NEW OPTIMIZATION FEATURE FOR THE DEVELOPED OPEN CNC CONTROLLER BASED ON ISO 6983 AND ISO 14649

NOOR HATEM OBAYES

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

UNIVERSITI TUN HUSSEIN ONN MALAYSIA

STATUS CONFIRMATION FOR THESIS
DOCTOR OF PHILOSOPHY

NEW OPTIMIZATION FEATURE FOR THE DEVELOPED OPEN CNC CONTROLLER BASED ON ISO 6983 AND ISO 14649
ACADEMIC SESSION: 2020/2021

I, **NOOR HATEM OBAYES,** agree to allow Thesis to be kept at the Library under the following terms:

1. This Thesis is the property of the Universiti Tun Hussein Onn Malaysia.
2. The library has the right to make copies for educational purposes only.
3. The library is allowed to make copies of this Thesis for educational exchange between higher educational institutions.
4. The library is allowed to make available full text access of the digital copy via the internet by Universiti Tun Hussein Onn Malaysia in downloadable format provided that the Thesis is not subject to an embargo. Should an embargo be in place, the digital copy will only be made available as set out above once the embargo has expired.
5. ** Please Mark (√)

☐ CONFIDENTIAL (Contains information of high security or of great importance to Malaysia as STIPULATED under the OFFICIAL SECRET ACT 1972) *Title and Abstract only*

☐ RESTRICTED (Contains restricted information as determined by the organization/institution where research was conducted)- *Title, Abstract and Introduction only*

☐ EMBARGO ______ until ______
(date) (date)

☑ √ FREE ACCESS

Approved by,

PROF DR YUSRI BIN YUSOF
Jabatan Kejuruteraan Pembuatan dan Industri
Fakulti Kejuruteraan Mekanikal dan Pembuatan
Universiti Tun Hussein Onn Malaysia

(WRITER'S SIGNATURE)

(Prof Dr. Yusri bin Yusof)

Permanent Address:

14 March 2021 House
NO.16, Dor- Alnaft
Basra, Iraq

Date : 24 November 2021

Date: 24 November 2021

NOTE: ** If this Thesis is classified as CONFIDENTIAL or RESTRICTED, please attach the letter from the relevant authority/organization stating reasons and duration for such classification.

This thesis has been examined on date 09 May 2021
and is sufficient in fulfilling the scope and quality for the purpose of awarding the Degree of Doctor of Philosophy.

Chairperson:

Prof. Ts. Dr. Badrul bin Omar
Faculty of Mechanical and Manufacturing Engineering
Tun Hussein Onn Universiti of Malaysia

Assistant Chairperson:

Assoc. Prof. Ts. Dr. Mohd Rasidi bin Ibrahim
Faculty of Mechanical and Manufacturing Engineering
Tun Hussein Onn Universiti of Malaysia

Examiners:

Prof. Ir. Dr. Puvanasvaran A/L Perumal
Faculty of Manufacturing Engineering
Universiti Teknikal Malaysia Melaka

Assoc. Prof. Dr. Sh Salleh bin Sh Ahmad
Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

NEW OPTIMIZATION FEATURE FOR THE DEVELOPED OPEN CNC CONTROLLER BASED ON ISO 6983 AND ISO 14649

NOOR HATEM OBAYES

A thesis submitted in
fulfilment of the requirements for the award of the degree of
Doctor of Philosophy

Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

NOVEMBER 2021

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged

Student : ……………………………………………………………

NOOR HATEM OBAYES

Date 24 NOVEMBER 2021

PROF. DR. YUSRI BIN YUSOF
Jabatan Kejuruteraan Pembuatan dan Industri
Fakulti Kejuruteraan Mekanikal dan Pembuatan
Tun Hussein Onn Malaysia

Supervisor : ……………………………………………………………

Professor. Dr. Yusri Bin Yusof

Co Supervisor : ……………………………………………………………

Dr. Aini Zuhra Abdul.Kadir

I would like to dedicate this thesis to

Almighty "Allah"

(Who gave me strength, knowledge, patience and wisdom)

My "Family"

(To my Father, who that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time)

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Prof. Dr. Yusri Bin Yusof, for encouragement, guidance, critics and friendship. I am also very thankful to my co-supervisors Dr. Aini Zuhra A.Kadir for and Dr. Kamran Latif for their guidance, advices and motivation. Without their continued support and interest, this thesis would not have been the same as presented here.

I would like to acknowledge the Malaysian Ministry of Higher Education (MOHE) and Universiti Tun Hussein Onn Malaysia research for providing the financial support and facilities for this research under Grant G011 PRGS - SUSTAINABLE PLATFORM CONTROLLER FOR STEP-COMPLIANT OPEN CNC SYSTEM FRGS.

Finally, I must express my gratitude to my husband Mr. Mohammed Mustafa and my kids Yousif and Laya, for their love, support and encouragement throughout my study. My heartfelt thanks are extended to my parents Hatem Obayes and Mada Kadhim, my sister and brothers, for their everlasting love and inspiration in my education.

ABSTRACT

The computer numerical control (CNC) system controls the movement of the machine tool automatically. The development of open CNC systems is one of the most popular topics in the last three decades due to the system remains exclusive all the time. PC-based open architecture controller (OAC) has been constructed to make adding, upgrading, swapping components easy, and broke the specific vendor chain. However, this system has some limitations, such as tool path optimization. This research aims to minimize tool path airtime during machining of input ISO codes via an ant colony optimization algorithm. A new optimized system was developed based on open architecture control (OAC) technology and interpreted STEP-NC (Standard for the Exchange of Product Model Data) programming approaches. The developed system can provide a new feature for both ISO data interface models (ISO 14649 and ISO 6983) interpretation, along with its graphical verification, execution and report generation functionalities into the CNC core. The system is composed of ISO data interface models interpretation, tool path optimization, 3D simulation, and automatic document generation modules. The functionalities of the system were validated through the manufacturing of case study components. Corresponding experimental results verified the proposed technique with satisfactory outcomes. Milling and drilling with G-code and drilling with STEP-NC were evaluated on tool path optimization. The optimization process that produced the shortest tool path was observed at different solved examples. The improvement percent for G-code was 10.41% and 16.58 % for milling and drilling, respectively. While improvement percent for STEP-NC was 16.98% for drilling. The results revealed that the optimization feature has a significant effect on the tool path.

ABSTRAK

Sistem kawalan berangka komputer (CNC) mengawal pergerakan mata alat secara automatik. Pembangunan sistem CNC terbuka adalah satu topik yang paling popular tiga dekad kebelakangan ini kerana sistem ini tetap eksklusif sehingga kini. Pengawal senibina terbuka berasaskan komputer (OAC) dibina bagi membolehkan penambahbaikan, menaik taraf, pertukaran komponen secara mudah, dan memutuskan rantai yang spasifik pembekal. Walau bagaimanapun, sistem ini mempunyai beberapa limitasi, seperti pengoptimuman laluan mata alat. Penyelidikan ini bertujuan untuk meminimumkan laluan mata alat semasa kod input ISO pemesinan melalui algoritma pengoptimuman koloni semut. Sistem pengoptimuman baru dikembangkan berdasarkan teknologi kawalan senibina terbuka (OAC) dan menafsirkan pendekatan pengaturcaraan STEP-NC (Standard bagi Pertukaran Data Model Produk). Sistem yang dibangunkan dapat memberikan ciri baru untuk kedua-dua model antaramuka data ISO (ISO 14649 dan ISO 6983) interpretasi, bersama dengan pengesahan grafik, pelaksanaan dan fungsi pembangunan laporan ke dalam teras CNC. Sistem ini terdiri daripada interpretasi model antaramuka data ISO, pengoptimuman laluan mata alat, simulasi 3D, dan modul pembangunan dokumen secara automatik. Fungsi sistem disahkan melalui pemesinan komponen melalui kajian kes. Hasil eksperimen mengesahkan teknik yang dicadangkan memuaskan berdasarkan keputusan eksperimen yang diperolehi. Pengisaran dan penggerudian dengan kod-G dan penggerudian dengan STEP-NC dinilai pada pengoptimuman laluan mata alat. Proses pengoptimuman yang menghasilkan laluan mata alat terpendek diperhatikan melalui contoh yang berbeza. Peratus peningkatan untuk kod-G masing-masing adalah 10.41% dan 16.58% untuk pengisaran dan penggerudian. Sementara peratus peningkatan untuk STEP-NC adalah 16.98% untuk penggerudian. Hasil kajian menunjukkan bahawa ciri pengoptimuman mempunyai pengaruh yang signifikan pada laluan mata alat.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACO.	-	Ant Colony Optimization
AIM.	-	Application Interpreted Model
ANN.	-	Artificial Neural Network
ARM.	-	Application Reference Model
CAD.	-	Computer Aided Design
CAM.	-	Computer Aided Manufacturing
CAPP.	-	Computer-Aided Process Planning
CNC.	-	Computer Numerical Control
CTTP.	-	Cutting Tool Travel Path
FMS.	-	Flexible Manufacturing System
GA.	-	Genetic Algorithm
HIPP.	-	High-level Inspection Planning
HOOM.	-	Hierarchical Object-Oriented Model
IMS.	-	Intelligent Manufacturing System
ISO.	-	International Standards Organization
LabVIEW.	-	Laboratory Virtual Instrument Engineering Workbench
OAC.	-	Open Architecture Controller
OACC.	-	Open Architecture CNC Controller
OCC.	-	Open CNC Controller
PLC.	-	Programmable Logic Control
PSO.	-	Particle Swarm Optimization
RAMP.	-	Rapid Acquisition of Manufactured Parts
SCSTO.	-	STEP Compliant System for Turning Operations
SMS.	-	STEP Manufacturing Suite
STEP-NC.	-	Standard for The Exchange of Product Data-Compliant Numerical Control
TSP.	-	Travel Salesman Problem
UOCC.	-	UTHM Open CNC Controller
VGM.	-	Virtual Gears Model

