기계가공 파트의 전자거래를 위한 XML 기반의 데이터 교환에 관한 연구

A Study on e-Commerce of custom machined Parts with a Data Exchanged format based on XML

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초 록

본 연구의 목적은 인터넷을 통하여 효율적으로 기계 파트의 설계 정보를 가공 및 제작 기관으로 전달하기 위한 방법에 관한 연구이다. 밀링머신과 같은 표준화된 기계설비를 이용하여 제작되는 시험 파트의 경우 파트의 설계 및 제작에 필요한 정보의 준비, 기계가공 업체의 선정 및 계약을 통하여 제작하고 실물을 획득 할 수 있게 된다. 이와 같은 과정은 실제적으로 책, 항공권 등을 인터넷을 통해 구매하는 것 보다 복잡하고, 제작과 관련된 충분한 정보의 미 전달로 재작업과 같은 경제적 손실을 야기 한다. 본 연구에서는 설계 기관과 가공/제작 기관과의 데이터 전달을 위하여 설계 정보를 XML 이용하여 표현 하였으며, 이를 통하여 기계 가공 파트 제작의 전자상거래화를 시현하기위한 시험 시스템을 구축하였다. 본 연구의 성과를 정리하면 다음과 같다. 1. 기계 가공 파트 정보의 교환을 위한 새로운 XML 기반의 데이터 교환 형식의 생성, 2. 생성된 XML을 통하여 가공을 위한 파트 정보가 효율적으로 교환 될 수 있는 지를 설명하기 위한 시험 시스템의 개발, 3. 다수의 기계 가공 파트를 본 연구에서 제안된 방법(데이터 형식, 제안된 프로시저, 및 개발된 시스템)을 사용하여 제작함으로써 본 연구의 타당성을 증명 하려고 하였다.

ABSTRACT

Currently, it is possible to buy almost anything from books(Amazon.com) to airplane tickets(Travelocity.com) using the world wide web. The purpose of this research is to develop a "clean interface" between design and fabrication facilities for the production of custom machined parts through Internet. The current mechanism for production of prototype parts that can be fabricated using standard machine tools like milling machines, requires a process of part description preparation, bidding, contract award, and finally fabrication and delivery of the part. This is a substantially more complex process than buying a book or airplane ticket. In this paper, we try to define the ambiguous part description using XML based data exchange format and to enable e-commerce in this field. The research accomplishments are summarized: 1.Creation of a new format for data exchange of machined prototype parts, 2. Development of a prototype system to illustrate how the XML data can be effectively used to conduct e-Commerce for custom machined parts, 3. Testing of the methodology with a number of parts.

키워드 : 전자상거래, 전자데이타교환, 프로세스 계획, 기계가공
e-Commerce, NC machining, Process planning, Electronic Data Interchange, Feature based Design, Feature based Manufacturing

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1. INTRODUCTION

The popularity of outsourcing fabrication introduces a problem, namely an inevitable loss of data as information is translated from design to fabrication or from one system to another. Unsatisfactory information, delivered to the outsourcing facility, and inefficient communications between design and fabrication certainly cause enormous economic losses from late product delivery or bad product quality.

The work in this paper covers the design and fabrication process, the introduction of a machined part description format, and the development of a relevant software system.

The concept of a clean interface between design and manufacturing is based on the Mead-Conway approach developed for VLSI chip design/fabrication[15,18]. To apply the Mead-Conway approach in the machining domain, it must be determined how the domain specific information can be delivered[3]. Manufacturing features[4,5,6,17,20] are one of the feasible concepts for communicating between design and manufacturing. Other successful document standards like IGES, STEP-NC, and XML are reviewed, for example, especially those that would be feasible with other web-based standards and technologies in E-Commerce[13,16,21].

Web based design and manufacturing software systems have appeared[8]. As an example of current trends Alibre, Inc.[1] is the first commercial web site to offer an Internet based CAD service providing a remotely hosted interactive design environment for data sharing among engineering and design teams. Virtual Manufacturing(VM) activities attempt to mimic manufacturing processes in a computer to prevent costly rework. Design checking by knowledge based systems, and cutting simulation/verification are some examples of VM activities in the metal cutting industry. VM research activities include CyberCut [22], a system that provides design checking capability for feasibility at the machining part design stage by applying simple fabrication rules like the required minimum machining corner radius[9].

