

**AUTOMATED CORE AND CAVITY DESIGN
SYSTEM FOR MOULD WORKS USING
GENERATIVE METHOD OF COMPUTER AIDED
PROCESS PLANNING**

MURSYIDAH BINTI MD YUSOF

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MOULD WORKS USING GENERATIVE METHOD OF
COMPUTER AIDED PROCESS PLANNING**

by

MURSYIDAH BINTI MD YUSOF

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LIST OF SYMBOLS

$+p_d$	Positive Parting direction
$-p_d$	Negative Parting direction
$+p_s$	Positive Side direction
$-p_s$	Negative Side direction
a	Area
A	Set of entities
B	Set of entities
D	Direction vector
De	Direction Unit vector
D_x	Random direction vector
D_x	Tool's centre axis at a random direction vector
D_f	Range of D for face shaped BE
D_s	Range of D for solid shaped BE
E	Edge
E_f	Number of edges in a face
E_{uv}	Number of U lines and V lines
F	Face
H	Hole or non-convex face group
H_s	Hole solid
l	Length
l_b	Length of segmented box on a face
L	Line
L	Direction vector between D and D_i
M	Mould piece
M	Direction vector between D and D_x
N_f	Normal vector of a face
N_{pf}	Normal vector of flat circle
O_f	Origin at a face
p_d	Parting direction
S	Solid

Sp	Number of surface points for a face
P	Surface point
T	Total number of BE
Ud	Undercut direction
U_f	U vector of a face
Up_f	U vector of flat circle
U_f	Undercut
V_f	V vector of a face
Vp_f	V vector of flat circle
w_b	Width of segmented box on a face
V	Vertex
v	Volume
Y	Final face group

Mathematical Symbols

\cdot	Dot product
$>$	More than
$<$	Less than
\neq	Does not equal to
\cap	Intersection
\cup	Union

Greek Letters

β	Angle between L_a and L_b
γ	Angle between L and M
θ	Angle between D_1 and D_2
α	Angle between D_1 and D_x

LIST OF ABBREVIATIONS

2D	2 dimension
3D	3 dimension
6D	6 dimension
ACCDS	Automated core and cavity design system
AFR	Automatic feature recognition
BE	B-rep entity
BEF	BE of a face
BEH	BE of a hole or non-convex face group
BEJ	BE of an intermediate face group
BER	Intersection result of two BE
BEY	BE of a final face group
B-rep	Boundary Representation
CAD	Computer-aided design
CADIMDS	Computer-aided injection mould design system
CAM	Computer-aided manufacturing
CAPP	Computer-aided process planning
CNC	Computer numerical control
EFAAG	Extended Face Adjacency Attribute Graph
FAAG	Face Adjacency Attribute Graph
GT	Group technology
GVM	Global V-map
IOT	Internet-of-things
LVM	local V-map
MPMA	Malaysian Plastics Manufacturers Association
NC	Numerical control
PLR	Parting line region
PMT	Parallel machine tool
V-map	Visibility map

**SISTEM REKABENTUK TERAS DAN RONGGA AUTOMATIK BAGI
PENYEDIAAN PERKAKASAN ACUAN MENGGUNAKAN KAEDAH
PENGHASILAN PERANCANGAN PROSES BERBANTUKAN KOMPUTER**

