Preface

Since the very first computer (Electronic Numerical Integrator And Computer, ENIAC for short) was conceived, designed, and built in 1946 at the University of Pennsylvania's Moore School of Electrical Engineering, its impact on almost all walks of our lives has been readily recognisable. Computers have certainly been responsible for the modern manufacturing industry that exists today. Indeed, applications of computers have been found in the entire spectrum of the product development process, ranging from conceptual design to product realization and even recycling.

Nowadays, regardless of company size, every manufacturing organization needs a well thought-out, long-term strategy in investing computer-related technologies, solutions, and systems. Selecting vendors and defining the scope of each business system from a plethora of rapidly changing options is incredibly difficult. Claims and testimonials are hard to evaluate against your business requirements. Previous generations of computer-based systems have had clean boundaries between system types as well as data formats, such as computer-aided design, process planning and manufacturing (CAD/CAPP/CAM), computer numerical control (CNC), product data management (PDM), and product lifecycle management (PLM) systems; whereas boundaries between today's products and product development processes are fuzzy. Some vendors offer a full suite of products covering "all" needs, nicely linked together, while others focus on a specific business need and provide a "best-of-breed" system, leaving it to customers to debate the benefits of each. Most users, even those choosing a product suite, will need to interface or integrate with multiple systems. Each organization and the systems to be interfaced and integrated have unique requirements and necessitate comparing those needs to the organization's long-term interconnection strategy.

COMPUTER AIDED TECHNOLOGIES

One of the areas that computers were first used to assist in engineering process is design, hence the birth of computer-aided design technology. Three-dimensional (3-D) computer-aided design models led to the development of new branches of technologies such as computational graphics and geometric modelling. These technologies are needed to serve as the underlying principles for a complete and unambiguous internal representation of any product. The wire-frame and surface-based models were first developed. A need for solid modelling then arose with the development of application programs such as numerical control (NC) verification codes and automatic mesh generation for finite element analysis (FEA). The research work on solid modelling technology commenced in the mid-1970s, and a decade later the technology was seen to be utilized by a number of CAD systems that are advanced enough to represent most of the common geometric entities, thanks to the underpinning solid modelling kernels such as ACIS®, Parasolid®, and Granite®. Most of these systems use a boundary representation (B-rep) scheme to represent 3-D information. It is also noticeable that computer hardware advancements have been in company with the development of geometric modelling techniques and CAD systems. The hierarchy of CAD hardware resources has progressed from large-scale computers to workstations and PCs. This trend was not accompanied by a reduction in functionality, owing to the rapid advancement of computer hardware.

Two critical advancements in the domain of computer-aided design are *parametric* and *feature-based design* (FBD) technology. Parametric design is a method of linking dimensions and variables to geometry in such a way that when the values change, the part changes as well – hence the dimension-driven capability. Designing with pre-defined features can reduce the number of input commands substantially. The most valuable attribute however, is the fact that the features can be used to capture the designer's intent as well as to convey other engineering connotations.

These days, users can easily be "spoiled" by a large number of choices of CAD systems offering targeted competitive solutions. While this may not be a bad thing, the data compatibility, or lack of it, has proven to be more than a nuisance. Companies are more and more involved in manufacturing various parts of their end-products using different subcontractors, many of whom are often geographically diverse as well as operationally heterogeneous. The rise of such globalization has created an acute need for sharing and exchanging information among vendors involved in multi-disciplinary projects. Accurate data transmission is of paramount importance. Thus, a mechanism for good data transfer is needed. Direct data translators provide a direct solution, which entails translating the modelling data stored in a product database directly from one CAD system format to another, usually in one step. A more viable option however, is the use of a common translator, which converts a proprietary CAD data format into a neutral data format and vice versa. This neutral data format may be of an international or industry accepted data format or a proprietary data format. Among these standards is STEP (Standard for the Exchange of Product model data), the only international standard that is soon becoming the norm of product data exchange.