STEP-NC[7,10,11,12] also has been developed as a high level language, which facilitates operating NC machines. It is currently a draft standard being developed by Technical Committee 184, Subcommittee 4 (TC184/SC4). STEP-NC seems to share many of the same goals tried in this paper. However, since STEP-NC is a fairly recent development, only a small amount of information is available and there are no commercial implementations yet.

To overcome these data transferring problems and to improve communications between the design and fabrication sides, a design and manufacturing methodology for custom machined parts in e-Commerce is suggested and implemented in this paper.

2. OVERVIEW OF ENABLING E-COMMERCE OF CUSTOM MACHINED PART FABRICATION

Essential design information for fabricating parts properly with NC (Numerical Controlled) milling machines is expressed in machining/manufacturing features, fabrication friendly terminologies[2,17,20], and is represented by a new language called NCML (Numerical Control Markup Language)[19]. NCML is based on XML (Extensible Markup Language) - the document-processing standard proposed by the World Wide Web Consortium (W3C). NCML is designed to include the minimum requisite information necessary for the manufacturer to produce the product. The designer defines NCML, which overcomes geographical separation between design and manufacturing, and minimizes unnecessary interactions caused from lack of information.

To prove the possibility of custom machine part fabrication and e-Commerce with NCML, three software systems are implemented. These three systems are FACILE/Design, FACILE/Fabricate, and E-Mill. FACILE is a prototype CAD/CAM system developed to verify NCML feasibility as an Electronic Data Interchange (EDI) format. FACILE/Design is a system based on manufacturing features like holes, contours, and pockets. It can be used to create geometric models, verify the design, and create NCML files. The NCML file is imported by FACILE/Fabricate and turned into G-codes by applying appropriate cutting conditions. Simplified machining simulation and cost estimation tools using NCML inputs are also developed to show some examples of NCML applications that can help design and manufacturing activities. To demonstrate how NCML could be used in a web-based application, an e-Business model called E-Mill has been implemented. E-Mill is a market place for machined parts whose data is encoded in NCML. To make E-Mill a feasible e-Commerce model, two-way communication based on NCML data and the visualization of 3D geometric models in the Virtual Reality Modeling Language (VRML) are equipped with a competitive matchmaking mechanism.

In this paper, a whole system based on XML bridges the gap between design and manufacturing.

3. AN XML FOR DESCRIBING CUSTOM MACHINED PARTS

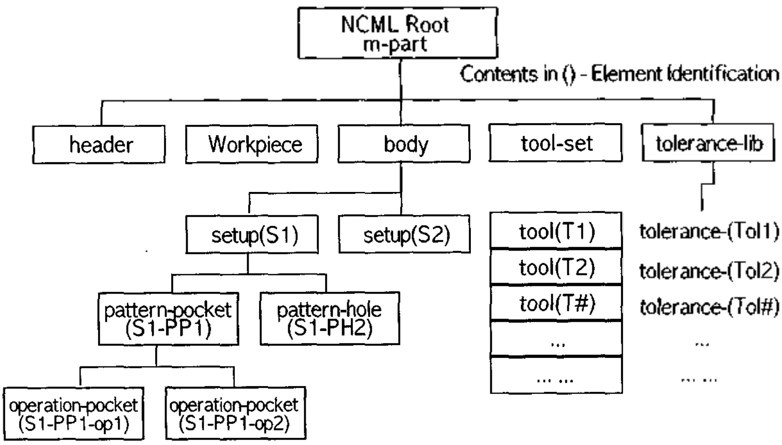
By adopting Object Oriented Programming (OOP) techniques, information in NCML is conceptualized as objects for the machining/manufacturing of features. The hierarchical structure makes it easy to transfer data components grouped or related in the parent-child data. The intended data is encoded in NCML as explained below:

- Manufacturing Features: Manufacturing features are used as a unit of data grouping. These include not only machining features like pockets, holes, contours, etc but also other part-specific information like tolerances, work piece, cutting tools, etc.
- Hierarchical Structure: The machining features in NCML are structured hierarchically. These features are machined from an intermediate work piece according to the machining order in the structure.

