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ORIGINAL ARTICLE

Survey on computer-aided process planning

Yusri Yusof · Kamran Latif

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Abstract Computer-aided process planning (CAPP) is the application of the computer to assist process planners in the planning functions. It is considered as the key technology for computer-aided design (CAD) and computer-aided manufacturing (CAM) integration. Nowadays, due to dynamic market and business globalization, CAPP research faces new challenges. In this article, an attempt is made to provide a comprehensive survey on CAPP based on features, knowledge, artificial neural networks, genetic algorithms (GA), fuzzy set theory and fuzzy logic, Petri nets (PN), agent, Internet, standard for the exchange of product data (STEP)-compliant method, and functional blocks (FB) method/technologies for last 12 years (2002–2013). The aim of this paper is to provide an up-to-date survey with graphical representation for easy understanding of the past, present, and future of CAPP. The design of this paper includes a brief introduction of CAPP and its approaches, methods/technologies of CAPP, survey on CAPP, discussion, and conclusion.

Keywords CAPP · Approaches · Method/technologies

1 Introduction

The use of computer technology for process planning was initiated four decades before. Since then, there has been a large amount of research work carried out in the area of computer-aided process planning (CAPP). One of the reasons for this is the role of CAPP in reducing throughout time and improving quality [1]. CAPP is the application of the computer to assist process planners in the planning functions. It is considered as the key technology for computer integrated manufacturing (CIM). It consists of the determination of processes and parameters required to convert a block into a finished part/product [2]. The process planning activities includes interpretation of design data, selection, and sequencing of operations to manufacture the part/product, selection of machine and cutting tools, determination of cutting parameters, choice of jigs and fixtures, and the calculation of the machining times and costs [1, 3].

There are two basic approaches to CAPP: variant and generative [4]. From these two basic approaches, the variant approach continues to be used by some manufacturing companies. Nowadays, the trend is toward a generative approach [1, 5].

1.1 Variant approach

Also called as retrieval approach, it uses a group technology (GT) code to select a generic process plan from the existing master process plans developed for each part family and the edits to suit the requirements of the part [6]. The variant approach is commonly implemented with GT coding system. Here, the parts are segmented into groups based on similarity, and each group has a master plan. The advantages of this approach is the ease of maintenance, but the lack of an on-time calculation of manufacturing process and quality of the process plan still depend on the knowledge of a process planner and it still requires manual inputs for the establishment of the mass data into manufacturing processes [3]. Figure 1 shows the variant approach to CAPP.

Y. Yusof (✉) · K. Latif
Faculty of Mechanical and Manufacturing Engineering,
Universiti Tun Hussein Onn Malaysia, Batu Pahat,
Johor, Malaysia
e-mail: yusri@uthm.edu.my

K. Latif
e-mail: engr.kamranqureshi@gmail.com

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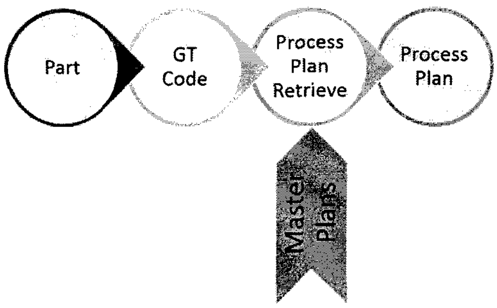

Fig. 1 Variant CAPP approach

1.2 Generative approach

In this approach, a process plan for each component is created from scratch without human intervention. These systems are designed to automatically synthesize process information to develop a process plan for a part. These systems contain the logic to use manufacturing database and suitable part description schemes to generate a process plan for a particular part [3, 4]. Generative approach eliminates disadvantages of the variant approach and bridges the gap between the computer-aided design (CAD) and computer-aided manufacturing (CAM). The bottleneck of this approach is the difficulty in obtaining useable features and the difficulty in representing, managing, and utilizing human expertise. Figure 2 shows the generative approach to CAPP.

2 Method/technologies of CAPP

This survey is based on the ten established methods/technologies of CAPP namely feature-based technologies, knowledge-based systems, artificial neural networks, genetic algorithms (GAs), fuzzy set theory and fuzzy logic, Petri nets (PNs), agent-based technologies, Internet-based technologies, standard for the exchange of product data (STEP)-compliant method, and functional blocks to overcomes the issues of machining operation, tool and machine selection and sequencing, feature extraction, reorganization, interpretation and representation, knowledge integration, representation, acquisition and sharing, setup planning, energy consumption, linear and nonlinear planning, integration of product and manufacturing data, intelligent tool path generation, optimization problems, intelligent decision making and sharing of knowledge, integration of process planning and scheduling, etc. Figure 3 shows the use of CAPP in manufacturing cycle.