Representation of a product's geometry and topology is just the beginning of any product development process. Manufacturing is often one of many subsequent activities. When computers are used to assist process planning and manufacturing activities (i.e. CAPP and CAM), multiple benefits can be derived. CAPP relies on the produce model data provided by a CAD system to perform precise and consistent process planning for manufacturing. The key research issue herein stems from the differing product descriptions used, (i.e. CAD is usually geometry-based whereas CAPP is manufacture-oriented (Zhou, Qiu, Hua, Wang & Ruan, 2007). It is a common practice to use design features in a CAD model and manufacturing features in a CAPP and/or CAM system. Design features are stereotypical shapes related to a part's function, its design intent, or the model construction methodology, whereas manufacturing features are stereotypical shapes that can be made by typical manufacturing operations (Shen & Shah, 1994). A feature, be it a design feature or a manufacturing feature, can be represented as a collection of faces or a solid. Careful examination about which representation scheme suits the jobs of process planning and manufacturing best, suggests that the volumetric scheme has more advantages over the surface scheme (Xu, 2001).

The differences between design features and machining features, and the need for "deriving" one from the other, have led to a new field of research: feature recognition. Specifically, the goal is to bridge the gap between a CAD database and a CAPP system by automatically recognizing features of a part from the data stored in the CAD system. Based on the recognized features, then one has to drive the CAPP system which produces process plans for manufacturing the part. It is important to acknowledge that the task of recognizing manufacturing features still remains with the usage of a feature-based design (FBD) tool. The reason is obvious; design features would be used in a FBD system and manufacturing features are needed for process planning. Difficulties in developing a generic feature recognition system arise from both presentational challenges of specifying the analysis required, and from computational challenges (Corney, Hayes, Sundararajan & Wright, 2005). When features come to interact with one another, recognizing and interpreting them can be even more difficult. Feature interactions tend to violate feature validity one way or another, which in turn may affect the semantics of a feature, ranging from slight changes in actual parameter values, to some substantial alterations to both geometry and topology, or even complete suppression of its contribution to the model shape. More importantly, feature interactions also impact on process planning and manufacturing.

Let there be no doubt that features are a common thread in any CAD, CAPP, CAM, or CNC system. They are often used to interface or integrate CAD, CAPP, CAM, and CNC. However, confusion often exists between integrated and interfaced feature technologies. One difference between interfacing and integration is that interfacing can be achieved at the result level, while integration must be addressed at the task level. In order to achieve an integrated environment and to make sure the features formed can be directly related to machining processes, machining information needs to be considered, such as roughing and finishing operations, as well as the cutting tools that may be used. In a feature-based design system, feature mapping from design to manufacturing can be an option.

The process plan for a part is usually further processed in a CAM system/module to obtain a set of machine control data (MCD), which is then used to drive a CNC machine tool. Numerical controllers were developed in the late 1940s and early 1950s by John T. Parsons in collaboration with the MIT Servomechanisms Laboratory. The first CNC systems still used NC-style hardware where the computer was used for the tool compensation calculations and sometimes for editing. Today's CNC machines have advanced to a point of little resemblance to their predecessors. With the increased automation of manufacturing processes using CNC machining, considerable improvements in consistency and quality have been achieved.

The MCD codes (or G-codes) used on a CNC machine contain mostly sequential machining commands that are structured in blocks of data. An alternative to G-codes when it comes to manually programming a CNC machine is the Automatic Programming Tool (APT). APT can describe some simple parts without using a 3-D modelling system or a graphics user interface. For complicated parts however, one has to use some of the contemporary tools (e.g. CAD/CAM systems). These systems can work with a design model, which is augmented with manufacturing information such as machining features and machining parameters, to arrive at a process plan.

In the recent past, manufacturing companies have been facing increasingly frequent and unpredictable market changes. As such, there is a recognised need for CNC machine tools to be further advanced so that they become more open, adaptable, interoperable, distributable, reconfigurable, and modular. Issues related to both hardware and software need more attention. More research seems to have been directed toward software improvement rather than hardware improvement. A noticeable advancement has been the development, publication, and implementations of a new international standard for CNC data models, (i.e. STEP AP238 or ISO 14649, both collectively known as STEP-NC). Unlike G-codes, STEP-NC contains higher-level information such as machining features.

FROM "POINT SOLUTIONS" TO A "COMPLETE SOLUTION"

Technologies developed for CAD, CAPP, CAM, and CNC are by and large localized within each of their domains, forming so-called individual "automation islands". Though there has been some success in bringing CAD, CAPP, and CAM under the same roof, there has been a lack of a universal platform on which data conversion across the board can be kept to a minimum. In fact, the gap between CAD/CAPP/CAM and CNC is even larger.