The XML format is used to define and to structure NCML. Among its many advantages, XML is extensible. Since the current implementation of NCML is quite simple, the extensibility of document contents must be considered for future practical application development.

Figure 1 illustrates the structure of NCML. The NCML document is comprised of everything it takes to define a machined part. The root element of the NCML file is the "part-spec" which contains five elements: header, workpiece, body, tool-set and tolerance-lib.

The operations of the body element are based on manufacturing features (e.g. Hole, Pocket and Contour) and are initially focused on 2 ½ machining operations such as those classified by Kramer [14]. These features are made more general by the tool-set elements of the NCML document. Gaines [4] introduced a tool-centric approach to feature recognition. NCML also uses cutting tool geometry to define manufacturing features. The concept that associates the manufacturing feature with a tool shape is called a "virtual tool".



〈Figure 1〉 Simplified NCML structure and components

The virtual tool concept not only allows the user to easily and simply define machining features such as counter-bored holes, edge rounds, or tapered sides on a pocket or contour, but also simplifies the machining feature geometry and reduces the required number of manufacturing features (called operations in NCML) without losing the ability to express a diverse set of manufacturing features. The cutting tools actually used by the machine shop may or may not be the same as the "virtual" tool defined in the NCML tool-set definition. Actual tool usage depends on the availability of each tool in the fabricator's tool crib. The feature definition along with the tool definition in the NCML file may be translated into several simple machining volumes in the machining process.

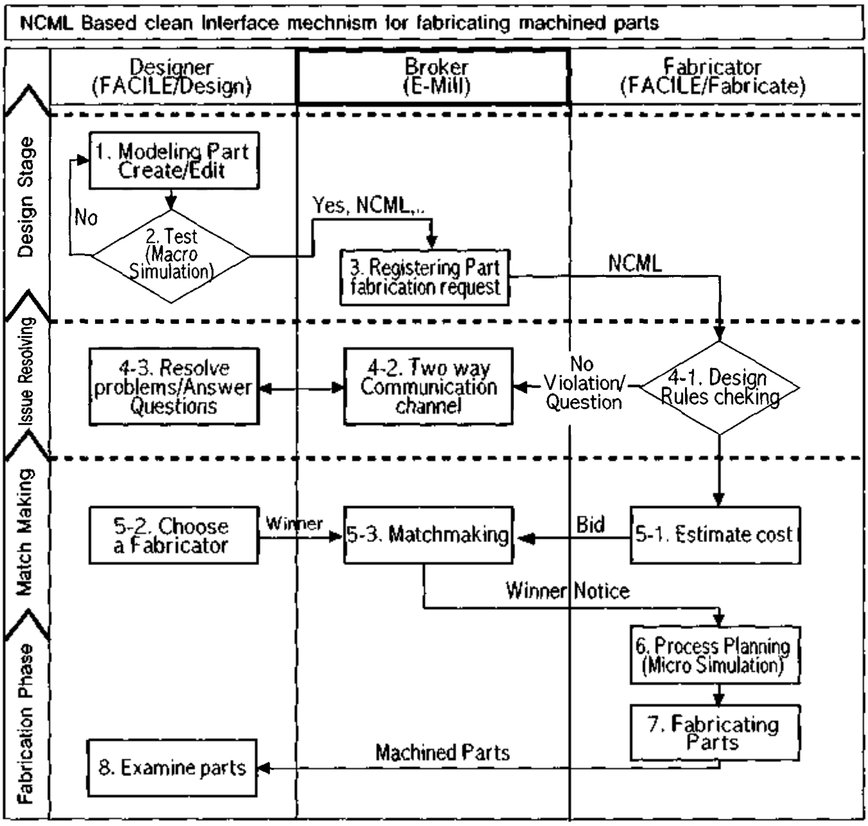
The body element is comprised of one or more setups. The setup element corresponds to an orientation of the workpiece on the NC milling machine. In each setup, machining operations may be grouped into patterns. The pattern element is a group of similar operations that use the same cutting tool and share the same machining strategies. The pattern element is directly associated with a tool element defined in the tool-set. Examples include bolt hole patterns or a set of nested pockets.

