An Analysis of the Various Automated Process Planning Methods Employed in Machining

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Abstract

The global trend of industry is moving in the direction of the next industrial revolution. 4.0 in the industry developing a Computer Integrated Production (CIM) system that integrates the many operational and information processing tasks in design and manufacturing is becoming an increasingly significant goal for modern manufacturing firms. In spite of the fact that over four decades have been spent doing research, it is abundantly evident that new features are required to integrate and achieve a totally optimum process planning that can be fully compliant towards Smart Factory. Computer-Aided Process Planning, also known as CAPP, is an essential component in the creation of a CIM system, which is why many academics have concentrated their efforts in this area. In order to get a better understanding of the present state of the art of CAPP methodology, 96 different research publications were read and analysed. The following sections will examine the various CAPP methodologies that researchers have utilised in order to automate the various process planning responsibilities. This presentation will examine some of the major techniques that are involved in smart manufacturing, as well as some potential future developments.

Keywords*: - Computer Aided Process Planning, Smart Manufacturing, Computer Integrated Manufacturing.*

INTRODUCTION

Modern manufacturing industries are increasingly turning towards automation by implementing computer-based technologies for design and manufacturing such as computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), and so on. These industries are doing this because they are confronted with various challenges such as increasing product variety, higher quality, shorter manufacturing lead time, and lower costs. CAPP has shown to be the essential connection in integrating the product design and manufacturing activities, and it is sometimes referred to as the "bridge" between CAD and CAM. This is due to the fact that CAPP serves as the intermediary between the two.

Historically, the individual process planning tasks were carried out utilising the knowledge and expertise of the process planner, which the process planner earned via prolonged interaction with the manufacturing procedures on the shop floor. A person who was responsible for deciding the shop floor process sequences for manufacturing the product was called a process planner. This person would take charge of the project after the design stage and steer it successfully through the final stage of manufacturing it in accordance with the product design specifications. On the other hand, process planners, because of the inherent variability that comes with being human and as a result of the fact that they often come up with different process plans for manufacturing the same product design, which are not necessarily the most efficient of those plans, do not always achieve the best possible results. As a result, it became clear that the process planning procedure needed to be standardised and automated in order to reduce the amount of inconsistency in the generation of process plans, improve productivity, and cut down on the amount of time needed for process planning in addition to ensuring optimality and adherence to design specifications and quality requirements, which was in the interest of both the manufacturer and the consumer.

Different CAPP approaches have been developed over the course of the past four decades in order to accomplish the aforementioned goals of automating the process planning. These CAPP approaches can be broadly categorised as either Variant or Generative CAPP approaches, depending on the specifics of the approach. While the generative approach was primarily driven by the motto "Automatically generating the process plan with as little human intervention as possible," the variant approach was primarily driven by the motto "Similar components need similar process plan." A variant approach is based on the idea that "Similar components need similar process plan." In the variant CAPP approach, an experienced operator was responsible for first of all classifying the similar parts into groups requiring similar manufacturing steps to produce, organising and storing the information in a database, and then analysing the part design information for a new part, searching for a similar process plan from the database, and then retrieving it in order to make the necessary modifications to it so as to suit the manufacturing needs for the new part. This was done so that the new part could be manufactured. On the other hand, the objective of the generative CAPP is to generate fresh process plans for each product.

To achieve this objective, the generative CAPP makes use of information regarding process planning as well as a variety of decision making logics, rules, etc. In contrast to the variant CAPP approach, which can only generate variants of already existing process plans for similar parts, this method involves the collection and encoding of expert knowledge from experienced process planners and shop floor engineers in the form of a computer programme. This programme is then used to automatically generate process plans for new parts starting from scratch.

The researchers in the past have utilised a wide variety of distinct strategies in order to successfully automate the several processes associated with Computer Aided Process Planning (CAPM). These methods have been applied in order to automate one or more of the numerous process planning functions, as well as the integration of computer-aided design (CAD) with process planning (PP), and the integration of process planning with process planning and control (PPC).