The STEP standard was initially designed to offer a neutral data exchange method in replacement of IGES. However, the standard is much more than a neutral data format that translates geometrical data between CAD systems. The ultimate goal of STEP is to provide a complete computer-interpretable product data format, so that users can integrate business and technical data to support the whole product life cycle: design, analysis, manufacturing, sales, and customer services. Currently, most of the commercial CAD systems can output STEP AP203 and/or STEP AP214 files via STEP translators. By implementing STEP AP203 and STEP AP214 within CAD systems, data exchange barriers are only partially upheaved in a heterogeneous design environment. This is because both APs only document pure geometric information, leaving high-level data such as features behind. Furthermore, data exchange problems between CAD/CAPP/CAM and CNC systems still remain unsolved. This is because on the output side of a CAM system, the 50-year-old international standard ISO 6983 (i.e. G-code) still dominates the control systems of most CNC machines. Outdated, yet still widely used, ISO 6983 has become an impediment for the contemporary collaborative manufacturing environment (Xu & He, 2004).

In order to achieve a complete integration of CAD, CAPP, CAM, and CNC, a suite of STEP Application Protocols may be used. When STEP AP224 is used to bridge CAD with CAPP, information more than just geometry and topology can be shared. This information includes machining feature information; dimensional and geometric tolerances; material properties and process properties; and even administrative information. STEP AP240 can support macro process planning by connecting CAPP with CAM. This is because AP240 defines such a high-level process plan for a machined part, and contains data about manufacture of a single piece or assembly of single piece parts. It serves as an interface for capturing technical data out of the upstream application protocols, and issuing work instructions for the tasks required to manufacture a part and the information required to support NC programming of processes specified in the process plan.

After macro process planning comes the micro process planning, which acts as a link between CAM and CNC. This can be done via STEP-NC. STEP-NC defines the process information for a specific class of machine tools. It describes the task of removing volumes defined as AP224 machining features in a sequential order, with specific tolerances, and with tools that meet all engineering and design requirements. In essence, STEP-NC describes "tasks", while G-code describes "methods" for CNC machines. The task-based NC programs can be made portable across different machine tools. Modifications at the shop-floor can also be saved and transferred back to the planning department that enables a better exchange and preservation of experience and knowledge.

Different STEP Data Access Interfaces (SDAI) may be used for implementing a STEP-compliant environment. Thus integrated product data can be easily managed by making complex engineering applications available across data implementations. Use of STEP-NC in replacement of G-code also promises a new generation of CNCs that are open, adaptable, and distributed. Alongside STEP-NC, the function block technology offers a complementary solution. Function blocks are based on an explicit event driven model and can provide for data flow and finite state automata-based control. Based on previous research, function blocks can be used as the enabler to encapsulate process plans, integrate with a third-party dynamic scheduling system, monitor process plans during execution, and control machining jobs under normal and abnormal conditions. They are suitable for machine-level monitoring, shop-floor execution control and CNC control (Wang & Shen, 2003).

EXTENDING INTEGRATION IN VERTICAL AND HORIZONTAL DIMENSIONS

Integration does not stop at CAD/CAPP/CAM/CNC, since the business of product development and manufacturing goes beyond activities such as design, process planning, and machining. Extension of an integrated CAD/CAPP/CAM/CNC system may occur in both vertical and horizontal dimensions.

Vertical integration may be backward or forward in the spectrum of a product development process. An example of forward vertical integration can be inspection as it is a logic step after CNC machining. With inspections, Closed-Loop Machining (CLM) can be realized to maximize the efficiency of a machining process by exercizing a tight control in a manufacturing system. Probing is defined in STEP-NC for inspection operations, and the dimensional inspection data model is specified in ISO 10303 AP219. Hence, it has become possible to consolidate machining and inspection operations in one single program.

Likewise, businesses have increasingly moved to outsourcing many functions, leading to the need for horizontal integration. Companies that have been practicing CAD/CAPP/CAM/CNC integration have now realized that there is a need to operate in a much broader scope with wider boundaries. This leads to the increased implementation of PDM and PLM systems. PDM systems integrate and manage all applications, information, and processes that define a product, from design to manufacture, and to end-user support. PLM brings PDM into an even broader paradigm in that all the information pertaining to the lifecycle of a product is actively managed. Unlike PDM, PLM is much more than a technology or software product. PLM is a strategic business approach that empowers the business.