The operation elements are the fundamental machining features and are currently limited to one of three basic types: hole, contour, and pocket. These three fundamental operations can be used to create holes, pockets, bosses, slots, facing, and side milling operations. The application which processes the NCML file can calculate the volume of each machining operation. Associating basic process planning with specific machining strategies makes it possible to automatically estimate machining time and cost for quotation purposes. A NCML file of a simple part is presented in Appendix A .

4. SYSTEM SOFTWARE IMPLEMENTATION

This section describes the functional aspects of the proposed systems. Figure 2 illustrates the basic ideas of the software architecture and communication based on the e-Commerce environment. FACILE/Design, FACILE/Fabricate and E-MILL are intended to support the processes of the designer, the fabricator and the e-market respectively for the proposed process based on NCML. Essential functions and possible communication modes are marked in Figure 2, according to the active roles in the process.

FACILE/Design is the design software system. This is a CAD software system that can be used to create NCML files. While NCML generation is the essential function, other functions are necessary for including machined part information in FACILE/Design. The following functions are part of



〈Figure 2〉 The proposed clean interface mechanism for fabricating custom machined parts

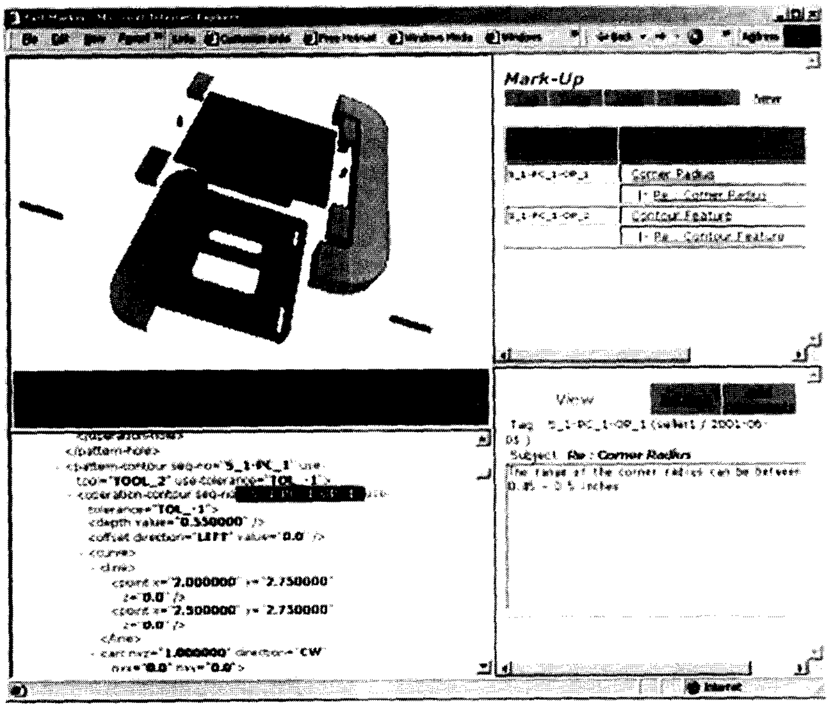
FACILE/Design:

- Part modeling and editing
- Macro Simulation
- NCML and VRML file generation.

VRML is the Virtual Reality Modeling Language commonly used for display of 3-D objects on the world wide web[13].

E-MILL was developed as a prototype e-commerce site for buyers and sellers of machined parts. The NCML format created in FACILE/Design is used as the standard part representation format in E-MILL. A registered designer in the E-MILL service can post a machined part in NCML format. The data posted includes a NCML document and the VRML 3D graphical model. The E-MILL application arranges the given data on the specified web page and informs the sellers that an RFQ is ready for bid.