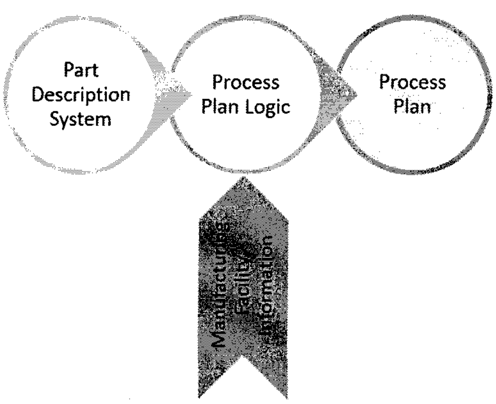

Fig. 2 Generative CAPP approach

Feature technology plays a key role in process planning with two approaches: feature recognition and design by features. This approach has been adopted by many process planning systems, due to its ability to facilitate the representation of various types of part data in a significant form to drive automated CAPP. Knowledge-based technology allows the capturing of knowledge from experts and is able to simulate the problem-solving skills of a human expert in a particular field. Neural networks have an ability to recognize transitional and complex features without feeding any pervious knowledge into the system, and they also have the ability to derive rules or knowledge through training with examples and can allow exceptions and irregularities in the knowledge. Genetic algorithms are generally good at finding acceptably good solutions to problems quickly. They do not need gradient information or smooth functions, and they have to be carefully structured and coded. Agent-based approach offers some unique functionality for distributed product design and manufacturing. The fact that process planning for a complex part can be broken down into smaller planning problems makes these problems manageable by a number of intelligent agents working in cycle. Fuzzy logic and Petri nets technologies are used in CAPP by combining with other technologies to offer better solutions. Internet-based technology enables engineers to achieve the dynamic tool and machine selection, thus aiding in the existing CAPP system to generate realistic and economical process plans. It also allows process planners in any industry to react to any unexpected changes and to support the data exchange between different systems used at different companies. STEP-compliant in CAPP leads to the likelihood of using standard data throughout the entire product process chain in the manufacturing atmosphere, hence increasing the system's capability of integrating with other systems in the complete CIM environment. The functional blocks approach plays active role in CAPP in response to shop floor uncertainty because functional block (FB)-embedded algorithms can make decision adaptively to changes at run time and can be integrated with dynamic scheduling and STEP-numerical control (NC) system.

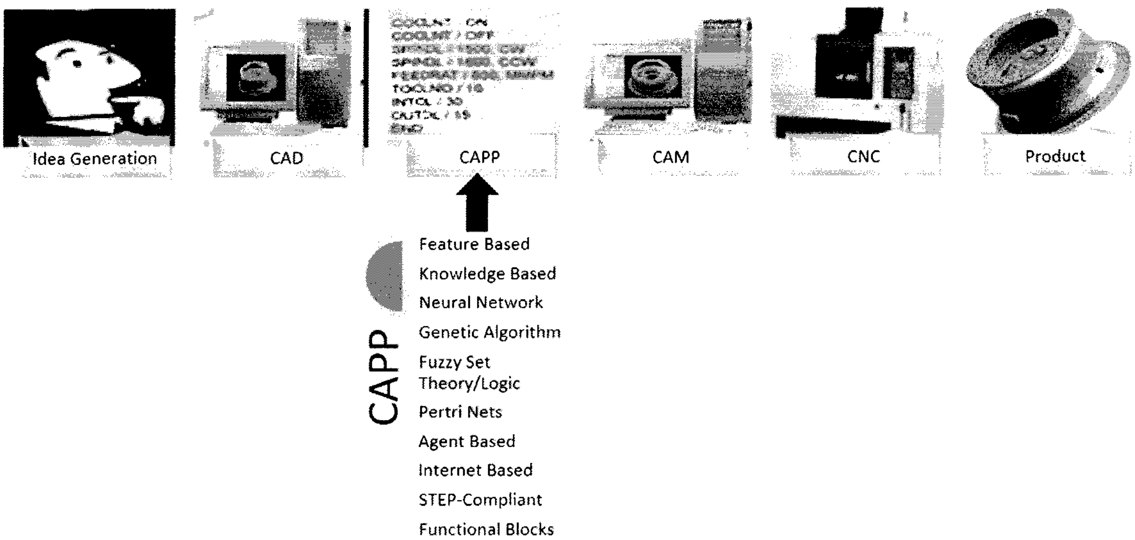

Fig. 3 Use of CAPP in manufacturing cycle

3 CAPP survey

The importance of CAPP in a manufacturing facility cannot be underestimated. One of the reasons for this is that it provides a link between design and manufacturing and reduces the time and cost and improves the quality [7]. The CAPP area has been greatly developed in the last three decades. In this section, a snapshot of the past and current survey in the field of CAPP is presented by dividing it into two: Sections 3.1 and 3.2. The aim of this section is to provide a comprehensive review on CAPP technology: past work is discussed in the Section 3.1, whereas the Section 3.2 presents the survey of the last 12 years based on work of the above-stated methods/technologies of CAPP.

3.1 Past survey

The idea of developing a process plan using computers was presented by Niebel [8] in 1965. In 1984, Harold presents the first review article on CAPP in which scholars discussed about the approaches and strategies for structuring manufacturing methods and data development for the development of a generative type-automated planning system. That article also outlines the anticipated development of a "common language of geometry" to relate a part to the process and development of CAD/CAM systems that incorporated CAPP [9]. In 1988, Ham and Lu presents an assessment of CAPP status and appropriately stated that the direction of future research lies on the integration of design, manufacturing, and the use of artificial intelligence (AI) technologies [10]. In the following year, the most significant survey of that time was accomplished by Atling and Zhang, which indicated that the difficulty in the integration of CAD with CAPP is due to the lack of common methods to represent geometric entities. In this survey, the author also recognized AI technologies as a crucial technology in the development of an effective process planning system and also pointed out the importance of the learning systems and identified an ideal approach to integrate all the information involved in production of a part into a single database. The authors also highlighted the issue of interfacing between CAPP and CAM and other computerized production systems such as NC tool path, MRP, production simulation, etc. [11]. In the same year, a survey of the 128 systems of CAPP was in print by Gouda and Taraman, which highlights the four types of CAPP systems: variant, semi-generative, generative, and expert process planning system [12].