LIST OF SYMBOLS

D	-	Distance
i	-	Current Ciry
j	-	Next City
k	-	Ant Number
L	-	Tour Length
p	-	Probability
α	-	Trail of Pheromones
β	-	Heuristic Data
η	-	Heuristic Value
τ	-	Pheromone Evaporation
ρ	-	Rate of Pheromone

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter presents computer numerical control (CNC) concepts by describing their background development. Then, the problem statement focusing on research gaps will be put forth, followed by the research objectives and scopes. Finally, the chapter examines the importance of the research and thesis organization.

1.2 Background of Research

Computer numerical control (CNC) is an advanced manufacturing technology that is widely implemented in different machine tools to ensure precise and efficient machining and easy operation. Moreover, CNC has become a central part of the modern manufacturing system [1]. The CNC system automatically controls machine tool's movements and can thus be regarded as the 'brain' of a machine tool [2]. After 60 years of development, modern CNC systems have become powerful, reliable, and secure, particularly concerning machining precision and speed. CNC machines are today used in various industries involving diverse controllers and abilities concerning different applications including drilling, turning, packaging, milling, robotic cutting, and tube welding [3]. Further, the CNC has several parts with the controller at its core consisting of two parts: software and hardware. While the hardware part includes different components such as motor drives and motion control, the software part includes Programmable Logic Control (PLC) as well as an interpreter to execute the machine hardware. As noted by Ertell [4], the CNC controller's interpreter receives the International Standards Organization (ISO) data interface model instructions that it translates into internal commands to move tools as well as execute auxiliary functions in a CNC system.

The ISO 6983 data interface model, previously called G & M codes, is implemented in CNC machines for their operations. CAM systems generate ISO 6983 data interface model program codes using CAD information. In this model, information is defined by numerical codes (G, T, M, F, S, etc.) that suggest a machine's movement and an axis to the controlle [5]. Further, when developing flexible CNC systems, the ISO 6983 data interface model depicted several limitations such as being unable to seamlessly integrate (computer-aided design and computer-aided manufacturing) CAD, CAM, and CNC; delivering limited information to CNC; and transferring one-way information from CAD/CAM to CNC, which can be significant problems and involve last-minute changes that cannot be handled at the shop floor [6]. Besides, various manufacturers also included additional commands into G codes to enable more facilities into the systems even though these extensions were not included in ISO 6983. Such additions led to the part programs creating interchangeability problems among various machines, making the G code more machine-specific [7].

Moreover, ISO is creating a high- level NC data model, known as Standard for the Exchange of Product Data-Compliant Numerical Control (STEP-NC), for addressing problems caused by the G&M codes [8]. Apart from the G&M codes, this data model implements the object-oriented 'Working steps' associated with advanced machining features and process parameters for defining the machining processes. Thus, using the STEP-NC can help with transitioning from the task-level data to the method-level data while maintaining machining information including feature, geometry, machine tool, tolerance, and cutters information [9].

CNC system is also always exclusive. This exclusivity does not concern a CNC system's software or hardware that is standardized. That is, a CNC software includes vendor-specific CNC domain logic regarding a specific type of machines such as traditional machining type (which includes turning, electrical discharge machining, and milling, among others), additive machining [10], as well as the latest hybrid additive and subtractive machining [11]. Therefore, CNC software can be regarded as proprietary software with high value-added products that tend to go over 30% of an industrial machine tool's price [12]. However, users do not have permission to copy, distribute, or change its functionality for various production orders.

Over the past few years, the machine device's traditional controller has been increasingly undermined by the PC-based open CNC system that is not dependent on the CNC merchant and can execute client-characterized application programs [13].

Moreover, a personal computer can be considered hardware that functions using real-time operating system software, thus decreasing costs while increasing the control system's flexibility. Developing an open architecture platform can make the CNC application framework more flexible as well as modular. It will also allow the system users to customize the designed function according to the demand concerning different applications. Thus, changing the programming or coding can make the software reusable. This enhances the overall system's performance as it simply upgrades the hardware system [2]. The past 30 years have been increasingly focused on the subject of developing open CNC systems. There have been several open CNC prototypes including Open System Architecture for Control within Automation Systems (OSACA) [14], Open Modular Architecture Controller (OMAC) [15], Linux NC [16], Twin CAT [17], and Open System Environment Consortium (OSEC) [18].

Besides the CNC system, 70% of the time in a manufacturing process is devoted to tool indexing as well as tool movement [19]. Through tool path optimization, the total processing cost involving tooling, non-productive tool traveling, machining, and tool switching costs is also minimized [20]. Further, researchers have optimized the CNC milling tool path's sequencing by utilizing particular algorithms such as Satin Bowerbird Optimizer (SBO) [21], ant colony optimization (ACO) [22], particle swarm optimization (PSO) and the genetic algorithm (GA) [23]. There are also other studies that have reduced the drilling tool path by implementing integrated genetic and simulated annealing (IGSA) [19], colony optimization [24] algorithms, and Lin-Kernighan Heuristic (LKH) [25]. Considering the fact that the new, cheaper, and more compact CNC system offers more advantages than the closed source systems, developing an open architecture controller as per the optimization algorithms for simultaneously and effectively addressing problems of energy, exclusivity, and time wastage are necessary.

1.3 Problem Statement

Computer numerical control (CNC) system is the "brain" of a machine tool as it controls the movement of the machine tool automatically. In progression towards CNC development, the current ISO 6983 contains low-level information [26]. To overcome these issues, a new ISO data interface model (ISO 14649) was introduced in 1999 [6]. While ISO 6983 and ISO 14649 implementation, the problem of being vendor dependent in commercial CNC systems was found. In order to overcome that issue, the researchers used software development to produce open CNC systems [2]. Basically, the open CNC systems used limited features such as interpretation, and simulation of the input code data. As technology grows, there are demands and new prospects to empower current CNC with more advanced features. As noted by Oysu and Bingul [27], the tool-path optimization problem is generally regarded as the NP-hard combinatorial optimization problem. Therefore, using optimization features to minimize non-machining time, efficient toolpath selection can be implemented [23]. Previous studies have also reported the open CNC system without optimization features [2, 28-31].

The open CNC systems tend to be utilized for extracting the points from ISO codes so that they can be applied in an open computer control (OCC) machine. The existed open CNC systems are closed source by developers. However, there are no open CNC systems available with open source that can be used to extract data from input code and add new features [32]. The developed optimization systems that are used with open CNC controllers deal with more than one system. Generally, it used one system for interpreting the input code and the other for optimizing the extracted data. Because the optimization feature is not used directly on the same system of interpretation but instead needs an extra step.

The researchers have focused on different methods of optimizing tool path including genetic algorithm [23] and colony optimization (ACO) [22] in terms of milling. The others researchers have examined it in terms of drilling by implementing ant colony optimization [24] and a genetic algorithm [33], although they manually input data to the optimization system. It has been shown that the ACO algorithm offers better results in terms of optimality and robustness [34] compare with other algorithms. However, the existed open CNC systems have some limitations such as tool path optimization, simulation and inspection.

1.4 Objectives of the Research

Considering the problem statement stated above, three major objectives were established:

i. To develop an interpretation open CNC system based on complete G code and STEP-NC data structure.
ii. To optimize the tool travel path of ISO code through combine open CNC system and ACO algorithm.
iii. To validate the developed open CNC system through case study components.