Sellers (Job shops) can place bids on the part and the buyer can choose a bid winner. This page also changes its contents according to part status and part ownership. A seller



〈Figure 3〉 A screenshot illustrating the design/fabrication collaboration using VRML graphical NCML display (Top-left window) and markups (right windows)

can examine the design information (geometry and specifications) and interact with the part buyer by using the markup capability. The left upper frame in Figure 3 shows a standard VRML viewer plug-in (Cosmo player). They can change the machining set up defined in the NCML document in the left lower frame. A user can pop out a fabrication feature by clicking on it in the VRML frame. This also leads the user to the geometric definition of the selected feature in the NCML frame.

The NCML file can also be imported to FACILE/Fabricate. The imported NCML document is translated into an internal solid model and viewed by the seller. By adding machining specific information to the delivered NCML document, the fabricator can implement the whole fabrication process in the FACILE/Fabricate system. This includes cost estimation for quote generation and G-Code generation.

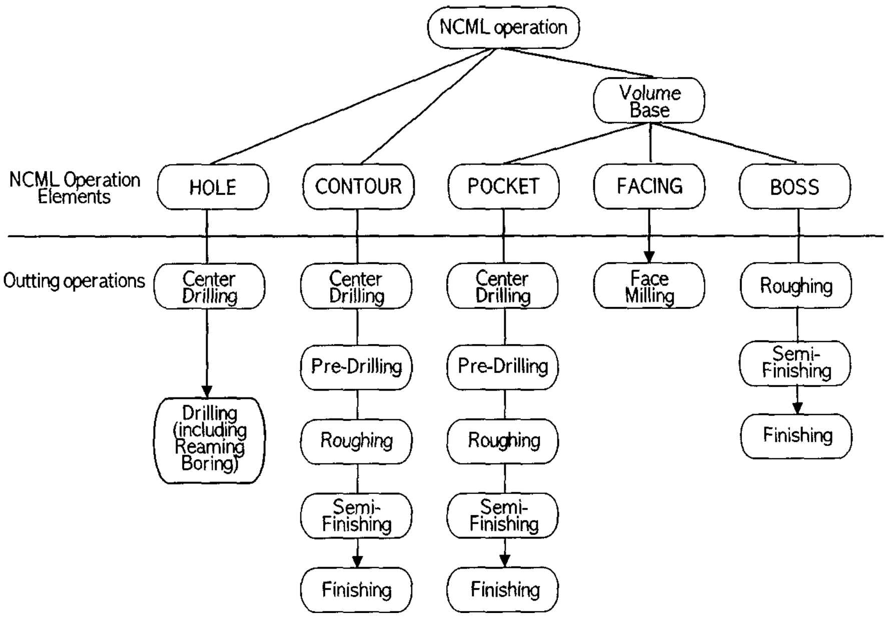
We assume that E-MILL employs an auction/bid method for matchmaking. Timely and accurate quotation is helpful for both buyers and sellers. Generating a quick and reasonable cost estimation of machined parts is crucial to competitive business in the machined part industry.

A heuristic method for quote estimation of the machined part in NCML is presented in Appendix B. The proposed method fully utilizes information in the NCML format to generate a quote for the machined part in NCML.

5. TRANSLATION INTO MACHINING OPERATIONS

The NCML document must be translated from the machining features (NCML operations) into a process plan consisting of a series of completely specified Unit Machining Operations (UMOs) [2]. The UMOs include all of the required process information, including depth of cut, roughing and finishing operations, pocketing strategies (i.e., spiral vs. zigzag), spindle speed and feed-rates. Since the specific process plan depends heavily on the capabilities of the individual machine shop, this information is not included in NCML. Only the information essential to defining the goal is provided; the individual details are left to the skills of the fabricator.

The goal of this process is to determine exactly how to machine the NCML operation elements: HOLE, CONTOUR, POCKET, FACING, and BOSS. As seen in Figure 4, it is assumed that each NCML operation can be represented as a set of UMOs. Based on this assumption, the next step is to assign cutting tools and cutting conditions to each NCML operation and its associated UMOs.