DIFFERENT CAPP APPROACHES FOR AUTOMATING THE PROCESS PLANNING TASKS

The various CAPP strategies for automating the process planning tasks have been broken down into the following categories: algorithm-based approaches, analytical methods, graph theoretic approaches, object-oriented approaches, expert system/knowledge-based methods, fuzzy logic-based approaches, neural network-based approaches, soft computing-based optimization approaches, and web-based methods. Each of these approaches is designed to achieve the same goal: to make the process planning tasks more efficient.

Algorithm based Approaches

An algorithm is a set of rules that precisely define a sequence of operations with well-defined instructions for calculating one or more function. There have been numerous applications of algorithm based approaches to automate various process planning tasks such as feature recognition from CAD database, operation and tool selection, operation sequencing, setup planning, etc. Srinivasan and Sheng [1], Dipper et al. [2], Li et al. [3], Zheng et al. [4] have implemented an overall sequencing algorithm in order to handle feature interactions. An algorithmic approach feature extraction from STEP AP224 has been reported by Azmi and Taib [5], Arivazhagan et al. [6], Sunil and Pande [7] and using common metrological equipment for extracting inspection features from CAD. In their paper Arivazhagan et al. [8] implemented 234 features; out of which, 32 are normal and 202 are tapered and developing 17 "feature type"-specific methodologies for calculation of the finish-cut machinable volume. Combined Surface Recognition and Operation Sequencing using comprehensive surface recognition approach proposed by Bok and Mansor [9] and combined Tool Selection and Operation sequencing have been dealt by Gologlu [10]. Phing et al. [11] proposed an algorithmic approach implemented using a vertex classification method for prismatic part features recognition. Sivakumar and Dhanalakshmi [12] took up Feature Extraction for cylindrical components. Zhang et al. [13] investigated machining simulation using STEP-NC. Precedence Selection for Interactive and Non-interactive STEP-NC Machining Features has been proposed by Mokhtar et al.

[14] using Rule-based Geometric reasoning approach. Kretz et al. [15] proposed a generative Process Planning using ISO Standard 10303, Setup Planning and Fixture Planning and their integration has been proposed by Joneja and Chang [16], Sun et al. [17], Kannan and Wright [18]. Sun and Chen [19], Gadakh and Shinde [20] selected cutting parameters. Process Planning using STEP-NC proposed by Qiu et al. [21]. Denkena et al. [22] proposed integration of process planning and production control using adaptive process. Optimization of different

process planning functions has been reported by Gologlu10 [2004a], Ridwan et al. [23]. An integrated module has been developed by Hargroove [24] for fixture design and fixture planning. Selvakumar et al. [25] proposed a machining fixture layout design and optimization. Machining Processes Time calculation has been developed by Blanch et al. [26] to present computer-aided software to calculate cutting time and unproductive time when machine operations are designed and integrate it with the CAPP.

Approaches Based on Mathematical Models

Mathematical models have been used by Hwang and Miller [27] for sequencing interacting features and operations selection, by Xu and Li [28] for process parameter selection in process planning using mathematical logic called ML-PPS and Nee et al. [29], Qin et al. [30] for fixture design, fixture clamping sequence analysis and optimization,

Manufacturability Evaluation for several machining processes of slot feature identified using STEP and the ascendant generation of process method proposed by Martin and Acunto [31] has been used to compare and evaluate the slot machining process by using experimental plan [Taguchi method] for the test procedure. Tests were carried out on machining centre using carbide-tipped drill bit for drilling.

Machining operations optimization carried by Raja and Baskar [32] and cutting parameter optimization by An et al. [33].

Graph Theory Based Approaches

The study of graphs, which are mathematical structures that may be used to describe pairwise interactions between different kinds of subjects, is known as graph theory. In this sense, the term "graph" refers to the collection of "vertices" or "nodes" and the lines called edges that link those nodes. Interacting machining feature identification was suggested by Sunil and his colleagues [34] utilising a CAD component model in B-Rep format.

