DEVELOPMENT OF GENERATIVE COMPUTER-AIDED PROCESS PLANNING FOR CNC MILLING PARTS

By

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LIST OF SYMBOLS

N	Number of loops
$ODV_{algorithm}$	Overall delta volume generated by algorithm
ODV_{manual}	Overall delta volume determined by manual calculation
OV	Overlapping volume
P_{low}	Bottom profile
P_{up}	Top profile
$SDVF_i$	SDVF of internal faces
$SDVF_p$	SDVF of peripheral faces
V_{CAD}	Boundary representation

LIST OF ABBREVIATIONS

2D	Two-dimensional
2.5D	Two-and-a-half dimensional
3D	Three-dimensional
AAG	Attributed adjacency graph
AFR	Automatic feature recognition
API	Application programming interface
B-rep	Boundary representation
B-spline	Basis spline
BEFG	Base Explicit Feature Graphs
BS	Boundary surface
CAD	Computer aided design
CAI	Computer aided inspection
CAM	Computer aided manufacturing
CAPP	Computer-aided process planning
CIM	Computer integrated manufacturing
CNC	Computer numerical control
CSG	Constructive solid geometry
DFA	Design for assembly
DV	Delta volume
DXF	Drawing exchange format
EBC	Edge boundary classification
FAG	Face Adjacency Graphs
FF	Feature face
FL	Finishing layer
FR	Filled region

FS	Feature surface
FSC	Feature shape complexity
FSV	Final stock model volume
GA	Genetic algorithm
IFRM	Intelligent feature recognition methodology
IGES	Initial Graphics Exchange Specification
MF	Machining features
MSV	Minimal stock model volume
MRV	Material removal volume
NURBS	Non uniform rational B-spline
OPF	Outermost planar face
ODV	Overall delta volume
RBM	Rule based method
RL	Roughing layer
SAT	Standard ACIS text format
SDV	Sub-delta volume
SDVF	SDV for finishing process
$SDVF_o$	SDV for outermost face
$SDVF_f$	SDV for feature face
SDV-VF	SDV for volumetric feature
SDVR	SDV for roughing process
STEP	Standard for the Exchange of Product
TL	Transition layer
TXT	Text
VDM	Volume decomposition method
VF	Volumetric feature

PEMBANGUNAN PERANCANGAN PROSES BERBANTU KOMPUTER YANG GENERATIF UNTUK BAHAGIAN PENGISARAN CNC

ABSTRAK

Aspek penting dalam perancangan proses berbantu komputer (CAPP) adalah untuk mengenali permukaan dan ciri-ciri bahagian bagi membantu pembuatan pintar hiliran. Pengecaman automatik bagi permukaan dan ciri-ciri dan akan membawa kepada kejayaan pencapaian CAPP generatif. Kerja pengecaman ciri dan bentuk yang dilakukan setakat ini tidak melakukan pengecaman terhadap semua ciri bentuk biasa dan bentuk bebas dan tidak mengahasilkan isipadu delta (DV) bagi pengecaman yang dilakukan. Oleh itu, terdapat keperluan untuk membuat klasifikasi baru bagi ciri-ciri dan pendekatan untuk mengencam ciri-ciri secara automatik supaya DV dijana secara automatik untuk setiap ciri yang dicam bagi pencapaian CAPP generatif. Satu usaha telah dibuat untuk mengklasifikasikan ciri-ciri baru ke dalam bentuk biasa dan ciri-ciri bentuk bebas yang selanjutnya diklasifikasikan ke dalam ciri-ciri permukaan dan ciri-ciri volumetrik. Isipadu delta keseluruhan (ODV) dikelaskan kepada SDVF, SDVT, SDVF dipenuhi kawasan dan SDV-VF dan SDVR. Algoritma dibangunkan untuk mengecam secara automatik bentuk dan permukaan bentuk bagi bahan mesin canai dan menjana ODV secara automatik. Algoritma ini menjana secara automatik pecahan pandangan ODV, melabel secara automatik isipadu sub-delta dan menentukan tahap kerumitan untuk menghasilkan bahagian. ODV yang dihasilkan disahkan oleh ralat peratusan (%) dan pemesinan produk. Algoritma ini memilih jenis operasi pemesinan yang akan dilakukan dan memperuntukkan secara automatik SDV-VF masing-masing ke permukaan yang dimilikinya. Ciri permukaan dan isipadu dari suatu bahagian yang berjaya dicam secara automatik oleh algoritma yang dibangunkan dan anggaran DV, jadual hasil yang memperincikan data kuantitatif setiap isipadu dihasilkan secara automatik. SDVT yang dibangunkan bersebelahan dengan SDVF untuk bentuk bebas, mengatasi DV kompleks bagi proses roughing. Kekangan kekurangan DV yang berlaku dalam beberapa kajian dapat dihindarkan. Penamaan ciri dan pengekodan warna permukaan SDV-VF menyatakan jenis ciri yang terdapat di bahagian tersebut. Pengesahan algoritma yang dibangunkan oleh ralat

peratusan (%) menunjukkan kesilapan kurang daripada 0.1% dan kriteria pemilihan mesin mencadangkan pengguna jenis mesin pencanai yang diperlukan untuk menghasilkan bahagian berdasarkan tahap kerumitan.