〈Figure 4〉 Decomposing of NCML operation elements to cutting operations

Since each NCML operation does not always need to use all of the cutting operations in its category, the fabricator can select a subset of the UMOs dependent on the machining requirements. For example, an NCML POCKET operation can be machined by the five UMOs shown in Figure 4. The first two UMOs (Center Drilling and Pre-Drilling) are implemented

6. EXAMPLE PARTS

Ten parts were chosen from three different design sources. Four of the ten parts were made with T6-6061 Aluminum and a plastic material was used for the remaining six parts. Figure 5 graphically illustrates the transition of one of these parts as information is added in the NCML based process. Four different phases are shown.

- The first image shows the FACILE/Design schematic drawing from which the NCML is generated.
- The second image is the VRML model of the part, which is generated from FACILE/Design with the NCML document. Each NCML operation is given as a machining volume. This VRML model is used as a graphical communication aid to accompany the NCML document in E-MILL.
- The third image shows toolpaths generated by the process-planning module of FACILE/Fabricate.
- The fourth and the fifth images show the actual machined part after executing toolpaths on the CNC machine.

The time required to generate detailed process plans was measured for some of the test parts, i.e. the time required to derive a complete set of machining instructions from a NCML file. These measured times will obviously vary with the skill of the operator but the relative values are still useful. We assumed that there was an exact correspondence between the virtual tools defined in the NCML file and the physical tools available in the machining workcell, and furthermore that the order of operations specified in the file did not need to be altered. In actual practice, these assumptions may be incorrect and additional time would be required to choose appropriate substitute tools and/or change the order of operations.

The average time for the process planning was 18 minutes. This is considerably shorter than the conventional process. The information rich content of NCML reduced the burden on the operator in a number of ways. The Macro Simulation in FACILE allows for excellent visualization of both the finished part and the series of setups and operations required to achieve it. The automatic conversion of NCML into VRML provides a further visualization tool that aids Internet based collaboration.

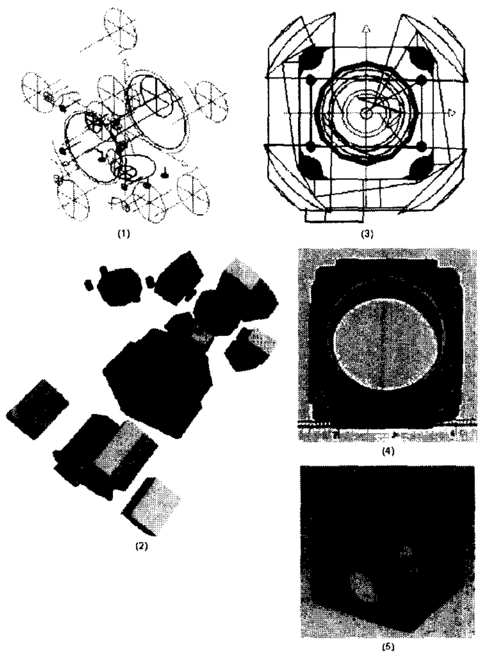
The hierarchical structure of NCML allows the operator to develop machining strategies which can be inherited from setups to patterns to operations and therefore contribute to time savings in generating G-codes.

Quotation parameter calibration was conducted at a local machine shop. Four parts, seven machining setups, and more than sixty UMOs were observed. All parts were made from aluminum 6061-T6.

Machining a part is composed of two phases. The machinist-centered phases are where the machinist does most of the work, e.g. loading/unloading parts, clearing fixtures, and manual de-burring. The other phase is cutting, carried out by the machining center through execution of the G-codes. Normal human variability causes variations in the machinist centered phase and the associated parameters used in the Quotation Helper software may need to be increased to reflect this reality. The procedure for generating the quotation parameters is more fully described in [19].