Extensions of CAD/CAPP/CAM/CNC integration, be it vertical or horizontal, have a common request for an environment in which manufacturing businesses should operate. Today, companies often have operations distributed around the world, and production facilities and designers are often in different locations. Such globalization means that companies should be able to design anywhere, build anywhere, and maintain anywhere at any time. Manufacturing engineers need to employ collaborative tools during planning to help improve production processes, plant designs and tooling, and to allow earlier impact on product designs. For all of this to happen in an orderly manner, an effective collaborative environment is a must. STEP and XML combined with the latest multi-tiered network technology can provide such a solution.

EMBRACING THE TECHNOLOGIES

While computers have proven to be instrumental in the advancement of modern product design and manufacturing processes, the role that various technologies have played can never be over-estimated. In the recent years, there has been a wealth of technologies being used in CAD/CAPP/CAM/CNC. Among them are the knowledge-based (expert) system, artificial neural network, genetic algorithm, agent-based technology, fuzzy logic, Petri Nets, and ant colony optimisation.

An expert system is a computer system that has a well-organized body of knowledge in a bounded domain, and is able to simulate the problem solving skill of a human expert in a particular field. Artificial neural networks, or simply neural networks, are techniques that simulate the human neuron function, using the weights distributed among their neurons to perform implicit inference. Neural networks have been used to assist both automatic feature recognition and process planning. Genetic algorithms mimic the process of natural evolution by combining the survival of the fittest among solution structures with a structured, yet randomized, information exchange. The agent-based technology utilizes agents as intelligent entities capable of independently regulating, reasoning and decision-making to carry out actions and to achieve a specific goal or a set of goals. Agent-based approaches enable functionality for distributed product design and manufacturing (i.e. modularity, reconfigurability, scalability, upgradeability and robustness). Other technologies such as fuzzy logic, Petri Nets, and ant colony optimisation methods have also been used. There is, however, a consensus that systems developed using a combination of two or more such technologies fare better than otherwise.

ORGANIZATION OF THE BOOK

The book is organized into two sections and altogether 17 chapters. Section I, titled “Principles and Backgrounds”, contains Chapters I-IX; and Section 2, named “Integration and Implementations”, contains Chapters X-XVII. A brief description of each of the chapters follows:

Chapter I, “Geometric Modelling and Computer-Aided Design” reviews various geometric modelling approaches, such as wire-frame, surface, and solid modelling techniques. Basic computational geometric methods for defining simple entities such as curves, surfaces, and solids are given. Concepts of parametric, variational and feature-based design in a CAD system are explained.

Chapter II “CAD Data Exchange and CAD Standards” discusses the data interoperability issues, such as the different types of data translation and conversion methods. The common data exchange protocols are explained together with some examples. These data exchange protocols include DXF, IGES, PDES, and STEP standards.

Chapter III, “Computer-Aided Process PLannning and Manufacturing” presents the basic concepts of, and steps taken by, a computer-aided process planning and manufacturing system. Two principal approaches of CAPP are discussed. They are manual experience-based planning method and computer-aided process method.

Chapter IV, "Feature Technology" gives an overall view of feature technology. Features are defined and classified according to design and manufacturing applications. Issues about surface and volume features are discussed and different feature-based methodologies are presented.

Chapter V, "Feature Recognition" discusses some of the basic issues and methodologies concerning feature recognition. Feature recognition systems are divided into two different types: feature detection and feature generation. Issues regarding concavity and convexity of a geometric entity, optimal interpretation of machineable volumes and the necessity of considering raw workpieces are all discussed at a length.

Chapter VI, "Feature Interactions" analyses the feature-feature interaction problems, which have a strong bearing on process planning. Feature interactions may be studied on the basis of surface information and volumetric information of a part. Either way, identification of interacting entities is the key to an effective way of dealing with feature interactions.

Chapter VII, "Integrated Feature Technology" addresses feature technologies from the integration point of view. When features are recognized, the related machining operations and cutting tools are considered. For a feature-based system, mapping design features to machining features can be an effective method.