Methods such as Graph Theory and Matrix Approach (GTMA) and Multiple Attribute Decision-Making (MADM) were utilised in the process graph that was proposed by Gologlu [10], Gadakh, and Shinde [20]. These techniques were used to rank and pick the cutting parameters. The use of graph theory in conjunction with matrix theory that is incorporated into the primary structure of GA has been employed for the purpose of implementing process planning optimization for operation sequencing. Huang et al. [35] adopted this combination.

Object Oriented Approaches

Object-Oriented Programming, or OOP for short, is a paradigm in computer programming in which concepts are represented as "objects" that include data fields. Teich and colleagues [36] put up the idea of visualising production characteristics. Grabiwik et al. [37] made a suggestion for the sequencing of operations by taking an approach that was object oriented. To develop Setup Planning, Ong and Nee [38] have employed objects representation for the purpose of depicting inexact connections between features that are required and features that are present on a final component. This was done in conjunction with fuzzy sets and production rules. Object-oriented technology was utilised by Wu and Zhang [39] in order to express the set-up planning information and produce the alternative set-ups. Gologlu [40] made use of a geometric relationship between the fixture and the machine tool. This relationship was expressed in an object-oriented style, which determined the free zones on the workpiece. The cutting-edge data decision system that Sun and Chen [17] developed was founded on knowledge categorization and the fundamental data model. Grabowik and Kalinowski [41] advocated the integration of CAD/CAPP/CAP Systems through the use of object-oriented modelling, with the primary components being a Technological Knowledge Base [TKB] and a Scheduling Knowledge Base [SKB]. The suggested technique is geared toward facilitating efficient decision making in the verification of production orders and improving the flow of production. In order to implement remote design and manufacture, Benavente et al. [42] presents a CAD/CAPP/CAM object-oriented prototype system that is compliant with ISO 14649 [STEP-NC] for the remote manufacturing of mechanical components using the Internet. This system is intended for use in the remote manufacturing of mechanical components. When comparing the process parameters, such as cutting velocity and feed rate, Denkena et al. [22] employed an object-oriented part model that was based on the STEP-NC standard "Technological Knowledge Base" [TKB].

Expert System / Knowledge [Rule] Based Approaches

An expert system is a type of computer programme that simulates the judgement and decision-making abilities of a human specialist. Expert systems are meant to solve complicated issues by reasoning about knowledge, just like an expert would, rather than by following the technique of a developer, as is the case in traditional programming. This allows expert systems to tackle problems that would otherwise be impossible. Several different process planning tasks have been automated by Wong et al. [43], Bansal et al. [44], Marchetta and Forradellas [45], Nagarajan and Reddy [46], Ong and Nee [47], Chlebus et al. [48], Deb et al. [49], Chu et al. [50], Liu and Wang [51], Deja and Siemiatkowski [52], Kojima et al. In order to create the Dissimilarity Degree matrix, Sun et al. [55] utilised three different rules. Gologlu [10] created the ProPlanner CAPP system, which is an application that makes use of the KAPPA-PC expert system development tool for automating the selection of tools. In yet another study, Gologlu [40] generated precedence relations by using geometric reasoning and heuristics about the features. These were applied to the features. Deb and Ghosh [56] used a knowledge-based technique that was implemented in the CLIPS Expert system shell to automate the setup creation, operation sequencing, and selection of locating and clamping surfaces. Using a rule-based approach that was devised and implemented based on the knowledge regarding machining precedence of the interacting features, Mokhtar and Xu [14] established a method for determining the order of precedence for features that interact with one another. Deja, M., and Siemiatkowski [57] provided the identification of several process options and the sequential ordering of working phases. Setup planning has been proposed by Deb et al. [58], Ong and Nee [38], Ong and Nee59 [1995], Ong and Nee [60], and Wu and Zhang [39] utilising a Knowledge Based method that combines object oriented and fuzzy set. [58], [38], [1995], and [60] Cakir and Cavdar [61], Stampfer [62], Hazarika et al. [63] The creation of the set-up plan was performed using a knowledge-based technique by Hazarika et al. [64] and Singh and Deb [65].