ABSTRAK

Sejak beberapa tahun kebelakangan ini, pelbagai usaha telah dilakukan untuk menjadikan aktiviti merekabentuk teras dan rongga menjadi automatik sepenuhnya. Tiga kekurangan ketara dalam sistem rekabentuk teras dan rongga automatik sebelum ini adalah (i) arah pemisah yang kurang fleksibel, (ii) ketidakupayaan untuk mengesan dan menjana arah pemisah untuk kedua-dua *undercut* dalaman dan luaran dan (iii) tiada pemindahan maklumat daripada sistem rekabentuk teras dan rongga automatik ke sistem pemesinan. Bagi mengatasi kekurangan ini, sistem rekabentuk teras dan rongga automatik (ACCDS) dihasilkan. Sistem ini bertindak sebagai satu komponen dalam sistem perancangan proses berbantuan komputer di mana ia mengambil maklumat daripada mana-mana model 3D CAD dan menyediakan maklumat kepada sistem pemesinan acuan. Kaedah penghasilan adalah asas kepada sistem ini di mana model teras dan rongga dihasilkan dari awal. Hasil yang dikeluarkan daripada sistem ini adalah (i) teras, rongga dan teras-sisi bersama arah pemisah acuan dan (ii) maklumat julat sudut bagi sifar perlanggaran antara mata alat dan permukaan bahagian acuan teras dan rongga. Dengan membandingkan ACCDS dengan sistem terkini yang telah dicadangkan oleh seorang penyelidik, penambahbaikan seperti rekabentuk teras dan rongga yang lebih baik dan pengurangan masa sistem komputer dapat diperhatikan. Ini menunjukkan bahawa ACCDS berjaya menyumbang dalam perbaikan sistem rekabentuk teras dan rongga secara automatik.

**AUTOMATED CORE AND CAVITY DESIGN SYSTEM FOR MOULD
WORKS USING GENERATIVE METHOD OF COMPUTER AIDED
PROCESS PLANNING**

ABSTRACT

In recent years, many efforts have been made for core and cavity design system to be fully automated. Three profound limitations in the previous automated core and cavity design systems are (i) the lack in parting direction flexibility, (ii) inability to detect and generate parting direction for both inner and outer undercuts and (iii) no information transfer from automated core and cavity design system to machining system. To overcome these limitations, automated core and cavity design system (ACCDS) is developed. This system acts as a component in computer aided process planning system where it takes information from any 3D CAD model and provides information to the machining system. Generative method is the basis of this system where core and cavity models are generated from scratch. The outputs from the system are (i) the generated core, cavity and side-cores with parting direction and (ii) the information of zero tool-face collision angle range of core and cavity mould pieces. By comparing ACCDS with a recent system proposed by a researcher, improvements such as better core and cavity design and the reduction of system computational time were observed. This shows that ACCDS were able to contribute in the betterment of the core and cavity design system in automatic manner.

CHAPTER ONE

INTRODUCTION

1.1 Background Study

Plastic parts are found everywhere in our daily life, for home, transportation, medical needs, electrical appliances and many more. The injection moulding industry in Malaysia takes about 34% of the total production processes (Malaysian Plastic Manufacturers Association 2014). Quoted from the Plastic and Rubber Asia magazine, President of The Malaysian Plastics Manufacturers Association (MPMA) Lim Kok Boon said that the manufacturing cost of plastic productions is increasing by more than 10%. He added that the manufacturing cost is however able to be reduced by shortening the amount of processing and production time with the assistance and application of advanced manufacturing technology (Plastic and Rubber Asia 2014).

Developing an advanced manufacturing technology is not an easy task. Manufacturers in Malaysia are confronted with many challenges to integrate advanced manufacturing technology into the existing technology. One of the challenges is to be able to quickly meet the consumers' change of demands. Nowadays, consumers not only demand for functional and high quality products, but also presentable with appearance that meets their taste. This leads to the complexity of product models which are increasing as the demand for modern, futuristic and artistic designs increases. Most of the plastic products are manufactured using injection moulding process and moulds are used. The most common mould is the two plate moulds which consist of a core half and a cavity half plate. However the design

for core and cavity changes as the product design changes. When a product model has high design complexity, it uses a large amount of time to manually create the core and cavity models. Hence researchers are trying to develop an automated core and cavity design system in order for the core and cavity models are able to be generated faster and for a large variety of complex designed product models.

System automation includes fast information transfer between CAD – CAPP – CAM systems. Core and cavity design system falls under the CAPP system since it takes product design information from the CAD system and gives machining information to the CAM system. For most newly developed core and cavity design system, generative method is commonly used. Generative method is a method where the core and cavity models are generated from scratch. Unlike variant and hybrid methods where a large library of existing core and cavity model is used as a basis. In order to develop the core and cavity design system, many aspects in creating the core and cavity model must be put into consideration such as the parting elements, undercuts, number of side-cores and many more. These are the fundamental aspects for an automated core and cavity design system to work. There are various approaches used by previous researchers to cover these aspects and develop an improved automated core and cavity design system. Even so, there are always room for improvements as the product design complexity increases. Several years before, products are designed with regular shapes and the mixture of it, but in recent years, with high demand of artistic designs, sculptured or free-form shapes are becoming more common. This increases the challenge for automated core and cavity design system not only to generate the core and cavity models but also for tool orientation during machining.