In the year 1993, a survey was conducted by ElMararghy in which the issues of quality and evolving standards are addressed. That survey also included the major development thrust in CAPP, evolving trends, challenges, integration of design, and production planning [13]. In the same year, Eversheim and Schneewinf suggest that the future of CAPP development is an extension to assembly planning, function integration with NC programming, use of AI methods in decision making, and use of database sharing for data integration with CAD [14]. In year 1995, an overview of the techniques and the role of process planning was discussed by Kamrani et al. That article also highlights the critical issues and the characteristics associated with evaluation and selection of a CAPP system [15]. In the following year, a comprehensive review on CAPP was published by Leung, in which the author observed that solid modeling in CAPP systems is not as adequate as anticipated, hence the revitalization of variant process planning systems. The scholars believed that it is logical that future process planning systems be built on intelligent system architectures with AI techniques [16]. In 1997, an 8-year survey (1990–1997) was in print by Cay and Chassapis, which provides an overview of manufacturing features and feature recognition techniques with CAPP research [17]. In the following year, a review was presented by Marrie et al., which covers the literature from 1989 to 1996. In that article, the advantages and disadvantages of the systems were discussed with the generative approach highlighted [18]. After a 10-year gap, Xu et al. presented an article which provides a comprehensive review on CAPP technologies developed for machining since the 1990s, but mostly after 2000. In that article, the researchers provided an up-to-date review of the CAPP research works, a critical analysis of journals that published CAPP research works, and an understanding of the future direction in the field [19].

3.2 Present survey

In this section, the entire work is presented in two subsections; each subsection is composed of a 6-year survey based on mentioned methods and presents the entire survey into graphical representation for easy understanding.

3.2.1 Survey of 2002–2007

This subsection presents the survey of CAPP work during 2002–2007 period based on stated methods, while the graphical representation of this survey is shown in Fig. 4.

1. Feature based In year 2002, [20] suggest a methodology to extract user-specific features from generic features. This is achieved by specifying patterns for these specific features. [21] also did a work on feature-based technology and developed a generative CAPP system for prismatic parts. The scholars have divided the system into three modules: the first concerns with feature extraction, while the second and third concern with the setup planning, machine selection, cutting tool selection, cutting parameter selection, and generation of process plan sheet. Later in year 2003, a generic CAPP support system (GCAPPSS) was proposed by [22], which invokes a set of algorithms that enable feature extraction, recognition, coding, classification, and decomposition. In year 2004, Gonzalez and Rosado presented an internal feature model for process planning by using STEP AP224 features to represent information around the machining features for process planning without the use of geometric entities [23]. Later in year 2005, Woo et al. integrate three feature recognition methods: graph matching, cell-based maximal volume decomposition, and negative feature decomposition to develop a hybrid feature recognizer for machining process planning [24]. In year 2006, Hou and Faddis investigated the integration of CAD CAPP/CAM based on machining features [25]. In the same year, Wang et al. presented a different approach as a part of their distributed process planning (DPP) system [26]. In this system, a two-layer hierarchy is considered to separate the generic data from those that are machine specific in DPP. Machining process sequencing is treated as machining feature sequencing within the context. In year 2007, Lee et al. developed a projective feature recognition algorithm that outputs features that can be directly used for process planning [27].

2. Knowledge based In year 2002, Zhao extended Arezool knowledge-based system expert computer-aided tool selection (EXCATS) by integrating it with a CAD system [28, 29]. This system is capable of processing CAD data and automatically generates the component representation file for EXCATS. In year 2003, the majority of work is carried out on a knowledge-based method of CAPP. Park discussed the knowledge-capturing methodology in process planning based on three submodels of knowledge identifications [30]. Jia et al. also adopted the object-oriented technology to represent setup process information,

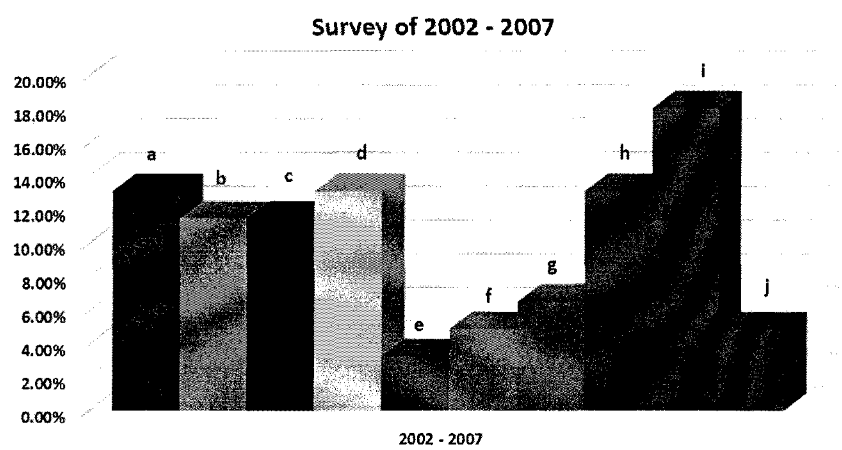

Fig. 4 Graphical representation of 2002–2007 survey: (*a*) feature based, (*b*) knowledge based, (*c*) neural networks, (*d*) genetic algorithm, (*e*) fuzzy set theory/logic, (*f*) Petri nets, (*g*) agent based, (*h*) Internet based, (*i*) STEP-compliant, and (*j*) functional block