Chapter VIII, "CNC Machine Tools" presents an overview of CNC machine tools and their designations of axis and motion. The tooling for CNC machine tools is also discussed.

Chapter IX, "Program CNCs" provides a detailed account of the basics of CNC programming. The emphasis is on the G-codes and APT. To programme using G-codes, both compensation and interpolation are the key issues.

Chapter X, "Integration of CAD/CAPP/CAM/CNC" begins with a general description of traditional CAD/CAPP/CAM/CNC integration models. This is followed by an industry case study showcasing how a proprietary CAD/CAM system can be used to achieve centralized integration.

Chapter XI, "Integration Based on STEP Standards" presents a scenario whereby CAD, CAPP, CAM, and CNC are fully integrated. The underlying mechanisms are those enabled by the STEP standard, or rather its suite of Application Protocols. Function blocks also contribute to building such an integrated environment.

Chapter XII, "Function Block-Enabled Integration" introduces the function block architecture that has been implemented in two types of integration. The first brings together CAD, CAPP, and CAM and the second connects CAM with CNC.

Chapter XIII, "Development of An Integrated, Adaptable CNC System" discusses topics related to the task-level and method-level information in machine control data, and the methodology of converting the task-level data to the method-level data.

Chapter XIV, "Integrating CAD/CAPP/CAM/CNC with Inspections" discusses the extension of CAD, CAPP, CAM, and CNC to include inspections. The objective is to maximize the efficiency of a machining process by maintaining a tight control in a manufacturing system.

Chapter XV, "Internet-Based Integration" describes the methods of developing an Internet-enabled, integrated CAD, CAPP, CAM, and CNC system to support collaborative product development. The main goal is to provide a team environment enabling a group of designers and engineers to collaboratively develop a product in real time.

Chapter XVI, "From CAD/CAPP/CAM/CNC To PDM, PLM, and Beyond" presents an even broader scope and wider boundary in which CAD, CAPP, CAM, and CNC systems need to operate, (i.e. PDM and PLM). PDM systems integrate and manage all applications, information, and processes about a product. PLM brings PDM into an even broader scope in that all the information pertaining to the lifecycle of a product is actively managed.

Chapter XVII, "Key Enabling Technologies" discusses some key enabling technologies in the field of design and manufacturing. These are knowledge-based systems, artificial neural network, genetic algorithm, and agent-based technology. Also briefly mentioned are the fuzzy logic, Petri Nets, and ant colony optimisation methods.

WHO AND HOW TO READ THIS BOOK

This book has three groups of people as its potential audience, (i) senior undergraduate students and postgraduate students conducting research in the areas of CAD, CAPP, CAM, CNC, and their integration; (ii) researchers at universities and other institutions working in these fields; and (iii) practitioners in the R&D departments of an organization working in these fields. This book differs from other books that also have CAD, CAPP, CAM, and CNC as the focus in two aspects. First of all, integration is an essential theme of the book. Secondly, STEP is used as a common data model for many integration implementations.

The book can be used as an advanced reference for a course taught at the postgraduate level. It can also be used as a source of modern computer-aided technologies and contemporary applications in the areas of CAD, CAPP, CAM, CNC, and beyond, since some 300 hundreds publications have been cited and listed in the reference lists of all chapters, in particular Chapter XVII.

As the book title suggests, the book commences with presentations of some of the basic principles (in Section I) and ends with integration implementations as well as implementation approaches (in Section II). For readers who need a "crash course" or revision on topics of CAD, CAPP, CAM, and CNC, in addition to integration issues, both sections of the book can be found useful. Those who are well informed about these topics and only have an interest in integration issues can start with Section II, for instance Chapter X, or even better start with Chapter VII which discusses the integration issues based on feature concepts. Those who are conversant with CAD and CAM technologies but less acquainted with topics in CNC may skip the first 7 chapters.

As mentioned above, this book can also be used as an introduction to STEP data models, their principles, and implementations. Should this be of a reader's interest, the following chapters may be considered for study, (a) Chapter II to read for some introduction to STEP and its use in exchanging CAD data; (b) Chapter XI to read for a grand idea of STEP-in, STEP-out and STEP-throughout as in an integration implementation; (c) Chapter XIV to see how a STEP-based integration between machining and inspection may be achieved; and (d) Chapter XV to see how an Internet-based integration may be realized using STEP.

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