In order for Malaysia's manufacturing industry to be at par with other leading countries, integration of advanced manufacturing technology is highly important. In fact, this technology must be flexible enough to be able to comply with the fast changes of local and international demands.

1.2 Problem Statement

In recent years, some researchers have proposed and developed automated core and cavity design systems. However there were limitations in the proposed automated core and cavity design system. One of the limitations is the lack in parting direction flexibility of the system. In order to generate core and cavity models, predetermined parting directions were used. This restriction is a downside for complex product designs with free-form surfaces. Pre-determined parting directions may not be able to efficiently be used for all types of free-form surfaces. The second limitation is the inability of the previous systems to automatically detect and generate parting direction for both inner and outer undercuts. The previous system either focuses on inner undercuts only or outer undercuts only. This is a disadvantage for complex product designs that have both inner and outer undercuts. The final limitation is there are yet an automated system that links the core and cavity design system to a machining system. Information transfer between the two systems such as tool position and angle are important to avoid collision between tool and work piece during machining.

1.3 Aim and objectives of Study

To overcome the limitations stated in the previous section, this research aimed to develop a system named the automated core and cavity design system (ACCDS) that is a component of a CAPP system linking CAD and CAM systems. This goal were accomplished by four important objectives listed as follow:

1. To generate visibility range of faces in the part body using visibility map (V-map) approach.
2. To determine the best parting direction from grouped faces using edge convexity and face connectivity approach.
3. To determine the internal and external side-core direction using parallel test approach.
4. To generate tool position range for faces in core and cavity using plane projection approach.

1.4 Scope of Study

This research focuses on developing ACCDS which specifies on core and cavity design. Core and cavity is one of the main injection mould components that directly affects the quality of the final product, which is known as the heart of the injection mould (Cracknell & Dyson 1993). It would be pointless if other mould components are designed extensively but the core and cavity design is scarce.

ACCDS focuses on two plate moulds only since it is the basic mould for core and cavity plates. Even so, it is not restricted from complex product designs since side-cores are generated as options for irremovable undercuts. The system is developed on the C++ and geometric modelling kernel platform. The approaches

used for this system is modified to fit this platform. In the proposed algorithm, representations of V-map were made to enhance the algorithm processing speed using B-rep shapes. This method retrieves information such as the vector of a certain parting direction where conversion from shape to value is done at the end of each sub-processes.

1.5 Research Approach

Quantitative and deductive approaches were used for this research. Studies and comparison of recent proposed systems, theories and algorithms were made in order to highlight the changes that could be done to improve the core and cavity design system. Hypothesis was made by mixing and matching existing approaches that were used by previous researchers to create new and improved algorithm for ACCDS. The ACCDS were tested and observations were made by comparing the ACCDS output with previous researchers' output. The comparisons confirm whether the proposed algorithm in ACCDS is of assistance in improving the core and cavity design system.

1.6 Organization of thesis

This thesis is arranged in five chapters which include introduction, literature review, methodology, result and discussion, and conclusion. Each chapter provides all the necessary information and findings related to the study and research.

In Chapter One which is introduction, the first section briefly introduces the background of this research. The problem statement is described in the section two

while the third section lists out the aim and objectives of the research. The next sections introduce the focus of the study and research approach while the last section explains the arrangement of the whole thesis.

In Chapter Two which is literature review, the chapter is divided into thirteen sections. The first to fifth section explains the current technology of integration between computer-aided techniques into mould design. The sixth to twelfth section describes the method and approaches of previous researchers. The final section summarizes the important components in mould design and the approach selected in this research.

In Chapter Three which is methodology, the first section illustrates the overall flow of the ACCDS and then briefly describes each of the sub-processes. The next sections explain in detail each sub-processes of the developed system, the approaches that were applied, and the equations that were used.