process decision knowledge, and decision procedure control knowledge [31]. Grabowik and Knosala presented a method of knowledge representation in the form of a set of objects [32]. Later in year 2004, Gologlu extended the hybrid CAPP system called pro-planner and developed an efficient heuristic algorithm for finding near-optimal operation sequences from all available process plans in a machine setup [5]. In this approach, a four-level hierarchy was used: feature level, machining scheme level, operation level, and tool level. In year 2007, [33] presents an approach to develop a road map method based on knowledge. The authors conclude that the road-map method can introduce flexibility and dynamics in the manufacturing processes and also simplifies the decision-making process in production planning. Later, Liu and Wang presented a hybrid approach to combine knowledge-based rules and geometric reasoning rules for the purpose of sorting out the sequence of interacting prismatic machining features [34]. In the same year, Denkena et al. also worked on knowledge-based system and described a holistic process planning model based on an integrated approach combining technological and business considerations [35].

3. Neural network In year 2002, the majority of work was carried out on neural networks by different researchers. Yahia et al. presented a feed-forward neural network-based system for CAPP [36]. Balic and Korosec addressed the issue of intelligent tool path generation [37]. The aim of this work is to show that artificial neural network is able to establish a desirable milling tool path strategy or sequence for free surface machining. In the same year, Devireddy et al. presented an approach to overcome some limitations of decision trees and expert system-based approaches [38]. Scholars have developed a three-layer neural network for selection of machining operations for all the features at a time by taking into consideration the global sequencing of operations across all the features of a part. Later in year 2005, Korosec et al. proposed a neural fuzzy model that uses the concept of feature manufacturability to identify and recognize the degree of difficulty in machining. The model was created by means of construction parametric fuzzy membership functions based on the neural network learning process [39]. In the same year, Ding et al. proposed an optimization strategy for process sequencing [40]. The authors used an artificial neural network to allocate the weights for three main evaluating factors of process sequencing to minimize manufacturing cost, time, and sequence rules. In year 2006, [41] used the back-propagation neural network method for the selection of all possible operations for machining rotationally symmetrical components. In the following year, Amaitik and Kiliç developed a process planning system using STEP features (ST-Feat CAPP) for prismatic parts where several neural network models were developed [42].

4. Genetic algorithms In year 2002, Li et al. presents a hybrid generic algorithm-simulated annealing (GA-SA) approach to solve the optimization problem of process planning for prismatic parts [43]. In year 2005, a fuzzy inference system for choosing appropriate machines was introduced [44]. In addition, the load for each machine is balanced by using the GA based on the capability information, which is measured by a reliability index. Afterward, a GA was developed to search for an optimal process plan for single and distributed manufacturing systems [45]. In the same year, Vidal et al. presented an algorithm based on operation cost optimization [46]. In this approach, the authors talked about the problems of manufacturing route selection in metal removal processes. The authors developed a system for cutting-process parameter selection for milling operations. In the same year, the developed system was extended for high-speed machining [47]. Later in year 2006, Bo et al. reconstructed generic algorithms based on the analysis of various constraints in process route sequencing, including the establishment of coding strategy, evaluation operators, and fitness function [48]. In the same year, Henriques developed a nonlinear, uni-criterion, and multivariable optimization model for the integration of process and production planning [49]. The developed model generates schedule according to performance measures. Later, [50] presents a method which utilizes the application of a newly developed ant colony algorithm search technique for the quick identification of the optimal operation sequence by considering various feasibility constrains.

5. Fuzzy set theory/logic In 2003, Wong et al. presented an approach for the solution of process sequencing problem by creating a prototype process planning system that uses a hybrid of fuzzy and generic approaches [51]. In the following year, Fuqing et al. introduced a fuzzy inference system for the purpose of choosing appropriate machines as an alternative way to integrate the production capability during scheduling [52].

6. Petri net In year 2002, Wu et al. proposed an ordered Petri net model (OPN) to address alternative and optimal operation planning with manufacturing resources constraints [53]. Later in year 2004, Kasirolvalad et al. introduced a technique based on AFPN to model, monitor, and control the surface roughness and machining operation quality [54]. In this work, the scholars have presented a net approach for planning machining operations and showed that Petri nets could be used to model all computer numerical control (CNC) machining operations in a graphic manner. In year 2006, Canales et al. proposed a methodology to extend fuzzy number approach to triangular function learning and introduced an adaptive fuzzy petri net (AFPNT) [55]. AFPNT has the learning ability via neural networks so that fuzzy knowledge in a knowledge base could be learned through that model.

7. Agent based In year 2003, Wang and Shen proposed a methodology by integrating feature-based process planning, FB-based control, and agent-based decision making. The developed system can deal with behavior among a group of autonomous agents about how they can coordinate their goals, plans, skills, and activities to work cooperatively toward a single global object [56]. Later in year 2005, Allen et al. developed a STEP-NC-compliant computational environment used to demonstrate agent-based process planning [57]. In the following year, Nassehi and Fichtner works on an agent-based technology of CAPP. The authors presented an approach to examine the application of collaborated multiagent system in designing an object-oriented process planning system called multiagent system for CAPP, for prismatic components in a STEP-NC-compliant environment [58], whereas Fichtner et al. also used STEP-NC information and introduced a combination of agent-based organization and self-learning of featured-based technological information for acquisition and preparation of distributed NC information in support of NC planning [59].