DEVELOPMENT OF GENERATIVE COMPUTER-AIDED PROCESS PLANNING FOR CNC MILLING PARTS

ABSTRACT

The important aspect of computer-aided process planning (CAPP) is to recognize part's surfaces and features to aid downstream intelligent manufacturing. The automatic recognition of surfaces and features will lead to successful attainment of generative CAPP. Feature recognition works performed so far do not recognize all regular form and freeform volumetric features, and do not generate delta volume (DV) for the recognized features. The works do not address the classification of freeform volumetric features. So there is a need for novel classification of features and approach to auto-recognize features so as to auto-generate DV for each recognized feature for the attainment of generative CAPP. An effort has been made to novel classify the features into regular form and freeform features which are further sub-classified into surface features and volumetric features. The overall delta volume (ODV) is classified into SDVF, SDVT, SDVF filled region, SDV-VF, and SDVR. Algorithm is developed to auto-recognize surfaces of a milling part and auto-generate ODV. The algorithm auto-generates exploded view of ODV, auto-labels the sub-delta volumes (SDVs) and determines the level of complexity to manufacture a part. The generated ODV is validated by percentage error (%) and machining of parts. The algorithm selects the type of machining operation to be performed and auto-allocates each SDV-VF to the face it belongs to. The surface and volumetric features of a part are successfully auto-recognized and estimated DV, results table are auto-generated. The SDVT developed contiguous to SDVF for freeform faces, overcomes the complex DV for roughing process. The DV discontinuity and overlap limitation that occurred in few studies are eliminated. The designation of feature faces and colour coding of faces of SDV-VF expresses the type of feature present in a part. The validation of developed algorithm by percentage error (%) shows error less than 0.1% and the machine selection criteria suggests user the type of milling machine needed to manufacture a part based on level of complexity.

CHAPTER ONE

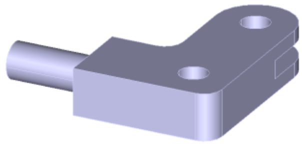
INTRODUCTION

1.1 Research overview

The research was into computer-aided process planning (CAPP) and mainly focused on attainment of generative CAPP by dealing with computer-aided design (CAD) model to manipulate its data structure to auto-generate delta volume (DV) for finishing process, roughing process and for volume decomposition to obtain feature volume for regular form volumetric feature, freeform volumetric feature. Feature classification, DV classification, surface and feature recognition, DV generation, level of complexity, selection of machining operations and auto-allocation of each sub-delta volume for volumetric feature (SDV-VF) to the face it belongs to are the stages performed in data manipulation.

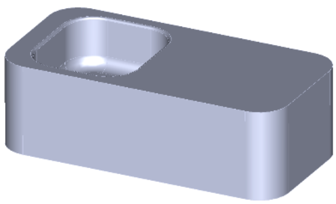
1.2 Research background

To manufacture a product, pre-generated novel product concept must be prototyped by detailed design, wherein the concept is outlined in two-dimensional (2D) engineering drawing or three-dimensional (3D) engineering drawing. With the origin of computer era, the shape and geometry of engineering drawing are started being exhibited electronically within the modelling space of a modelling software in a computer. This exhibition is known as CAD and the output obtained is known as CAD model containing geometrical structure and topological information. The planar, cylindrical, conical, spherical, torus, spline, and ellipse are different types of geometrical shapes and a CAD model can be of any one or a combination of these geometrical shapes. The CAD model and its features are categorized into regular form, freeform and two-and-a-half dimensional (2.5D) form based on their geometrical shapes, for example an engineering part CAD model (Figure 1.1(a)) made of planar and cylindrical surfaces is a regular form model, and an impeller CAD model (Figure 1.1(b)) made of 3D B-spline surface or Non uniform rational B-spline (NURBS) surface is a freeform model. A sink die CAD model (Figure 1.1(c)) is categorized as 2.5D model since it’s made of a spline surface on the top and planar, cylindrical surfaces on the side and planar surface on the bottom.