7. CONCLUSIONS

This research was initiated with the idea that the "Clean Interface " using the Mead-Conway method for VLSI chip manufacturing could be applied to mechanical parts. The specific application domain is fabricating prismatic parts that can be made with a standard NC machining center. The concept



〈Figure 5〉 Sample Test Part

of machining/manufacturing features was adopted to represent the part geometry. This information is encoded using the current web document standard XML in a data format called NCML. To prove the feasibility of NCML as a data interchange format, a number of test parts were used. Software systems were implemented to correspond with the core components of the proposed process. These computer software systems are FACILE/Design, E-MILL and FACILE/Fabricate. Machined part descriptions were created in the NCML format using FACILE/Design and hypothetically distributed to fabricators through E-MILL, a web-based e-commerce application. Several parts were fabricated with the aid of the process planning and G-code generation capabilities of FACILE/Fabricate.

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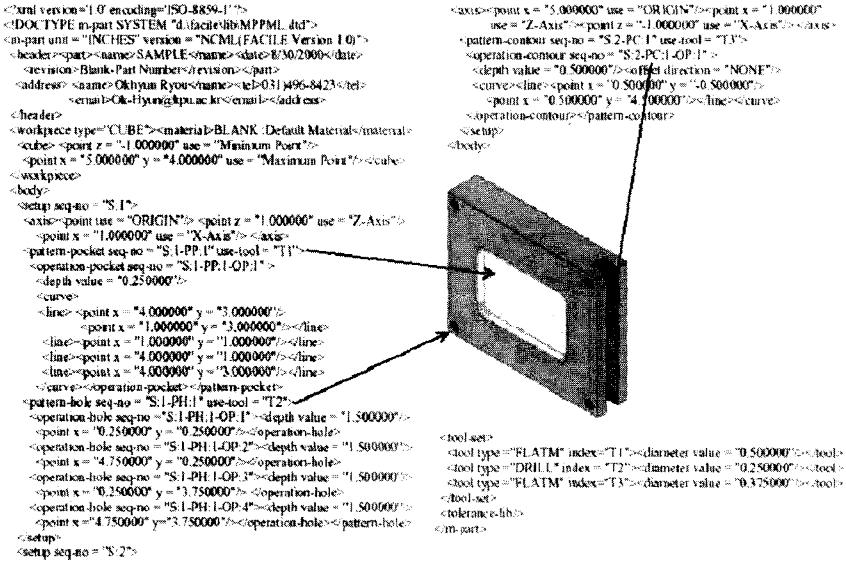
APPENDIX A. SAMPLE PART IN XML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<revision>Blank-Part Number</revision></part>
<address> <name>Okhyun Ryou</name><tel>031)496-8423</tel>
<email>Ok-Hyun@kpu.ac.kr</email></address>
</header>
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<cube> <point z = "-1.000000" use = "Minimum Point"/>
<point x = "5.000000" y = "4.000000" use = "Maximum Point"/></cube>
</workpiece>
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<line><point x = "1.000000" y = "1.000000"/></line>
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<line><point x = "4.000000" y = "3.000000"/></line>
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<point x = "0.250000" y = "3.750000"/> </operation-hole>
<operation-hole seq-no = "S:1-PH:1-OP:4"><depth value = "1.500000"/>
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use = "Z-Axis"/><point z = "-1.000000" use = "X-Axis"/> </axis>
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<operation-contour seq-no = "S:2-PC:1-OP:1" >
<depth value = "0.500000"/><offset direction = "NONE"/>
<curve><line><point x = "0.500000" y = "-0.500000"/>
<point x = "0.500000" y = "4.500000"/></line></curve>
</operation-contour></pattern-contour>
</setup>
</body>
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<tool type ="DRILL" index = "T2"><diameter value = "0.250000"/></tool>
<tool type ="FLATM" index="T3"><diameter value = "0.375000"/></tool>
</tool-set>
<tolerance-lib/>
</m-part>

Appendix-A Here

APPENDIX B. QUOTATION MODEL

A quotation model can be stated as:

$$C = C_m\ (T_m + T_p) + Q\ (C_w + C_p) \qquad (1)$$

where C : Total cost for fabricating parts

C_m : Operator rate and machine overhead (\$/hr)

C_w : Cost of workpiece

C_p : Cost of part post-machining operations

T_m : Machining time for all quantities

T_p : Pre-machining processing Time

Q : Quantity of part

Machining Time (T_m) can be expressed as:

$$T_m = T_s + T_c + T_t + T_u \qquad (2)$$

where T_s : Total setup time

T_c : Total cutting time

T_t : Total tool change time

T_u : Total work piece setup (load/unload time)