8. Internet based In year 2002, Zhang developed a CAPP system based on Internet-based technology by adopting knowledge-based methods written in JSP and Java language [60]. The CAPP system can receive and process CAD data and produce final process plans that meet production requirements. Later in year 2004, Changyi et al. and Chung and Peng research on Internet-based technology of CAPP. Changyi et al. developed a CAPP system based on the COM component technology, NET technology, and the extensible markup language (XML) technology. The computing model was a mix of client/server (C/S) and browser/server (B/S) models. Customization on such an integration system can solve the problem between a general CAPP system and a custom CAPP system [61]. Chung and Peng developed a web-based tools and machine selection system (WTMSS) that provide intelligent decision making and sharing of production knowledge through the Internet [62]. In year 2005, the majority of work is carried out on Internet-based technology. Xu et al. put forward an idea that used screen sharing technology to support cooperation for overcoming the limitations of process resources and knowledge in the traditional narrow-sense process planning and improves engineer's cooperative work [63, 64]. You and Lin presented a Java-based process planning proposal which used STEP AP224 data model to define the manufacturing features and to bridge CAD and CAPP systems [65]. Gaoliang et al. also presented an Internet-based system for setup planning and also incorporate STEP in their Java-based system. The system input uses a format file of STEP and communicate with process planning, fixture design, and NC programming systems [66]. In this system, XML was used for the information transmission between various manufacturing systems. Peng et al. also presented an Internet-based integrated system for setup planning [67]. The system's ability to communicate with process planning, fixture design, and NC programming generates global optimal setup plan.

9. STEP compliant In year 2003, the first work on STEP-compliant method of CAPP is done by [68]. In this work, the scholars have proposed an approach to interlink design and process planning using an integrated product model based on the STEP format. This work deals with the recognition of machining features, incorporation of manufacturing information, and implementation of a neural interface. Later, Ong et al. also proposed a manufacturing feature recognizer for the uni-graphics system to integrate feature recognition with design by feature approaches to generate a STEP-based manufacturing feature model [69]. Lau et al. worked on feature recognition for automatic process planning where STEP design files are used as the information source for generating detailed manufacturing process [70]. In the same year, You and Lin, and Gaoliang et al. also utilize this technology in their Internet-based CAPP systems [65, 67]. In year 2006, Nassehi and Fichtner work on an agent-based technology and STEP-compliant methods of CAPP. Nassehi et al. presented the approach to examine the application of collaborated multiagent system in designing an object-oriented process planning system called multiagent system for CAPP, for prismatic components in a STEP-NC-compliant environment [71], whereas Fichtner et al. also used STEP-NC information and introduced a combination of agent-based organization and self-learning of featured-based technological information for acquisition and preparation of distributed NC information in support of NC planning [59]. Stroud and Xirouchakis works on a STEP-compliant CAPP method. In this work, the authors have extended the feature definitions in STEP-NC to support process planning for esthetic products in stone manufacturing industry [72]. Later, Brecher et al. developed a prototype system for closed loop machining processes, which include the generation and execution of a STEP-NC program and feedback of measured results [73]. In year 2007, Amaitik and Kiliç developed a process planning system using STEP features (ST-Feat CAPP) for prismatic parts where several neural network models were developed [42]. Later in the same year, Nassehi et al. introduced a software platform entitled the integrated platform for process planning and control (IP3AC) to support STEP-NC-compliant process planning. Scholars have also developed a prototype process planning system (PPS) based on that platform [74].

10. Functional block In 2007, Wang et al. works on the utilization of the FB in CAPP. In this work, the tasks of process planning are divided into two groups and accomplished at two different levels: shop-level supervisory planning and controller-level operational planning. In this work, the scholars have used FBs to encapsulate high-level generic process plans and low-level planning algorithms [75, 76]. Liu et al. applied knowledge discovery in database (KDD) process planning. In this approach, process data selection, process data purge, and process data transformations are employed to get optimized process data [77].

3.2.2 Survey of 2008–2013

This subsection presents the survey conducted on CAPP during the period of 2008–2013. Whereas its graphical representation is shown in Fig. 5.

1. Feature based In year 2008, Babic et al. presented a survey on three major feature reorganization problems: extraction of geometric primitives from a CAD model, defining a suitable part representation from feature identification, and feature pattern matching/recognition [78]. In year 2010, Abu and Md Tap presented an approach to feature recognition using a rule based on different characteristics specific to each feature such as the total number of faces, edges, etc. [79]. The authors have implemented the approach by using graphic interactive programming (GRIP) and uni-graphics solid modeler. Later in year 2011, Garcia et al. introduced a method which utilizes feature-based modeling for defining a preprocess plan. A preprocess plan defines the required capabilities on a high level. This method of feature reorganization offers both geometric and nongeometric information [80]. In year 2012, Yu et al. presented a CAPP method for rotational parts based on case retrieval [81]. In this approach, the authors had proposed a method which combines feature and characteristics of part information. This method was proposed to achieve reuse process characteristics for manufacturing process information models. In the same year, Behra et al. developed feature detection algorithms in STL part specification [82]. Developed algorithms were able to detect 33 different features of geometry, curvature, location, orientation, and process parameters within an expert CAPP system for SPIF. Later in year 2013, [83] proposed a method of features coding for prismatic parts. The authors highlighted the use of developed method in process planning environment.