(a)

(b)



(c)

Figure 1.1. CAD part models (a) engineering part (b) impeller (c) sink die

With the advancement of freeform feature modeling concepts, freeform products are being introduced widely in the consumer market. Nowadays the requirements of a consumer are moving towards the products having aesthetical features due to the incorporation of ergonomic and freeform feature modeling technique in designing of a product. Therefore, with the trend of consumer requirements moving toward aesthetical-based designed product, it is important to capture the ever growing market by producing a higher quality product that is freeform in shape and at the same time reduced the lead time and manufacturing cost in manufacture out the product. Time and cost reduction are made possible in the early stage of design by analyzing the CAD model for its manufacturability in term of machining process, especially the process involved in transforming from the initial raw stock model into final product. To be able to develop an optimum process planning for manufacturing a product, CAPP is a necessary tool in bridging the CAD and computer-aided manufacturing (CAM) through computerized integration to facilitate computer integrated manufacturing (CIM) system. The role of CAPP is to make use of the information available in CAD model and transform it into usable data for CAM application. This research is placed in the field of CAPP by developing workable algorithms to assist proper planning of CAM. Automatic feature recognition (AFR) holds the crucial key element in realization of this integration system. Recognized features can then be utilized for various engineering purpose.

The interpretation of digital representation of concept of feature is important to understand the actual environmental application of automatic feature recognition (AFR). A feature is defined as a set of geometrical entity having corresponding relationship among the entities that perform an engineering function and the feature of a CAD model must be definable by its linear dimensions such as length, width and height so as to recognize it by pre-set recognition rules. The developed feature recognition system can recognize surfaces and features of a CAD model by utilizing the topology of CAD model, geometry of entity and linear dimensions.

After the recognition process, there must be material removing processes that are performed to machine out the features. In order to obtain the required features, material removal volume must be calculated to enable the machine to manufacture the final product according to the designed features from the raw stock model. The material removal volume is then further decomposed into several individual volumes according to the type of form feature. As a product may have different features on it, there is a need for volume decomposition for machining purpose to fulfill the engineering requirements of the surface feature. The volume decomposition is sub division of a stock model into two or more DV and the decomposition of a stock model into DV for finishing process, roughing process and recognized features after feature recognition gives quantified values to manufacture a product from the stock model. For example, the decomposition of stock model (Figure 1.2(a)) for a bottle opener product gives DV for pocket feature, finishing process and roughing process (Figure 1.2(b)) and the so obtained DV can be quantified to manufacture bottle opener.

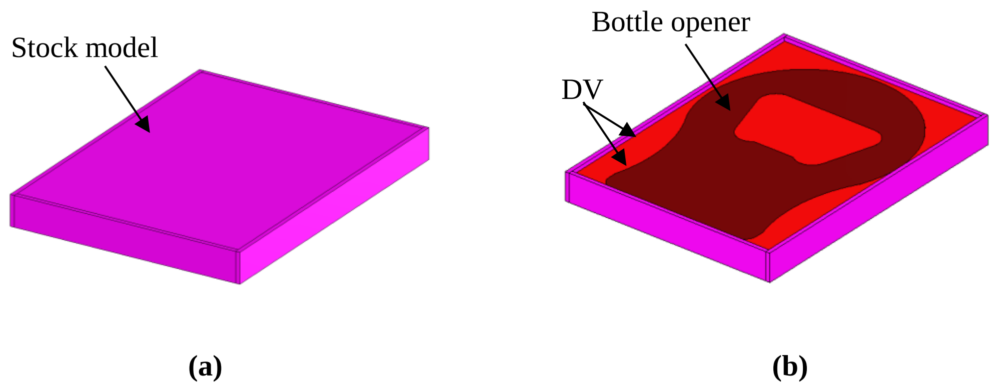


Figure 1.2. Volume decomposition for bottle opener (a) stock model (b) DV

1.3 Problem statement

Based on the research works reviewed, feature recognition works were found to be performed on regular form features and freeform features with limitations. The regular form feature recognition works performed so far by approaches (such as ruled based approach, graph based approach and volume decomposition method) do not recognize all the interacting and non-interacting features, compound features, and also do not generate DV for the recognized features. The freeform feature recognition works have classified freeform features and recognized them, but the classification and recognition was limited to freeform surface based features and do not address the classification and recognition of freeform volumetric features. The generation of DV for freeform volumetric features, surface based features is also found to be lacking, and other scarce works that focused on the generation of DV for recognized faces of a CAD model resulted in following drawbacks (i) occurrence of discontinuity between two adjacent DV's generated for recognized faces of CAD model that form convex geometry (ii) overlapping between two adjacent DVs generated for recognized faces of CAD model that form concave geometry (iii) the generated DV for roughing process is complex. The machining operation type selection cannot be performed without successful attainment of machining feature recognition in CAPP system.