1.5 Scopes of the Research

To achieve the objective, the study was conducted within the following scopes:

i. The developed open CNC system was designed for ISO 6983 and ISO 14649 data that considering a 3-axis CNC milling machine (PROLIGHT 1000 Milling CNC).
ii. The optimization of the extracted tool path points involved implementing an ant colony optimization algorithm (ACO).
iii. The present study also considered example cases of milling and drilling processes in terms of ISO 6983 and considered an example case of drilling process regarding ISO14649.
iv. A three-dimensional (3D) simulator used to conduct verifications graphically as well as to automatically document generation systems concerning optimized data is included in this system.
v. The experimental validation only involves verifying the performance of interpreters, optimization, along with modern features and does not address problems concerning surface roughness or accuracy.

1.6 Significance of the Research

This study aims to amplify an existing CNC controller to optimize the both ISO (14649 and 6983) data interface models' tool path and to conduct the milling and drilling machining processes. Moreover, it aims to aid concerning optimization, interpretation, automatic document generations, simulation, as well as tool path generation. Such functionalities not only offer more flexibility, interoperability, portability and adaptability but also provide more open CNC environment on one platform (all-in-one).

1.7 Thesis Organization

This thesis includes six chapters. The first chapter presents the fundamentals of CNC including the background, research problem statement, objectives, and the scopes of the research. Chapter 2 briefly introduces and examines the concerned technologies. Chapter 3 describes the methodology that was used to address the research gaps. Chapter 4 illustrates the system's development based on research findings as well as adopted methodology. Chapter 5 presents the experimental validation concerning the developed system. Finally, Chapter 6 presents the conclusions along with suggestions for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the fundamentals of CAD/Computer-Aided Process Planning (CAPP)/CAM, CNC, CNC controller technologies, ACO algorithm, G codes, and STEP-NC. Moreover, it examines the entire process of creating the next generation CNC systems. This chapter also explores the diverse methods presented in numerous previous studies as well as present the latest machines ranging from NC to the modern CNCs, focusing on the earlier techniques, approaches, and methods used in this development.

2.2 Computer Numerical Control of machine tools

CNC refers to the control system, including a computer. It was in the 1970s that the first CNC machine was constructed, and it involved computers replacing the earlier NC systems' electronic hardware as well as punch cards [35]. CNC system implements microcomputers or minicomputers for creating, filtering, and then performing the sequential control depicting the end effectors' behavior, and it is used frequently for applications such as milling, turning, metal cutting, welding, cutting robots, and sheet metal formatting [3].

As the modem systems continued to develop, in the 1970s and 1980s, it became necessary to manufacture a wider range of parts, which further needed the Flexible Manufacturing System (FMS). The CNC machine is thus crucial in ensuring a flexible environment to manufacture systems as these machines can be reprogrammed to produce various complex parts on a large scale [36]. CAM and CAD systems were utilized for creating the CNC program parts as sophisticated programs were necessary for producing such parts [37, 38].

The CAD system refers to geometric primitives such as lines, curves, and points were used for defining a design's geometry. It was only the Two-Dimensional (2D) drawings that needed the first CAD systems. Further, the solid modeling methods defined the 3D CAD systems in the 1980s [39]. The existing files generated by CAD systems are stored using proprietary fonts, with these files being imported and exported by all systems considering defined standards. With the CNC systems' further development, an increasing number of studies began focusing on CAM techniques. Computer systems were utilized in this technology for planning, managing, and controlling the manufacturing processes. Also, the CAM system included cutting methods, tools, as well as operation sequences information in the CAD file. CAM and CAD integrated systems were launched in the 1970s, with the turnkey CAD/CAM system gaining more popularity in the 1980s. An integrated CAD/CAM system intended to reduce the distance between designing and manufacturing. To this end, CAPP systems are necessary [40].

The specifications of the CAD design are translated by the CAPP system into manufacturing information such as raw material selection, product geometry, equipment, and machine tool selection, as well as machining operation conditions and manufacturing operation and sequencing [41]. This stage involves the information being reserved in CAM file, and this CAM file is then used to develop the machine tool's manufacturing instructions by the CAM system post-processor [42]. Moreover, the post-processor's output is an NC file that is formed as per the particular language that translates the drawing of the job information to computer controlled machine [43]. This language was earlier called Automatically Programmed Tool (APT) [44]. ISO later implemented APT in 1982 as an international standard ISO 6983, which was commonly referred to as G & M codes and formally as RS-274D [45].

2.3 Development progress of G-M Code

Over the last 60 years, there has been significant development in machine tools, from basic machines that had controllers without memory and were operated with punching tape to the current improved CNC multi-processor workstations [46]. Such workstations can perform various functions such as versatile control, multi-axis control, mistaken payments as well as multi-process produce including pounding machine and joined plant/turn/laser. Such capacities have resulted in responsible programming becoming increasingly complicated while also making it necessary in the productive age to develop disconnected programming devices in terms of CAD/CAM that can verify NC code. Although machines and tools have fundamentally changed, there has been no significant change in the programming dialect that has G-code. Moreover, the "how to make" refers to instructions concerning which path to move to and where and how. As Figure 2.1 presents, the ISO 6983 CNC coding is developed as per five specifications [47].

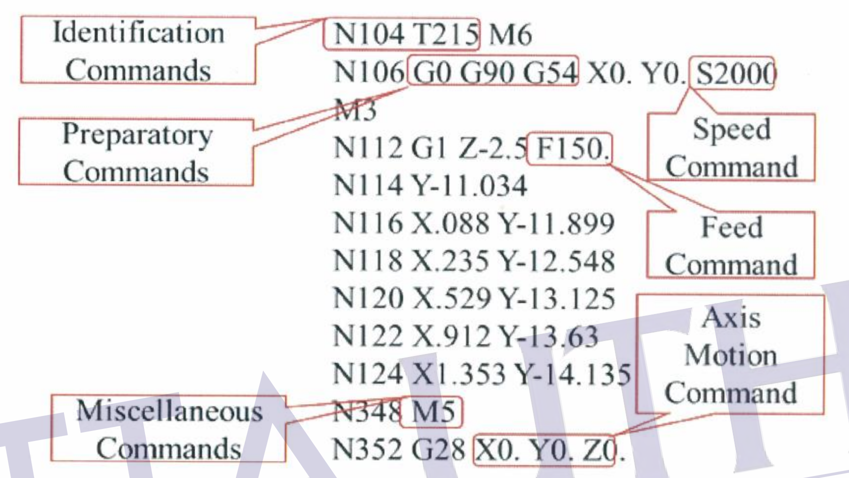

Figure 2.1: ISO 6983 CNC coding [48]

The first specification is "Preparatory Functions" that are commands indicated by "G," suggesting the controller concerning the types of motions such as fixed cycle, rapid positioning, and linear or circular feed. Thus far, from GO to G99, approximately hundred commands are being used. The second specification is "Miscellaneous Commands" that commands indicated by "M". These are auxiliary commands or action codes that are primarily implemented for machine functions. The third specification is "Axis Motion Commands" that are commands that define the incremental or absolute positions concerning machine tool axis, suggested by X, Y, Z, A, B, C. The fourth specification is "Feed and Speed Commands" that are commands that define the spindle speed (S) and feed rate (F). Finally, the fifth specification is "Identification Commands" that are commands that define the cutting tool selection function (T) and line number (N).

G-code is a form of CNC programming and refers to the language that is implemented for controlling CNC machines. CNC programmers often use G-code for programming apart from CAM programming. G-code is quite commonly executed in a typical machine's CNC controller. Presently, post-processors are used to develop G-code naturally in the majority of computer-aided design/CAM programming frameworks. Further, G-code is committed to enhancing the present manufacturing technology. The program form that G-code defines typically refers to ISO 6983, which specifies the control program's format that is used for the machine's numerical controls (NC). On the other hand, ISO 6983 is also useful in various geometric designations as well as to communicate with machines [5].

Although G-codes are used in all CNC machines for controlling their operations, there continue to be several difficulties that hinder CNC technology's development. There are three reasons for which ISO 6983 restricts program portability. To start with, the language concentrates on programming the tool focus way as for machine axes, instead of the machining procedure regarding the part. Second reason is that through the standard characterizes the program descriptions' language, it keeps the semantics ambiguous. Third reason is sellers tend to use expansions to add to the language, and these expansions are not included in ISO 6983, with the postprocessor translating the low-level information into NC code. Moreover, the information flowing to CNC from CAD is unidirectional and does not provide an explanation concerning data manufacturing at the CNC level [49].