2. Knowledge based In year 2008, a knowledge-based decision-making model was proposed by [84]. The model was based on the IDEF methodology, the aim of which is to integrate the process planning and scheduling in metal removal processes. In year 2010, Zhang et al. presented an approach driven by process planning to reconstruct the serial three-dimensional (3D) models for rotational parts [85]. This approach introduced the process planning course and relevant information to implement a dynamic, incremental, and knowledge-based reconstruction. Marchetta and Forradellas proposed a hybrid procedural and knowledge-based approach based on artificial intelligence planning, to address the problems of classic feature interpretation and feature representation [86]. Chen et al. proposed a parametric flow chart (PFC) based on knowledge representation method which efficiently combines parameter information, flow chart technology, and visualization technology to provide user-friendly and effective way of representing knowledge [87]. Helgoson and Kalhori proposed a conceptual model which includes an adoption of the methodology of knowledge acquisition (MOKA) and contains the activities as to identify, justify, capture, formalize, package, and activate for sharing and integration of knowledge in process planning to increase the level of efficiency, reliability, and productivity in process planning process [88]. In year 2011,

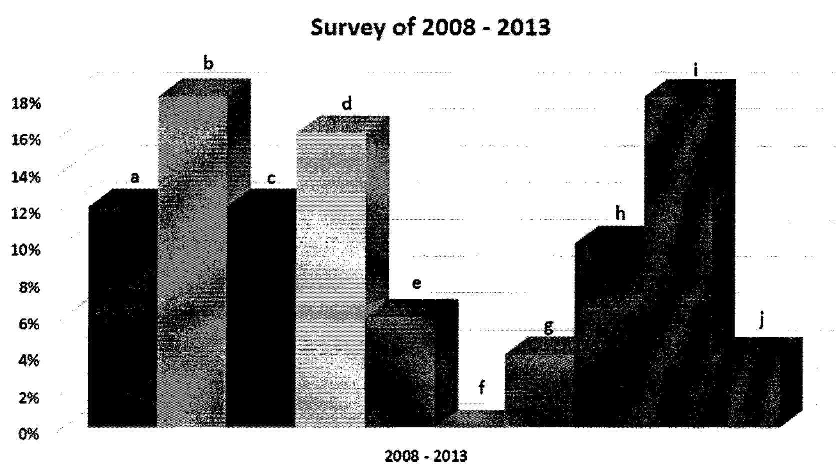

Fig. 5 Graphical representation of 2008–2013 survey: (*a*) feature based, (*b*) knowledge based, (*c*) neural networks, (*d*) genetic algorithm, (*e*) fuzzy set theory/logic, (*f*) Petri nets, (*g*) agent based, (*h*) Internet based, (*i*) STEP-compliant, and (*j*) functional block

Wang et al. introduced a model in which knowledge is represented as neural network weight value [89]. In the same year, Liang developed a knowledge-based unit composed of object, functional, and dynamic models for the troubleshooting of process planning [90].In year 2012, Chen et al. presented a knowledge-based CAPP system for NC control tool path generation of complex shoe molds [91]. In this approach, the authors proved that knowledge-based CAPP systems can resolve the problems of complicated process planning. In the same year, Lin et al. uses a knowledge-based approach in sheet metal manufacturing. The scholars proposed a two-step process for finding proper layouts of strip in progressive dies [92]. In the following year, a knowledge-based expert system was introduced for the process planning of axisymmetric sheet metal parts. The developing system automatically models the part geometry, calculates blank size, selects process parameters, and finally generates process sequencing [93].

3. Neural network In year 2008, Sunil and Pande proposed a 12-node vector scheme to represent machining feature families having variations in topology and geometry [94]. The data of recognized feature was then postprocessed and linked to a feature-based CAPP system for CNC machining. In year 2010, [95] presented an approach to integrate key product realization activities using neural data representation. The authors concluded the approach as very useful for direct distributed applications, which passes the data in the form of XML streams. Later in year 2011, Wang et al. introduced the artificial neural network for unstructured manufacturing knowledge model in which knowledge is represented as a neural network weight value matrix and the form artificial neural network database to support intelligent CAPP [89]. In year 2012, [96] developed a new algorithm based on ant colony for operation sequencing. The developed system has a new search technique for quick identification of the optimal operation sequence by considering various feasible constrains. In year 2013, Liu et al. proposed an approach to solve some of the process planning problems. The authors had developed an algorithm to resolve the machining resources, manufacturing constraints and iterations, machining resource strategy, setup planning, and cost of machining process problems of process planning [97]. Later in the same year, a neural network method was utilized by [98] for the development of a learning agent of the multiagent-based system approach.

4. Genetic algorithm In year 2009, Salehi and Tavakkoli-Moghaddam presented an approach to divide the planning into preliminary and detailed planning stages and applied generic algorithms for process planning in both stages [99]. In year 2011, Taiyong proposed an algorithm based on the Pareto genetic algorithm for the cutting parameter selection and optimization to solve the decision-making problems of the cutting parameters in CAPP systems [100]. In the same year, [101] presented an approach for manufacturing analysis based on generic algorithm and fuzzy combination. In this approach, the authors utilize generic algorithms for result optimization. In the following year, Ouyang and Shen present a STEP-NC-oriented process planning optimization based on a hybrid genetic algorithm to solve the nonlinear process planning problem [102]. The hybrid algorithm was proposed by integrating a search of operation precedence graph with genetic algorithm. Fan and Wang presented multiobjective decision and optimization of process routing based on a genetic algorithm [103]. In this approach, the decision space of process routing based on process constraints was constructed with improved search efficiency of generic algorithm. In the same year, Liu and Qiao proposed a genetic algorithm for operation sequencing in process planning [104]. In this approach, an iterative generic algorithm based on constraint matrixes was developed for the optimization of manufacturing features and operations. The authors concluded that the iterative generic algorithm is proved to be superior on traditional simple generic algorithms in terms of shortening operation sequence time. In year 2013, an algorithm was developed to enable concurrent process planning and scheduling environment in manufacturing of tuned parts by [105]. The developed algorithm is based on GA, which performs strategic resource optimization for process planning development and also handles unplanned events. In the same year, Petrović et al. utilize GA for the development of optimization agent in a multiagent-based system for the integration of process planning and scheduling [98].

