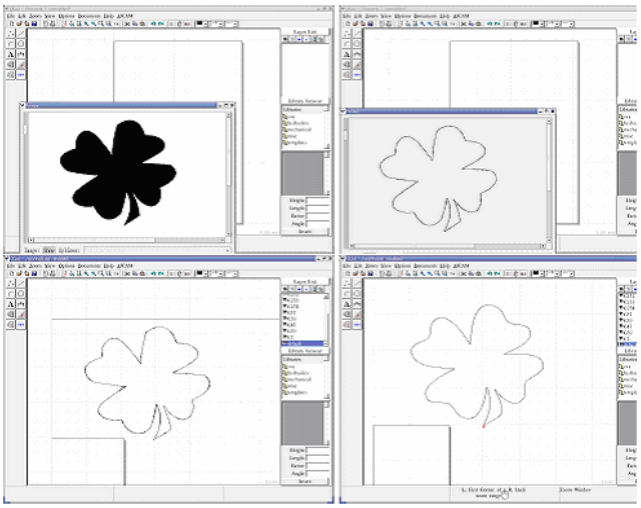

Figure. 2 Image preprocessing module.

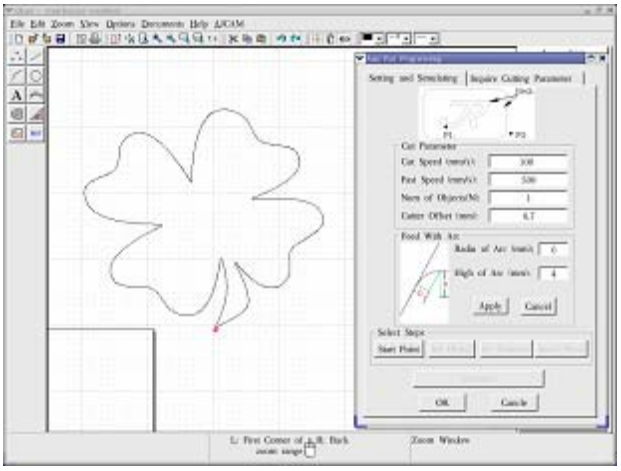

Figure. 3 CAD/CAPP module interface.

QCAD has been embedded in this module, and we can perform all the CAD functions via that interface. In the left of figure 6, we can design and modify our drawing in that area. And in the right, it is a CAPP plugged in the module, where we can get points, lines, layers, dimensions, direction and some process parameters easily and we can generate G-code text for the next step. We could interact with CAD system via this module, where CAD information can also be transferred to CAPP information in the background.

Finally we jump into the emulator module emulating the actual manufacturing, which is programmed with C language so it can be also run in the embedded Linux platform to operate the machine, as it is shown in figure 4. In the top left part of figure 4, it is a cutting process display, where we can have an intuitionistic cognition of cutting path, cutting velocity, current coordinate and etc. We also can know the information of components' shape, the amount, path we have finished, and path left. In the top right of figure 4, it is a frame where numerical code is shown. We can check it, modify it and save as a new one. The bottom of the interface has some parameters listed and adjusting buttons.

And the figure 5 is the CNC module in the embedded Linux platform. We used the trimmed Linux2.4.20 as the

operating system, adopted the MiniGUI as the GUI system, and adopted RTAI as the real-time solution. All the software was programmed with C language, so it is compatible with the foregoing modules running in Windows and Linux platform.

Now we have finished a cycle from a digital photo of a finished product to a new product machining using INC system in the Linux platform, as it is shown in figure 6.

V. CONCLUSIONS AND PERSPECTIVES

This paper proposes a new type of CNC - INC. It is a new conception in CNC field which gives an integrated theory oriented to manufacturing. And paper emphasizes on discussion and analysis of one of its key technology: CNC technology based on CAD&CAPP (CNCbCAD&CAPP), which mainly includes interface technology with a STEP extension, embedded system and microcontroller technology, real-time Linux technology and so on. And finally it gives a case study on narrow-sense INC realization in the engineering field.

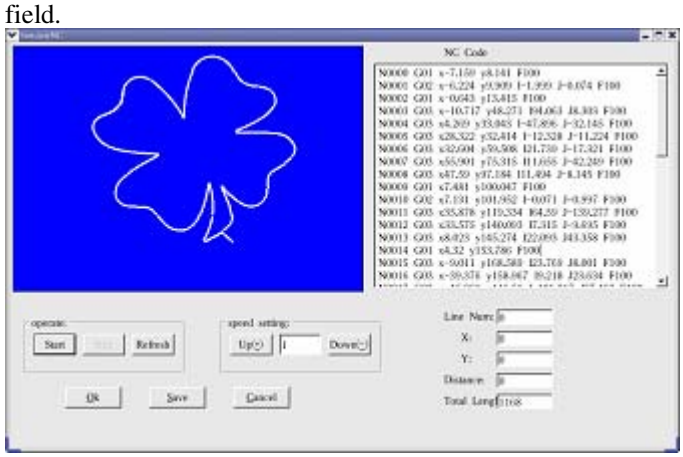

Figure. 4 CNC emulator module interface.

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INC – with a friendly interface based on graphics and special tools – is such a system replacing Distributed Manufacturing with Collaborative Manufacturing that it is a novel philosophy using a cost-effective means to directly facilitate the manufacturing to enhance productivity. It is an integrated manufacturing or intelligent manufacturing.

As far as CNCbCAD&CAPP is concerned, it solves the problem how to setup a two-way communication between CNC and CAD&CAPP. And it gives a solution using embedded system and real-time Linux kernel to substitute traditional PC or SCM to make INC have a unified external standard controller interface and have extensible and configurable modules

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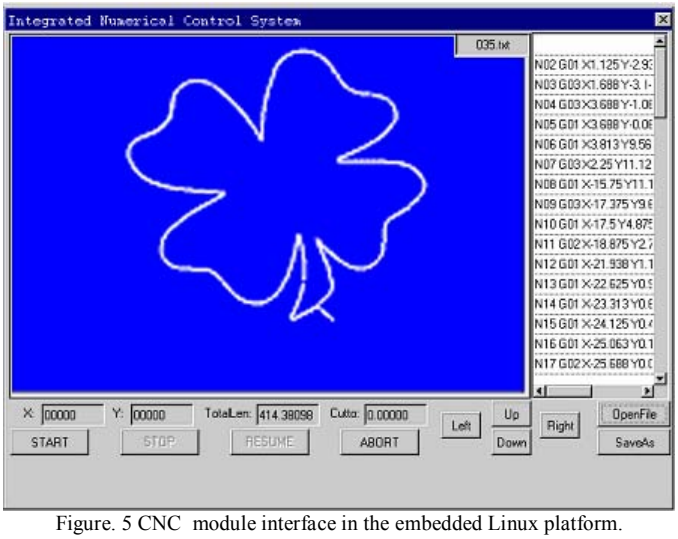

Figure. 5 CNC module interface in the embedded Linux platform.

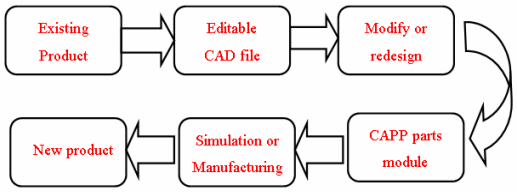

Figure. 6 A cycle from a photo to a new product.

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