Today, although certain controllers continue to use punch tape for information storage, several tools such as networking and USB flash drives have replaced the NC controller's punch card. Data transport is crucial for ensuring the likeability of the configuration of all parts and that people can peruse them. Nevertheless, both G-code and M-code have obstructed the manufacturing process as well as the development of a CNC framework [50]. There are three types of motions in G-code: G01, G02, and G03. While G01 depicts linear motions, G02 and G03 depict circular motions. Moreover, as G-code does not sustain spline data, it cannot control five or more axis milling. Although the fact that CNC framework is becoming increasingly refined and developed cannot be questioned, this framework also has a disadvantage as it uses the old codes, the G-code and M-code, for information exchange.

The Electronics Industry Association (EIA) enhanced the G and M based on the ANSI standard [51] code during the mid-1960s. It should be noted that the ISO 6983 can be considered as a low-level international standard that refers to switching commands and an axis movement control. Several CNC manufacturers have attempted to address this problem by merging the existing ISO 2983 standards with their own standards if high-level command code. In addition, this design enabled the CNC machine manufacturer to create a programming language that helped prevent interoperability between manufacture and design [52]. It should be noted that GM code programs are important as they combine the operator experience and micro-process plan [53], which is why G code working environment is included in this study.

2.4 STEP-NC Development

When discussing information models that can improve CAD/CAM information sharing, it is important to examine STEP-NC. To ensure that the data flow between CNC and CAM was seamless, a new standard called ISO 14649, commonly referred to as STEP-Compliant Numerical Control or STEP-NC, was introduced. This standard enabled applications' data integration to be seamless from design to manufacturing [54]. At present, ISO focuses on developing the STEP manufacturing environment that encompasses STEP in, STEP throughout, as well as STEP out [53]. STEP-NC intends to rectify ISO 6983's limitations through machining processes and not tool motion. For this, object-oriented and feature-oriented concepts concerning working steps are implemented that create a seamless connection in CAx so that CNC becomes more portable, open, adoptable, interoperable, intelligent, and flexible. In particular, STEP-NC uses ISO 10303's existing data models to create seamless and smooth information exchange regarding CAx. Moreover, there are numerous information sets included in ISO 14649 such as "How-to-make" (process plan) and "What-to-make" (geometry).

2.4.1 Versions of STEP-NC

At present, two versions of STEP-NC, which are ISO 10303-238 and ISO 14649, are being worked on by the Technical Committee's two sub- committees. It can be said that ISO 10303-238 and ISO 14649 are the STEP-NC standard's two distinct implementation methods. There is a high possibility that the ISO 14649 standard will be implemented when the shop floor provides precise information to the CAM systems. On the other hand, STEP AP 238, which is included in the STE standard, is better suited for a thorough integration of design and manufacturing. Moreover, STEP-

NC is able to offer CNC machine tools direct input involving product information including features, geometry, tool path, and machining steps [42]. Presently, G-codes have to be used for programming CNC machines, and thus, they can only explain the precise tool movements and not provide information concerning the processed part. Unlike G-codes, STEP-NC does not explain to the machine how to perform a task but simply tells it what to do.

Figure 2.2 illustrates the information that STEP-NC presented in EXPRESS-G. That is, STEP-NC utilized the working steps concepts that depicted a series of material removals, locations, as well as related process parameters to define the machining processes. It should be noted that every working step is connected to an operation as well as a machining feature. It is assumed that CNC controllers will translate the tool movements and working steps to machine parts and axis motions, respectively [55]. This type of STEP-NC includes a CAM software being able to completely access all production data [56]. Further, there are six parts included in ISO 14649:

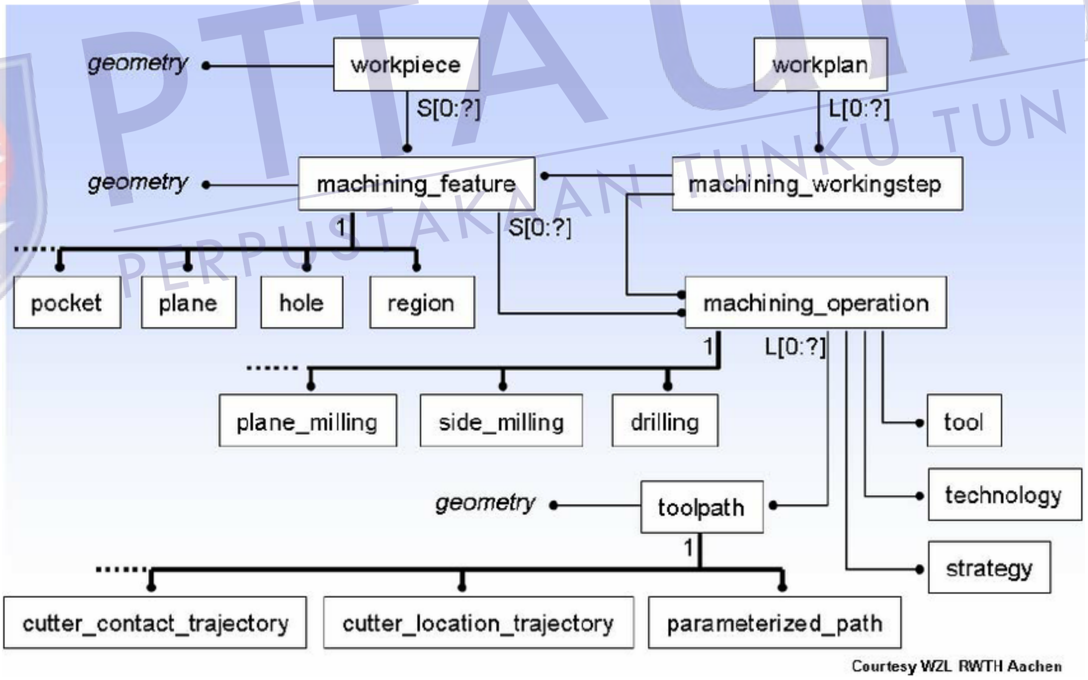

Figure 2.2: Information diagram of STEP-NC [57]

ISO 14649-1 that presents an overview of CNCs' data model and describes its benefits as well as fundamental principles as per the product data concepts [58]; ISO 14649-10 that outlines a set of essential capabilities concerning the machined parts' process planning; ISO 14649-11 that identifies the milling machine's process planning abilities; ISO 14649-12 that presents the turning machine's process planning capabilities; ISO 14649-111 that presents tools for milling; and ISO 14649-121 that presents tools for turning.

Moreover, these parts are organized according to their hierarchy and utilized considering their relevant forms. For example, in terms of the milling machine part, 10 refers to the overall process plan data while part 11 outlines the milling's process plans and part 111 introduces tools data considering milling. Figure 2.3 illustrates other machining processes' chain including turning, grinding, and drilling. This model, however, does not include the complete designing data, thus making it difficult to combine CNC and CAD [42].

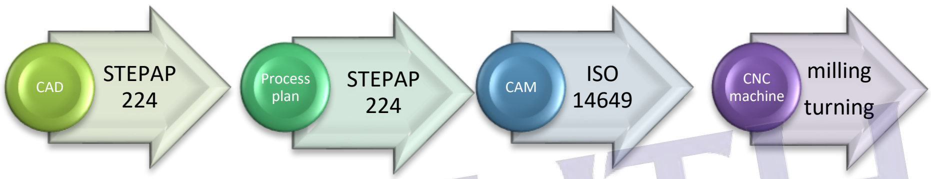

Figure 2.3: ISO 14649 design manufacturing life cycle

Table 2.1 presents the first Reference Model ISO 14649 along with Interpreted Model (ISO 10303), with the AIM and ARM models considered as the STEP-NC models' two distinct execution frameworks. However, it is also appropriate to use ISO 14649 standard when the shop floor provides precise information to CAM frameworks, while STEP AP-238, included in the STEP standard, is more suited for assembling joining and a complete outline. Moreover, while the AIM is entirely agreeable to with STEP, the ARM included data that is assumed will program a CNC machine [59, 60].

Table 2.1 Comparisons between 14649 and 10303 model

Comparison criteria	**ISO 14649 model**	**ISO 10303-model**
File size	10 times smaller than AIM	10 times bigger than ARM
Programming	Simple	More complicated
Human legible	Hard	Nearly impossible
Data compatibility	Initial design information is desolate	Initial design information is saved

2.4.2 Benefits of STEP-NC

STEP-NC refers to a feature-oriented as well as an object-oriented data model that offers unique possibilities for supporting standardized and high-level information from the design to the manufacturing process [61]. STEP-NC's development and use can aid the manufacturing field in several aspects, some of which are explored in this section, as highlighted in [7, 42, 62-66]. In the present CAx, it is possible for the information to get lost in the process as the CAD to CAM data transfer may be incomplete. In such cases, the geometry fixes are done in CAM and not communicated with CAD, thus resulting in the data flow to the post to be restricted. Using diverse standards is also a reason for information loss, as depicted in Figure 2.4. STEPNC resolves such problems by offering a structured and complete data model that is connected to technical and geometrical information.