5. Fuzzy set theory/logic In year 2009, Agrawal et al. addressed the DPP problem in the e-manufacturing environment based on multi agent system [106]. In year 2010, an agent-based approach was proposed by [107]. In this approach, two functions were carried out simultaneously for the integration of process plan and scheduling. In year 2013, Moghaddam et al. addressed the operation sequencing problem of CAPP, and the authors have developed a system for the design of stamping die [108]. In the proposed system, the authors have sequenced embossing and cutting operations by applying fuzzy set theory method.

6. Agent based In year 2009, authors presented a multiagent system consisting of three autonomous agents: global manager, design, and optimization [106]. Later in year 2013, a multi agent-based methodology was proposed for the integration of process planning and scheduling [98]. The developed system was composed of six agents: job, machine, mobile, optimization, learning, and robot.

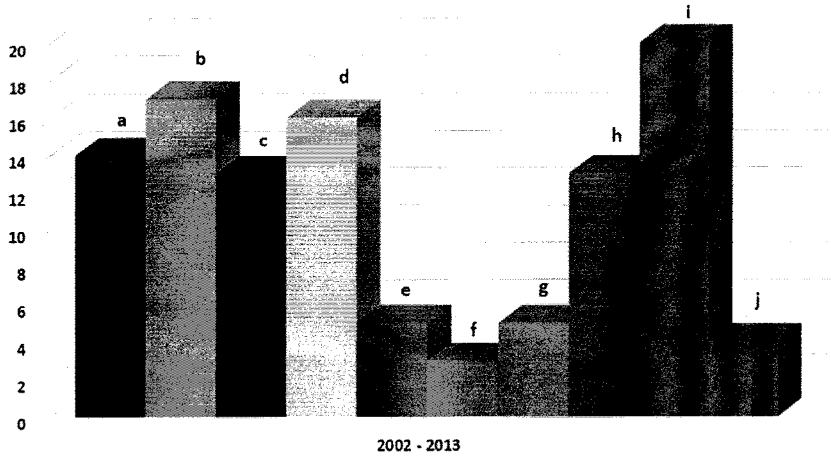

Fig. 6 Graphical representation of 2002–2013 survey: (*a*) feature based, (*b*) knowledge based, (*c*) neural networks, (*d*) genetic algorithm, (*e*) fuzzy set theory/logic, (*f*) Petri nets, (*g*) agent based, (*h*) Internet based, (*i*) STEP-compliant, and (*j*) functional block

7. *Internet based* In year 2008, Hu et al. presented XML-based implementation of manufacturing route sheet documents to solve the operation sequencing problem for web-based process planning. This method is an extension of the artificial immune system approach and inherits its characteristics from Maslow's hierarchy of needs theory related to psychology [109]. In the same year, Alvares et al. presented an integrated web-based CAD/CAPP/CAM system for the remote design and manufacture of feature-based cylindrical parts [110]. In this system, the information about features was manipulated through a relational database system. A GUI was implemented in Java and HTML. Later in year 2009, Agrawal et al. addressed the DPP problem in the e-manufacturing environment. In that article, the authors presented a multiagent system consisting of three autonomous agents: global manager, design, and optimization. These agents are capable of communicating to each other through XML [106]. In year 2013, an Internet-based CAD/CAPP/CAM prototype system for the remote manufacturing of mechanical components was developed [111]. In the same year, Wang developed a process planning and machine availability monitoring system based on the Internet [112].

8. *STEP compliant* In year 2008, Yifei et al. presented an automatic feature extraction and process planning system using the STEP application protocol (AP) 214 data format and also presented an approach to processing tolerance information by utilization of CAD system self-provided functions for macro recording and editing [113]. In the same year, Chung and Suh developed an optimal solution algorithm for nonlinear process planning based on STEP-NC [114]. The developed algorithm was tested on TurnSTEP system. Later in year 2009, the majority of work were carried out on STEP-compliant method of CAPP. Rameshbabu and Shunmugam proposed a hybrid approach that uses volume subtraction and face adjacency graph to recognize manufacturing features from 3D model data in