Lin and Yang [66] developed a modular fixture design using an AI-based technique. Through the use of the expert system that was built for this research, face milling procedures have been automated. The method of Collaborative and Interoperable Product Design/Development that Valilai and Houshmand [67] presented makes use of a platform with three layers that is both integrated and interoperable and is given the term INFELT STEP. Amaitik [68] created a CAD/CAPP system that was fully integrated. At an early point in the design process, Shehab and Abdalla [69] implemented a knowledge-based system that they had built for product cost modelling. Iqbal and colleagues [70] made a suggestion to optimise the milling settings. A technique for optimising the feeding rate that was introduced by Ridwan et al. [71]. The STEP-NC data model was employed to carry out the activities, and the EXPRESS programming language was utilised throughout the data model's construction. The authors Liu et al. [72] proposed employing polychromatic set theory to optimise NC machining for box-shaped items. To reduce scrap cost, raw material cost, and processing cost, Prakash et al. [73] assessed cost optimization in the CIM system using the Knowledge-Based Artificial Immune System (KBAIS). Machining Optimization by the Implementation of STEP-NC is an idea that was presented by Ridwan et al. [74].

Fuzzy Logic Approaches

The field of study known as "fuzzy logic" is a subset of "many-valued logic" or "probabilistic logic," and it focuses on reasoning that is more approximative and fluid than concrete and precise. Md. Adnan and colleagues [75] studied the Fuzzy Logic components for predicting the performance of machining. The fuzzy set theory was utilised in the set-up planning process by Ong and Nee [38]. Fuzzy sets, fuzzy relations, and fuzzy matrices have been utilised to describe and express these feature relations. Set-up Planning was developed by Ong and Nee [59] utilising fuzzy sets and fuzzy relations. Ong and Nee [60] used fuzzy sets, fuzzy relations, and fuzzy matrices in the representation and manipulation of the constraints and feature relations in set-up planning to ensure the validity of the produced setup for set-up planning. This was done in order to ensure the validity of the produced setup for set-up planning. Ong and Nee [47] and Wu and Zhang [39] have utilised an optimization approach that is fuzzy-set based. Fuzzy arithmetic was utilised by Hazarika et al. [63] and Hazarika et al. [64] in order to deal with the uncertainties that were linked with the work material, clamp material, and clamping torque. For the fuzzy parameters, we will assume that linear triangular fuzzy membership functions are appropriate. The Machinability Data Selection (MDS) model, which was proposed by Hashmi et al. [76], made use of a fuzzy logic model to describe the relationship between a given material's hardness and the drilling speed. These fuzzy relations were used for a variety of cutting tool materials, hole diameters, and feed rates. Xu [78] proposed machinability data selection for part programming utilising cutting tool and cutting parameters selection process for efficient utilisation of machine tools. Yilmaz et al. [77] presented a system, called as CAS-CUPFUL [Computer Aided Selection of CUtting Parameters by using FUzzy Logic] developed using Matlab Fuzzy Logic Toolbox and Matlab Programming Language to implement cutting parameter selection for turning operations. Razali et al. [79] have presented their findings about the Cutting Speed Prediction and the Feed Rate Prediction. The peripheral end milling process has been equipped with fuzzy modelling, and wrought carbon steel and high-speed steel have been decided upon as the materials for the work piece and the cutting tool, respectively. Surface roughness was modelled by Kovac et al. [80]. [Citation needed] Iqbal et al. [70] used a forward-chaining expert system shell called Fuzzy CLIPS [fuzzy extension of C language integrated production systems] to optimise milling parameters for hard milling. The fuzzyfying was done with the max–min inference method, and the defuzzification was done with the CoG method. They used the converted experimental data as ANOVA and the numeric optimization output to develop the knowledge-base in the form of Fuzzy IF–THEN rules. Machining Feed-rate Optimization is a concept that was developed by Ridwan et al. [23], and it is based on the idea that the behaviour of the machine may be obtained by a cutting force sensor and then controlled by a fuzzy control algorithm. In a different published work, Ridwan and Xu [81] discussed the optimization of the feed-rate.