Further, it puts forth one standard for different systems' data integration, and thus, there is no information lost from the design to the manufacturing cycle, as illustrated in Figure 2.5. The information flow in the present systems is uni-directional. As Figure 2.4 shows, CAx does not have any information feedback.

Moreover, it is almost impossible to make any exigency changes considering the present CAx's uni-directional data flow. In addition, as the STEP-NC model structure, as well as standard feature description, coincides with ISO 10303, it is able to maintain CAx's bi-directional information, as presented in Figure 2.5.

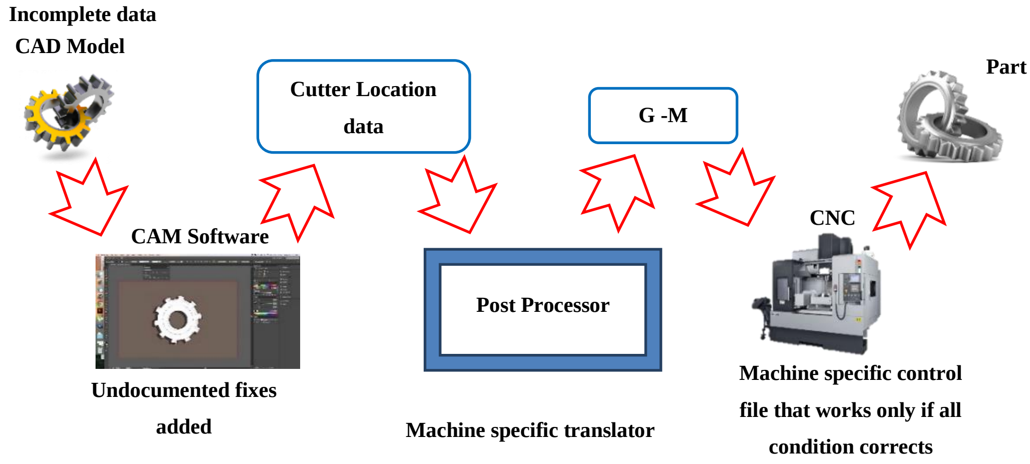

Figure 2.4: Current CAx data flow

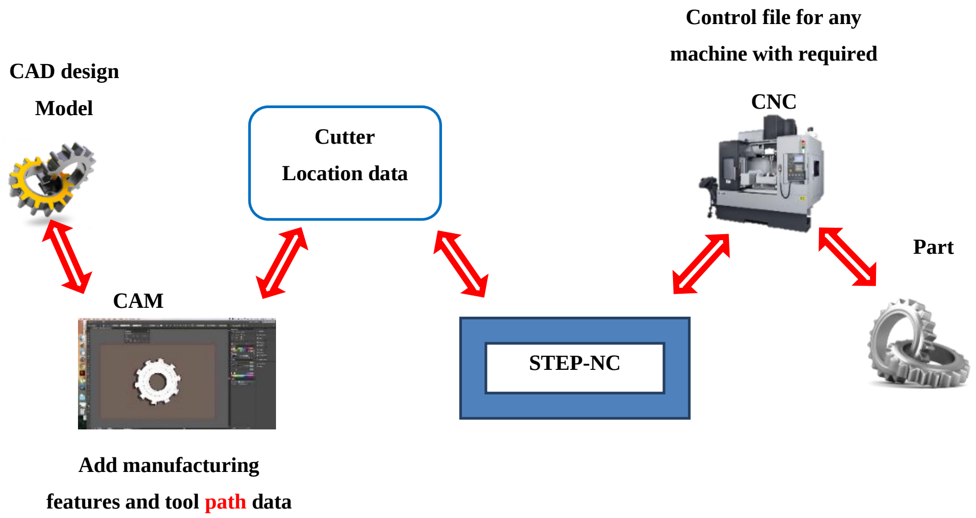

Figure 2.5: STEP-NC CAx data flow

The present CNC machines have been working as per ISO 6983 data interface model that has low level information, according to "how-to-make" instructions. STEP-NC standard, on the other hand, includes high level information as per "how-to-make" and "what-to-make" instructions that can aid facilities such as simulation, optimization, and inspection in CNC controller. It can thus be said that STEP-NC's data elements can sufficiently describe NC data that is task oriented. Moreover, as systems today implement post-processor to develop ISO 6983 standard, ISO 6983 become more dependent on vendor and machine specific. Thus, generated code has to be modified before it used on various systems. STEP-NC standard, however, consists of a neutral format that does not include machine specifications and vendor dependency. It thus removes the necessity of post-processor while decreasing the CAx chain, thus saving time. Moreover, it is possible to execute the STEP-NC file on any machine with the necessary tooling, as the STEP-NC file is not machine specific. There are also other advantages to using STEP-NC compared to ISO 6983, as follows:

i. The STEP-NC data model can be applied to other technologies, and CCs can be used to scale it for matching the capabilities of NC systems' particular CAM Shop Floor Programming (SFP).
ii. STEP-NC offers adequate information to aid intelligent optimization facility, thus decreasing machining time concerning small- and medium-sized jobs.

iii. As the STEP-NC file includes all information necessary for developing a job, manufacturing operations can be altered to enhance efficiency in production.

iv. As STEP-NC is independent of vendor and specifies fixtures' safety areas as included in the setup, it ensures the machine tools' complete safety as well as adaptability.

v. The data in STEP-NC is self-documented, and thus, there can be a considerable decrease in the number of drawings that CAD sends to CAM.

vi. CNC or CAM systems can be used to provide documentation for presenting the state of the part prior to and following every working step.

vii. STEP-NC uses XML (ISO 14649-28) information transfer for ensuring e-manufacturing or web-based manufacturing.

viii. As STEP-NC enables 3D geometry's changes to occur instantaneously directly on control, it will diminish the necessity of paper documents.

ix. The data required for developing the part is stored in one file.

There are several other advantages of STEP-NC compared to ISO 6983, as presented in Table 2.2.

Table 2.2 Comparison between STEP-NC and ISO 6983

G -code	**STEP-NC**
Hard NC programs for easy geometry Manufacturing	High-level Programming language
Program Length too big and limited information	Smaller than ISO 6983 and contain more information
Limited Control of Program with low speed	Easily Control of Module with high speed
Unidirectional data flow of Information	Bidirectional data flow of Information
Manufacturing features its modern	Manufacturing features its primitive
Limited optimization support	High optimization support

2.4.3 Structure of STEP-NC

The STEP-NC file includes high-level information that is object-oriented regarding manufacturing features' programming. Moreover, the STEP-NC data model's structure is classified into two sections: HEADER and DATA [42, 67, 68]. The HEADER section begins and ends with the special token HEADER and ENDSEC toke, respectively, and consists of general information including author, filename, organization, and date. The DATA section is regarded as STEP-NC's critical section as it is the STEP-NC data model's major section. It starts and ends with the DATA token and ENDSEC token, respectively and includes all information about geometries and manufacturing tasks.

In addition, this section's contents are classified into three sections that are workplan or executables, geometry description, and technology description. Every STEP-NC program's DATA section includes a PROJECT entity that suggests the NC functions' starting point as well as the workpiece on which operations are going to be conducted and the workplan that should be executed. There are also three types of executables including NC functions, program structures, and working steps. In the workplan, the working steps are crucial executables that specify manufacturing aspects of two-and-a-half-dimensional (2.5D) as well as 3D regions.

Further, every working step has sub-features such as a pocket, round hole, and a slot that have a cutting condition environment [69-71]. The DATA section's technology description part thoroughly describes all working steps data including machining strategy, tool, definitions of the workpiece, feed rate, depth of a hole, tool diameter, and spindle speed [72]. On the other hand, the geometry description part contains the geometry data utilized for the components and is defined in ISO 10303 format. Figure 2.6 presents the STEP-NC data model's overall structure. The present study uses a STEP-NC part 21 implementation method as this implementation is conducted in text format and is used extensively in offline systems. Additionally, ISO had presented a part program, previously called EXAMPLE [8], as per the Part 21 implementation method to research STEP-NC activities and has been used as part of the case study in the present study.