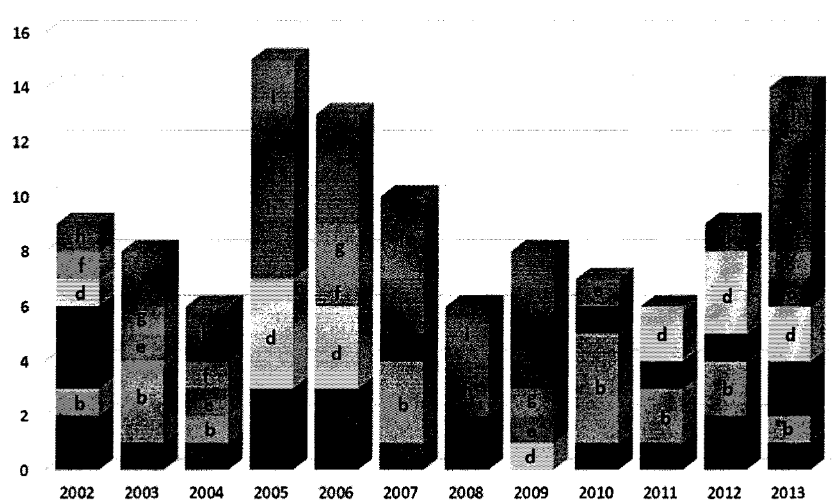

Fig. 7 Year vise Graphical representation of 2002–2013 survey: (*a*) feature based, (*b*) knowledge based, (*c*) neural networks, (*d*) genetic algorithm, (*e*) fuzzy set theory/logic, (*f*) Petri nets, (*g*) agent based, (*h*) Internet based, (*i*) STEP-compliant, and (*j*) functional block

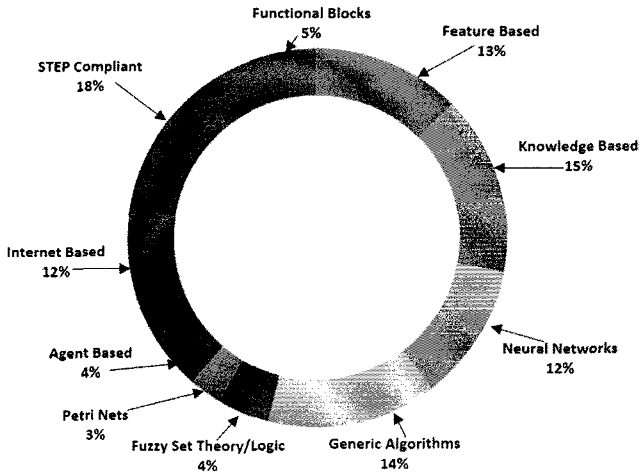

Fig. 8 Graphical representation of 2002–2012 survey

STEP AP203 format [115]. Yusof et al. developed a STEP-compliant system for the manufacturing of asymmetric parts on CNC turn/mill machine and also provided the structured view of a proposed system framework [116, 117]. Zhao et al. presented an intelligent STEP-compliant manufacturing system in which geometric description data described in AP203 or other formats are translated into machining features defined in AP224. The machining feature definitions are used as inputs to macro process planning applications and micro process planning for machining (AP238). Inspections (AP219) are then carried out for each of the application process [118]. In year 2012, Zhang et al. proposed a universal process comprehension interface (UPCI) to regenerate a high-level process plan from shop floor part programs and encapsulate the generate plan in STEP-compliant data structure [119]. In this approach, a novel method was proposed to capture the machining process knowledge from CNC part programs with UPCI and reuse it on a new manufacturing resource. In year 2013, a STEP-compliant approach was introduced for the solutions of the setup planning problems on machining centers [120]. That approach minimized the process planning time by automating some time-consuming steps. In the same year, a STEP-compliant CAD/CAPP/CAM system was introduced which utilizes the Internet as the main source of communication [111].

9. Functional block In year 2012, Wang et al. developed methodologies for distributed, adaptive, and dynamic process planning as well as machine monitoring and control for machining and assembly operations using event-driven functional blocks [121]. In 2013, Wang utilizes functional blocks in the development of Internet-web-based service-oriented system for process planning and monitoring. The proposed system was based on closed-loop information flow with real-time monitoring functions [112].

4 Discussion and conclusion

CAPP plays an important role in the CIM systems, and it eliminates the gap between CAD and CAM integration. Therefore, the need of CAPP is always there in CIM systems. In this article, an attempt is made to provide a survey carried out on CAPP based on features, knowledge, artificial neural networks, GA, fuzzy set theory and fuzzy logic, PN, agent, Internet, STEP-compliant method, and FB methods/technologies in the past and present.

From this survey, it has been found that most of the CAPP work carried out on machining manufacturing resolve the problem issues of operation, tool and machine selection and sequencing, feature extraction, reorganization, interpretation and representation, knowledge integration, representation, acquisition and sharing, setup planning, energy consumption, linear and nonlinear planning, integration of product and manufacturing data, intelligent tool path generation, optimization problems, intelligent decision making and sharing of knowledge, integration of process planning and scheduling, etc.

This paper present a survey of CAPP of the last 12 years based on ten established techniques. From this study, it is found that during the 2002–2007 period of time, there was a pretty balanced work on feature-based, knowledge-based, neural network, genetic algorithm, Internet-based, and STEP-compliant techniques. Whereas during the 2008–2013 period, knowledge-based and STEP-compliant technique utilization was increased to some extent as compared to the 2002–2007 period. However, the rest of the techniques are almost utilized at the same rate. Figure 6 shows the overall status of CAPP research based on stated methods, while Fig. 7. represents the present survey in terms of yearly divided pattern. For more clarification, Fig. 8 presents the complete method vise status of the present survey in terms of percentage. From this survey and graphical representations, it has been identified that the STEP-compliant, knowledge-based, generic algorithm, feature-based, neural network, and Internet-based methods had been used in the majority of CAPP works as compared to fuzzy set theory/logic, Petri nets, and agent-based methods. However, the functional block method is still new as compared to other works and considered to be a new direction for CAPP with STEP-compliant method.

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