In Chapter Four which is result and discussion, the system were validated by taking two 3D CAD model as input to the system. The results and outputs generated were discussed in detail. Comparison was also made with output from previous researcher.

In Chapter Five which is conclusion, the findings of the study is summarised and a conclusion is made. Several recommendations and future works are proposed.

CHAPTER TWO

LITERATURE REVIEW

2.1 Manufacturing Technology

Manufacturing technology has been constantly growing since the 80's with the introduction of computer-based system in all stages of product development starting from marketing, industrial design, product engineering, tooling and production. In the earlier days of manufacturing, the development of a new product uses the "over-the-wall" concept where the process always begins at the marketing stage which new ideas for a product are generated. Then the information is passed to the next stage which is industrial design where the initial model is developed with concern of ergonomics and aesthetics of a product. The design is then passed to product engineering stage where the final requirements of a product are ensured by deciding the type of material and manufacturing processes. Then the design and information are passed to the next stage which is tooling where the tooling engineer decides the tool design and tool fabrication. If the design and information from every stage is approved by the production engineer and possible to manufacture, the designed product is ready for the last stage which is the production stage (Malloy 2011). This concept of passing forward information from one stage to another and passing backwards when a problem arises can take a great amount of time before a designed product can actually be manufactured. Therefore a better concept is replaced known as concurrent engineering. The advantage of this concept is the ability to work in parallel among the marketing, design and production team. In recent decade, digital manufacturing has revolutionized this concept, allowing for

more improvements and giving it a new approach which integrates computer technology. Digital manufacturing has been a promising technology that reduces the product development time and cost while at the same time fulfilling to market demands, increasing the quality of products and addressing the need of customization (Chryssolouris et al. 2008). The example of concurrent engineering meets digital manufacturing is the computer-aided process planning (CAPP) which was introduced in the early 80's and became a better solution for the previous concept. CAPP uses computer systems to aid in the manufacturing process planning which bridges the computer-aided design (CAD) and computer-aided manufacturing (CAM) (Tepic et al. 2011).

A report by US-based software company, Citrix, stated that a new wave of technology, the internet-of-things (IOT) or also known as Industry 4.0, will not only make the gap between production and corporate level decision makers closer by transferring data more streamlined and efficient, but also narrow the gap between marketing team and manufacturing team to ensure designed products are up-to-date based on market demand. The automation of manufacturing system has also improved and helped to optimize the manufacturing process.

2.2 CAPP

Process Planning is the systematic determination of operation sequence and work centres to manufacture a product and its components economically from the initial stage in the form of raw material to the final stage where the desired form is produced. The process planning that is assisted by a computer is called CAPP. Initially, the design team creates a 3D CAD model using CAD systems that are

equipped with design knowledge. Then, the process planning team takes the 3D CAD model and creates a process plan using CAPP systems with process planning knowledge. Finally, the manufacturing team takes the process plan and creates a numerical control (NC) code using the CAM system with manufacturing knowledge. These processes are linked with one another with the aid of computers which makes the passing of information faster and more efficient.

Among other benefits of CAPP are, the reduction of cost as the use of resources are efficient, productivity increased, and more accurate and consistent plans are produced (Todic et al. 2008). The previous manual process planning has many limitations such as inconsistent plans that are tied to the knowledge, experience and skill of the planner, and inefficient communication between design team and manufacturing team. These are the reasons why manufacturing firms and researchers started to try to automate the task and come up with different strategies (Elmaraghy 1993). Generally, there are two types of strategy, a lower level and higher level strategy. The lower level strategy only uses the computer to store and retrieve information or data for the process plan while the higher level strategy generates the process plan automatically without human interaction.

There are basically three approaches to a CAPP system. The first approach is the variant approach or also known as the retrieval approach. This approach uses the group technology (GT) code to select an existing process plan developed for each part family and then make small changes to suit the part design. The second approach is the generative approach (Cai et al. 2011). This approach analyses the part design information and creates a process plan from scratch without the intervention of human. The third approach is the hybrid approach or known as semi-generative approach (Wang et al. 2009). This approach is a combination of the two mentioned