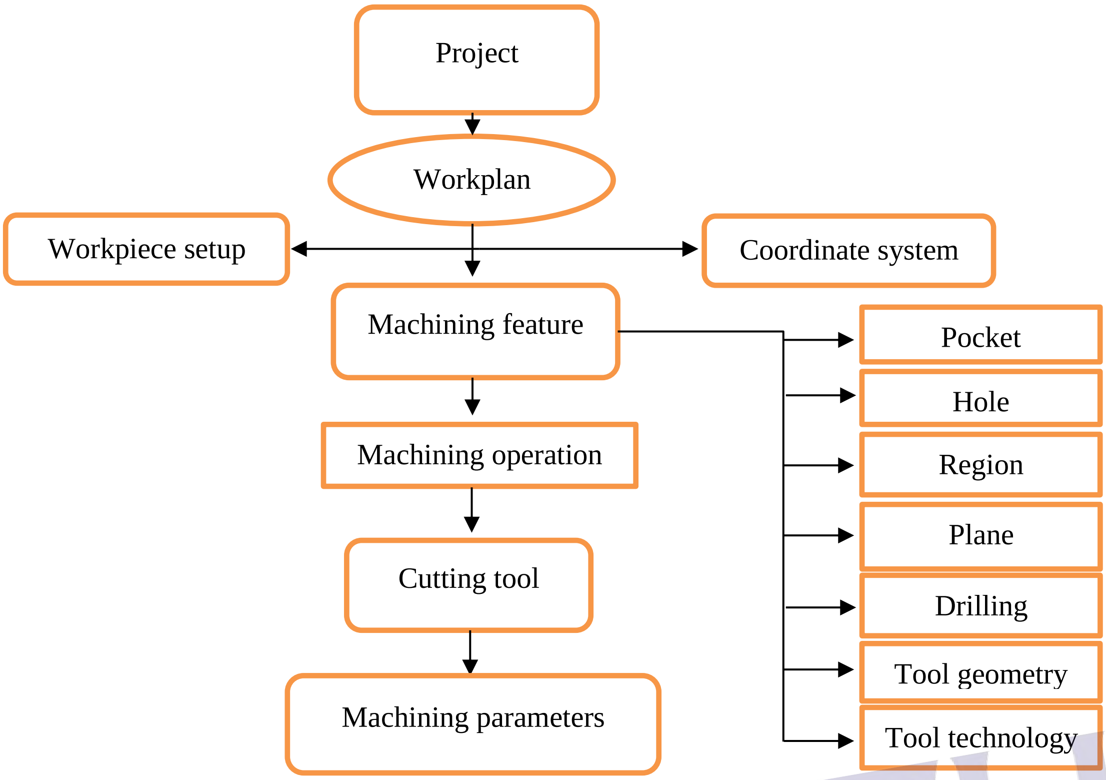

Figure 2.6: Structure of STEP-NC data model [73]

2.4.4 Implementation Strategies for STEP-NC Controller

Using STEP-NC for CNC was continued from years of numerous previous studies. Of these studies, few important projects were funded by institutes, companies, and industries including Intelligent Manufacturing System (IMS) STEP-NC [74], Rapid Acquisition of Manufactured Parts (RAMP), STEP Manufacturing Suite (SMS), Implementation of the STEP-NC and MT Connect Standards for Additive Manufacturing [75], European Strategic Program on Research in Information Technology (ESPRIT) STEP [76] Super Model [60], Intelligent Manufacture for STEP-NC Compliant Machining and Inspection [60], Architecture and implementation of closed-loop machining system based on open STEP-NC controller [77], and Rapid Prototyping Project Description in STEP-NC Model [78]. Different approaches have adopted different strategies based on the implementation of STEP-

NC on the CNC system, and these approaches can be categorized into several development levels in the future, as present in Table 2.3.

Table 2.3 Research work related to enabled intelligent STEP-NC controller

Researcher [Ref.]	Year/country	Strategies	Technology	problem limitation
Xu [50]	New Zealand, 2006)	Realization of STEP-NC enabled machining	Turning-AP238	Different machine controller needs to build up a different interpreter of STEP-NC.
Wang [79]	2007 New Zealand	An adaptable CNC system based on STEP NC	Plug and Play Module For Milling	Still utilized ISO 6983 for end controller
Kramer [80]	2009/USA	(FBICS)	CAPP, milling	An automated program f ramework utilizing six sorts of input information in STEP
Yusof [81]	2009/Malaysia	STEP-NC-compliant system	Turning	Concentrates on two tasks, to be specific the Intelligent Manufacturing System (IMS) for STEP-NC Compliant and Inspection
Ridwan [82]	2010- New Zealand	Generic Feed-Rate Optimization	Milling-ISO14649	No input information to STEP-NC controller for mistake correction
Hua [83]	2011/China	Converting design features g features	Feature Recognition AP214	A possible method to execute for integration with other CAD/CAPP/CAM
Lei [84]	2017/China	Closed-loop machining	STEP-NC-CAM Laser tracker	STEP-NC has been demonstrated to perform superbly in data exchange between CAD/CAM and CNC,

2.4.5 Challenges of STEP-NC

Though researchers have shown increasing interest in STEP-NC, it has certain challenges that must be addressed. As using STEP-NC results in moving some CAM system capabilities to NC controllers, including feed rate and tools rotation information, it creates more complex controllers and needs the machine operators to provide more information [55]. It is important to first develop the NC machines' new STEP-NC compliant controllers prior to using STEP-NC in manufacturing. After this, NC controller manufacturers must redesign their controllers' strategies and structures. Moreover, ARM (ISO 14649), AIM (ISO 10303–AP 238), and ISO have been simultaneously developing two versions of STEP-NC. These two models primarily differ in the extent of their utilization of STEP representation methods as well as technical architecture. These models can both be considered as STEP-NC's different implementation methods.

Thus far, there has been no consensus regarding whether ARM or AIM should be used. Moreover, there are several inconsistencies regarding standards that must be addressed for the STEP-NC data model to be standardized. Hence, extensive systems-building work is required for ensuring the commercial feasibility of STEP-NC related technology. Despite the several years of effort, STEP-NC has not yet been implemented in the industry as CNC machine makers must include an interface for reading data, and CAM vendor must include a system interface for writing STEP-NC data [85]. Additionally, vendors are not keen on investing unless there is a necessary demand. Every CAD/CAM/CNC vendor's system is particular and unique and does not intend to share their algorithms. On the other hand, there must be a complete collaboration between CAD/CAM/CNC vendors for STEP-NC to be feasible. Moreover, in terms of developing STEP-NC's database, it is difficult to develop a working process as the EXPRESS language's fundamental concepts are low. As it is difficult to be read on a computer, another programming language must be used to translate it [86]. The author believed that if STEP-NC is developed and marketed successfully, its usage will need the programming to undergo a paradigm shift as well as machine-tool users to undergo a culture change and trust their manufactured parts' programming to intelligent CAM systems CNC controllers. For this change to occur, company owners will have to reduce the costs involves in the design to manufacturing process chain, thus reducing the lead times and decreasing component prove out, increasing machine utilization, and enhancing part quality.

2.5 STEP-NC Related Research

Several efforts have been made from the late 1990s to use the STEP concept as a data interface between CNC and CAD/CAM. It is important to note that STEP-NC was developed following numerous research projects being conducted by educational institutions (universities) and companies across the world. To reduce decrease the time lag between a product being conceptualized to it being produced, there have been several studies on using information technology in design, analysis, as well as manufacturing practice [87]. At a STEP meeting in 2007 in Ibusuki, Japan, a STEP-enabled on-machine inspection demonstration was conducted. This meeting was attended by various major industry companies such as NIST, Boeing, STEP Tools Inc., and Airbus. At this meeting, an on-machine inspection was conducted on a workpiece shaped like a fish-head. Though this demonstration did not take into account measurement points optimization and inspection path planning, it was the first time STEP-enabled on-machine inspection was physically demonstrated [88]. Moreover, a High-level Inspection Planning (HIPP) system was also proposed to execute STEP-enabled inspection tasks. Figure 2.7 shows the tabulations of the main contributions of the research on STEP and STEP-NC.

2.5.1 Research Work in Europe

It was in 1999 that the first project was launched in the European region that involved industry and scientific partners for assessing and improving ISO 14649 [89]. This project used control vendors, universities, CAM system suppliers, and end-users and associations that represent machine tool builders. As a result systems to handle STEP-NC data for milling where STEP-NC interfaces to Dassault's CATIA V5, Open Mind's Hyper Fact and to the Siemens controller, EDM (Based on a Agie Chramilles machine tool CAD CA Mation did realise a STEP-NC driven scenario for wire EDM) and contour cutting of wood glass and stone were developed.