Neural Network Based Approaches

The term neural network was traditionally used to refer to a network or circuit of biological neurons. The modern usage of the term often refers to artificial neural networks, which are composed of artificial neurons or nodes. Optimized back-propagation artificial neural network trained with a large set of feature patterns, following 12-node feature representation vector scheme was used by Sunil and Pande [7] for feature recognition. Deb et al. [49] used back propagation learning based Neural Network approach for automation of operation selection. Joshi et al. [82] proposed setup planning using unsupervised learning Neural Network Approach Machining operation selection has been developed by Deb et al. [58]. This paper aims at contributing to the applicability of back-propagation neural network method for the selection of all possible operations for machining rotationally symmetrical components, by pre structuring the neural network with prior domain knowledge in the form of heuristic or thumb rules. It has been achieved by developing two forms of representation for the input data to the neural network. Amaitik [68] integrated CAD/CAPP System using a hybrid approach of neural network and expert system used as the inference engine of the proposed CAPP system. Artificial Neural Networks [ANN]-based algorithm with Design of Experiments [DoE] has been proposed by Selvakumar et al. [25] to design an optimum fixture layout in order to reduce the maximum elastic deformation of the work piece caused by the clamping and machining forces acting on the work piece while machining for implementing machining fixture layout design. Mahdavinejad et al. [83] proposed milling parameters optimization.

Soft Computing based Optimization Approaches

Earlier computational approaches could model and precisely analyze only relatively simple systems. A number of soft computing based optimization techniques have been developed such as Genetic Algorithm [GA], Ant Colony Algorithm [ACO], Particle Swarm Optimization [PSO], etc. Joshi et al. [82], Wang et al. [84], Raja and Baskar [32], Kafashi et al. [85], Nallakumarasamy Huang et al. [35], Kumar and Deb [86], Li et al. [87], Sreeramulu et al. [88], Wen et al. [89] implemented setup planning and operation sequencing. Baskar et al. [90], Bouaziz and Zghal [91], An et al. [33] developed an algorithm for the generation optimal set of cutters. Sardinaz et al. [92], Mahdavinejad et al. [83], Othmani et al. [93], Yildiz [94], Yildiz [95] optimized cutting parameters. Wang et al. [96] also optimized process planning to handle uncertainty in the decision of process planning using the multi-objective optimization function established. Prakash et al. [73] proposed cost optimization in CIM System using Knowledge-Based Artificial Immune System [KBAIS] to optimize scrap cost, raw material cost, processing cost. The output unit cost has been minimized by considering precedence relationships, availability of machines, tools, TAD and scrap. The proposed algorithm has three basic steps: initialization, selection and hyper-mutation.

Web Based Approaches

Web-based approach is the invocation of computer services over the World Wide Web, specifically through a web browser.

Increasingly, the web is being looked upon as an environment for providing modeling and simulation applications, and is an emerging area of investigation within the process planning community. Kojima et al. [53] used internet technology, including XML markup language and the Java programming language, has been used for developing the system. Benavente et al. [42] proposed remote design and manufacture.

CONCLUSIONS AND PLAN FOR FURTHER WORK

It was discovered that a knowledge-based system is able to automatically generate a detailed sequence of machining operations. This sequence includes the manufacturing precedence constraints that are subject to which the operation sequences are to be determined, the various machining setups in accordance with the given Tool Approach Directions, the operations that are to be performed within each setup, the method of locating and clamping the component for fixturing it, and the method of determining how to fixturing it. It is necessary to further optimise the generated operation sequences subject to the precedence constraints by taking into consideration a variety of factors, such as the number of cutting tool changes, machine tool changes, setup changes, etc., in addition to the amount of time and money spent manufacturing the product. It has been suggested that novel optimization strategies based on soft computing should be investigated, and the outcomes of these strategies should be compared to those obtained by using conventional methods, such as GA, PSO, ACO, and so on. Along with making an effort to cut down on the amount of waste that is produced, one of the most important aspects of the production cost that has to be addressed is the amount of energy that is used.

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