The time required for machining setup includes fixture making, cutting tool loading, trial machining and machined part inspection. Since, the number of setups can be easily gained from the NCML format, Ts can be stated as:

$$T_s = N_s A_s \qquad (3)$$

where N_s : Number of setups

A_s : Average machining setup time

Since the number of cutting tool changes depends on the detailed process plan, it is quite difficult to get an exact number. However, since NCML associates a "virtual tool" with each individual pattern element, an approximation can be made. In this case, the total time required for changing cutting tools can be stated as:

$$T_t = Q A_t \Sigma N_t(i) / N_b \qquad (4)$$

where $N_t(i)$: Cutting tool change number for setup i, i=1..

N_s, N_b = Batch size

A_t = Average cutting tool change time

Loading /unloading can be expressed as: $T_u = Q N_s A_u / N_b$ (5)

where Nt(i) : cutting tool change number for setup i, i=1..

Ns, Au : Average workpiece load/unload time

During Macro Simulation, machining volume and the area of each machining feature can be estimated by subtracting the post-operation workpiece volume from the pre-operation one. NCML cost estimation uses this material removal volume and machined surface area as the primary input to its algorithms.

Machining operations defined in NCML are of type HOLE, CONTOUR, POCKET, FACING, AND BOSS. The machined volume created from the CONTOUR or POCKET falls into the aforementioned roughing and finishing cutting category. The FACING and BOSS operations are a volume removing operation like the pocket operation. The FACE cutter usually sweeps across a plane area, and the machining time depends on the machining area not the volume. Considering these discussions, the total cutting time can be stated as:

$$T_c = Q \Sigma(c_1 V R_r + c_2 V R_d + c_3 A_w R_w + c_4 A_f R_f) \qquad (6)$$

If operation type is hole, $c_1 = c_4 = 0$, $c_2 = c_3 = 1$

If operation type is contour, pocket or boss, $c_2 = c_4 = 0$, $c_1 = c_3 = 1$

If operation type is facing, $c_1 = c_2 = c_4 = 0$, $c_3 = 1$

where V : Volume removed from the current cutting operation

A_w : Area of wall created from the current cutting operation

A_f : Area of bottom surface created from the current cutting operation

R_r : Material removal rate for rough cutting

R_d : Material removal rate for hole machining

R_f : Bottom surface cutting rate, R_w : Wall surface cutting rate

c_1 ..., c_4 : Permutation parameters

Although, in general, the cutting tool with a large diameter has a large associated material removal rate, it is difficult to derive an accurate relationship between material removal rate and the tool used. We assume the material removal rate is inversely related to the cutter diameter. Surface finish level and tolerance also affect the material removal rate. Material removal rates are stated as:

$$R_d = F_t R_{dr} (D_c/D_r)^3 \quad (7)$$

$$R_f = F_t R_{fr} (D_c/D_r)^2 \quad (8)$$

$$R_w = F_t R_{wr} (D_c/D_r) \quad (9)$$

where R_{dr} : Reference MRR for hole machining

R_{fr} : Reference bottom surface cutting rate

R_{sr} : Reference wall surface cutting rate

D_c : Tool diameter of the current cutting tool

D_r : Tool diameter of the reference cutting tool

F_t : Weight factor, changes with tolerance and surface finish assigned on the feature

Different power numbers are used in Equations 7-9 to adjust the material removal rate for specific operations. This value is determined mainly depending on which geometric element is machined. For example, power 3 is used for a 3 dimensional element volume, power 2 is used for a 2 dimensional element surface, and we assume that a cutter for wall machining moves in one dimension along lines and arcs, therefore power 1 is chosen. Although, this assumption may not be true for some sophisticated tool shapes and machining geometry, it predicted well in our experiments.

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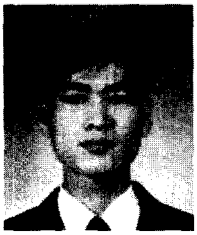

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