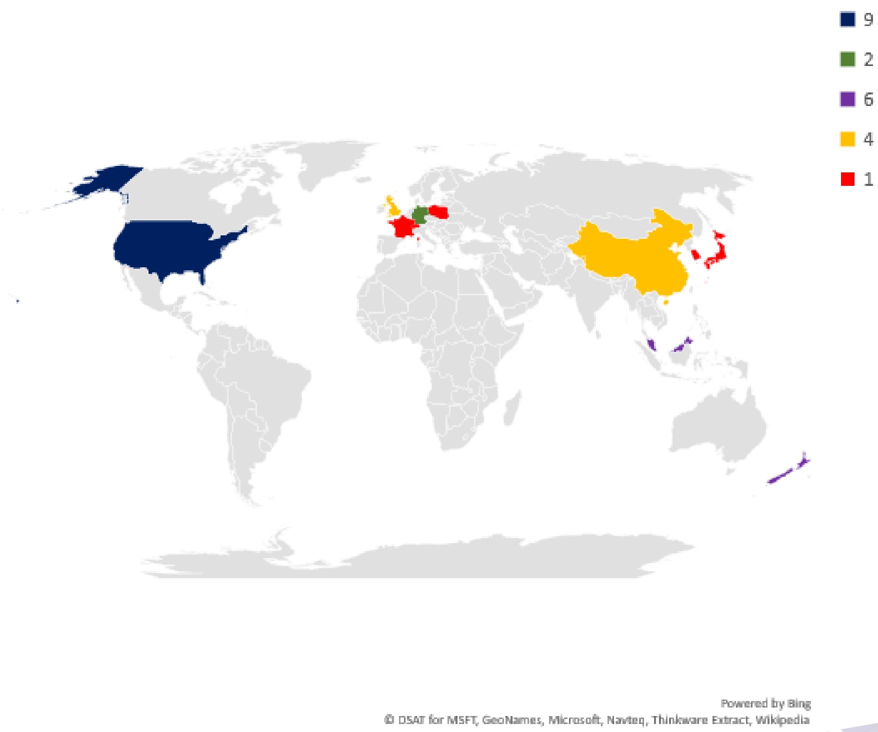

Figure 2.7: Main contributors to STEP-NC Research Approach

As per particular countries, in Germany, the study focused on developing and using STEP-compliant CAPP/CAM systems as well as NC controllers. In the STEP-NC project in Europe, Siemens, which is the CNC system vendor, and two German institutes, ISW in Stuttgart and WZL (Laboratory for Machine Tools and Production Engineering) RWTH in Aachen that were involved significantly [90]. ISW devised a prototype system called STEPturn that used STEP-NC and STEP standards in terms of turned parts. Overall, STEPturn can be considered a CAPP system that connects CAM with CAD. First, STEPturn reads a STEP AP 203 Part 21 file's geometry data, and then, it creates a STEP-NC physical file by executing process-planning tasks including Working step sequencing and feature recognition [91].

In a study by Brecher, Vitr and Wolf [92] at Germany's Aachen University's Laboratory for Machine Tools and Production Engineering (WZL), a system was devised concerning a closed loop process chain that combined examination of the STEP-NC machining information flow. This study put forth a system that aids milling along with CMM-employed inspection operations in terms of closed-loop and feature-based machining. Further, Loughborough University's research primarily focused on strategizing the STEP-NC process plan's creation and machining process regarding milling and milling/turning components. Moreover, Allen, Harding and Newman [93] presented a STEP-NC compliant computational environment regarding a multi-agent framework in which the component's individual features were represented by the agents who also work independently while cooperating with each other for developing STEP-NC process plans regarding manufacturing of discrete component known as AB-CAM. This system ensures that a standard format is applied to transfer data between various CAM systems and machine tools that present data concerning machining operations, component geometry, tooling, detailed process plan, and fixturing. Figure 2.8 by Newman, Allen and Rosso [94] presents the AB-CAM system's framework.

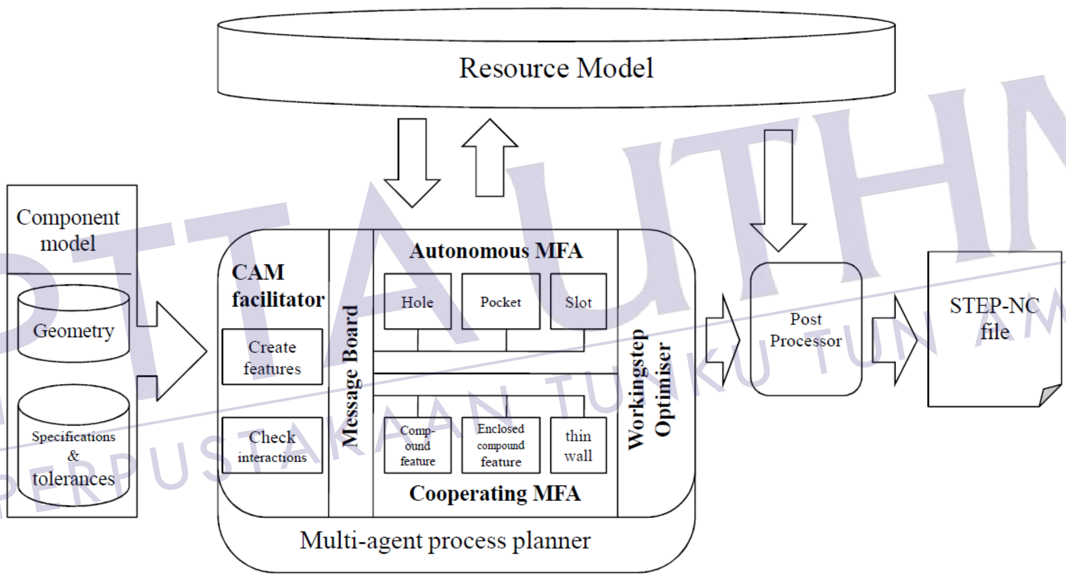

Figure 2.8: Framework of AB-CAM system

Moreover, Rosso, Newman and Rahimifard [95] and Rosso [96] explored the necessity of a new ISO 14649 machining schema particularly in terms of asymmetric rotational parts, and they devised a system known as STEP-TM CAPP System as a practical solution for implementing the ISO 14649 data model regarding turn/mill machining. Figure 2.9 illustrates the STEP-TM CAPP system's operational structure. Moreover, Ali, Newman and Petzing [97] further examined this, focusing primarily on using a CMM and devised a STEP compliant inspection framework that could establish standardized measuring as well as inspection throughout the

CAD/CAM/CAPP chain. That is, this inspection framework intended to close the inspection loop by combining information across the CAD/CAM/CAPP chain. This framework implements working step, an inspection workplan, as well as a mechanism for sending inspection results throughout the CAD/CAM/CAPP chain. It also used DMIS, STEP-NC (ISO 14649-16), and ISO 10303 AP 219 (implementing protocol for CMMs' dimensional inspection information exchange) to represent the manufacturing models and product.

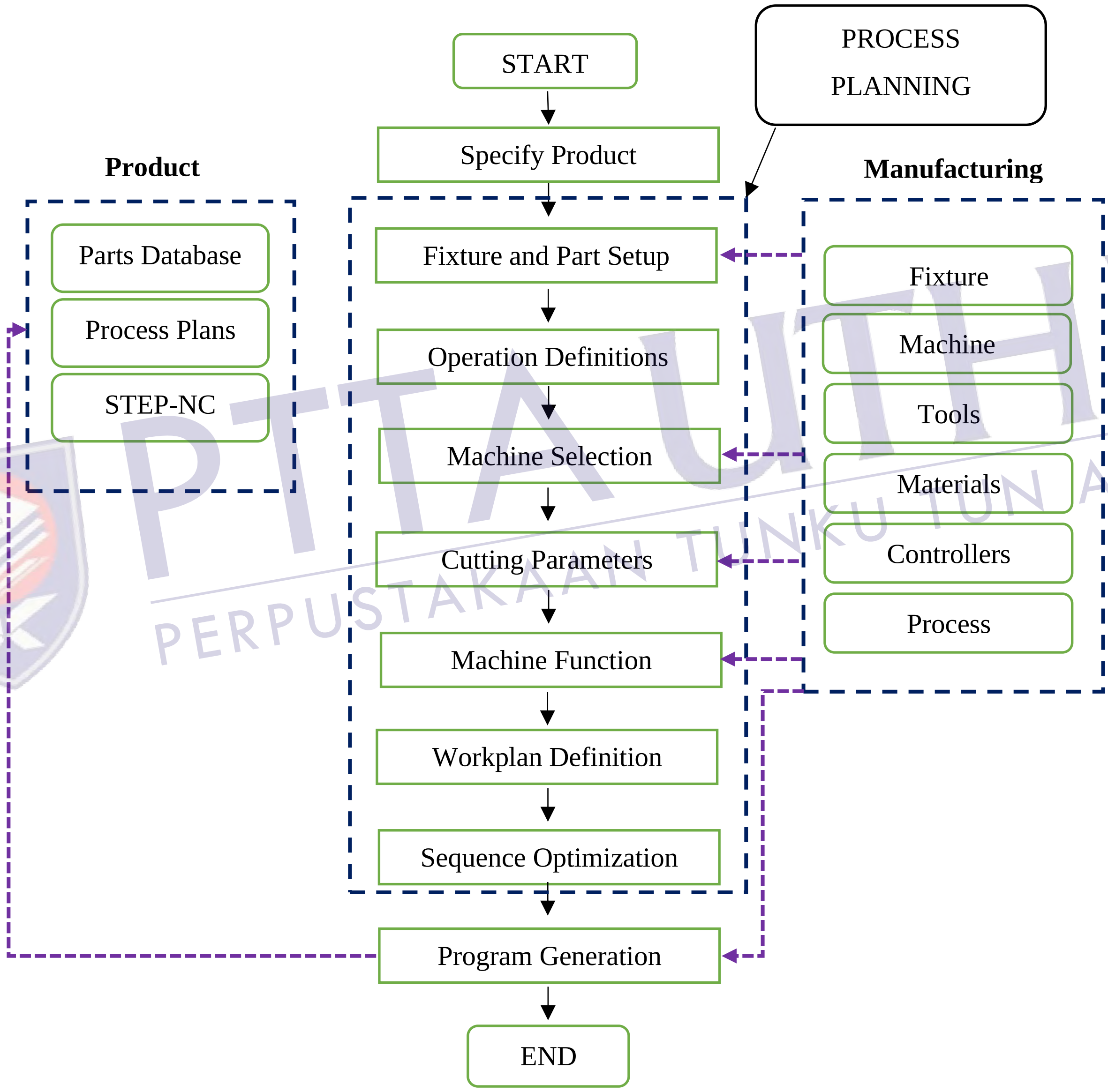

Figure 2.9: Operational Structure STEP-TM CAPP System

REFERENCES

1. Zhang, Y., Zeng, Q., Mu, G., Yang, Y., Yan, Y., Song, W. and Gong, Y. A Design for a Novel Open, Intelligent and Integrated CNC System Based on ISO 10303-238 and PMAC. *Tehnički vjesnik*. 2018. 25(2): 470-478.
2. Liu, L., Yao, Y. and Li, J. A review of the application of component-based software development in open CNC systems. *The International Journal of Advanced Manufacturing Technology*. 2020. 107: 1-27.
3. Groover, M. P. Automation, production systems, and computer-integrated manufacturinged. *India*: Pearson Education. 2007.
4. Ertell, G. G. Numerical controled. *USA*: Wiley. 1969.
5. ISO. *Automation systems and integration - Numerical control of machines - Program format and definitions of address words - Part 1: Data format for positioning, line motion and contouring control systems*. US, 6983-1. 2009.
6. Suh, S. H., Chung, D. H., Lee, B. E. and Cho, J. H. Developing an integrated STEP-compliant CNC prototype. *Journal of Manufacturing Systems*. 2002. 21(5): 350-356.
7. Xu, X. W. and Newman, S. T. Making CNC machine tools more open, interoperable and intelligent—a review of the technologies. *Computers in Industry*. 2006. 57(2): 141-152.
8. ISO. *Industrial automation systems and integration–physical device control–data model for computerized numerical controllers–part 11: process data for milling*. USA, 14649-11. 2004.
9. Wang, S., Jia, Z., Lu, X., Zhang, H., Zhang, C. and Liang, S. Y. Simultaneous optimization of fixture and cutting parameters of thin-walled workpieces based on particle swarm optimization algorithm. *Simulation*. 2018. 94(1): 67-76.
10. Bandari, Y. K., Williams, S. W., Ding, J. and Martina, F. Additive manufacture of large structures: robotic or CNC systems. *Proceedings of the 26th international solid freeform fabrication symposium*. August 10-12. Austin, TX, USA: University of Texas at Austin. 2015. 12-14.
11. Flynn, J. M., Shokrani, A., Newman, S. T. and Dhokia, V. Hybrid additive and subtractive machine tools–Research and industrial developments. *International Journal of Machine Tools and Manufacture*. 2016. 101: 79-101.
12. Rauch, M., Hascoët, J.-Y., Simoes, V. and Hamilton, K. Advanced programming of machine tools: interests of an open CNC controller within a STEP-NC environment. *International Journal of Machining and Machinability of Materials 7*. 2014. 15(1-2): 2-17.
13. Paprocki, M., Wawrzak, A., Erwiński, K., Karwowski, K. and Kłosowiak, M. PC-based CNC machine control system with LinuxCNC software. *Measurement Automation Monitoring*. 2017. 63(1): 15-19.
14. Lutz, P., Sperling, W., Fichtner, D. and Mackay, R. OSACA—The vendor neutral control architecture. *Proc. European Conf. Integration in Manufacturing*. 15 August. Germany: Selbsterlag der TU Dresden. 1997. 247-256.
15. Michaloski, J. L., Birla, S., Weinert, G. F. and Yen, C. J. Framework for component-based CNC machines. *Sensors and Controls for Intelligent*

Machining, Agile Manufacturing, and Mechatronics. December 17. USA: International Society for Optics and Photonics. 1998. 132-143.
16. EMC, D.(2018). *LinuxCNC. National Institute of Standards and Technology*. Retrieved on January 31, 2018, from http://linuxcnc.org/docs/2.7/.
17. Beckhoff.(2021). *PC-based control*. Retrieved on January 31, 2021, from https://www.beckhoff.com/english.asp?start/?pk_campaign=AdWords-AdWordsSearch-IndustrialAutomationEN&pk_kwd=pc.
18. Sawada, C. and Akira, O. Open controller architecture OSEC-II: architecture overview and prototype systems. *1997 IEEE 6th International Conference on Emerging Technologies and Factory Automation Proceedings, EFTA'97*. 9-12 September. USA: IEEE. 1997. 543-550.
19. Karthikeyan, A., Karthikeyan, A. and Venkatesh Raja, K. Machine learning in optimization of multi-hole drilling using a hybrid combinatorial IGSA algorithm. *Concurrent Engineering*. 2020. 28(2): 1-12.
20. Kolahan, F. and Liang, M. Optimization of hole-making operations: a tabu-search approach. *International Journal of Machine Tools and Manufacture*. 2000. 40(12): 1735-1753.
21. Kucukoglu, I., Gunduz, T., Balkancioglu, F., Topal, E. C. and Sayim, O. Application of precedence constrained travelling salesman problem model for tool path optimization in CNC milling machines. *An International Journal of Optimization and Control: Theories & Applications (IJOCTA)*. 2019. 9(3): 59-68.
22. Abdullah, H., Ramli, R. and Wahab, D. A. Tool path length optimisation of contour parallel milling based on modified ant colony optimisation. *The International Journal of Advanced Manufacturing Technology*. 2017. 92(1-4): 1263-1276.
23. Karuppanan, B. R. C. and Saravanan, M. Optimized sequencing of CNC milling toolpath segments using metaheuristic algorithms. *Journal of Mechanical Science and Technology*. 2019. 33(2): 791-800.
24. Iberahim, F., Ramli, R., Narooei, K. D. and Qudeiri, J. A. Tool path optimization for drilling process by CNC milling machine using ant colony optimization (ACO). *Aust J Basic Appl Sci*. 2014. 8: 385-389.
25. Orazi, L., Montanari, F., Campana, G., Tomesani, L. and Cuccolini, G. CNC Paths Optimization in Laser Texturing of Free Form Surfaces. *Procedia CIRP*. 2015. 33: 440-445.
26. Yusof, Y. and Latif, K. New technique for the interpretation of ISO 14649 and 6983 based on open CNC technology. *International journal of computer integrated manufacturing*. 2016. 29(2): 136-148.
27. Oysu, C. and Ã, Z. B. Engineering Applications of Artificial Intelligence Application of heuristic and hybrid-GASA algorithms to tool-path optimization problem for minimizing airtime during machining. *Engineering Applications of Artificial Intelligence* 2009. 22: 389-396.
28. Boyang, M., Maoyue, L., Xianli, L., Lihui, W. and Liang, S. Y. Open architecture CNC system based on soft-integrated communication. *Procedia CIRP*. 2018. 72: 671-676.
29. Wang, W. and Zhou, K. An extensible NC program interpreter for open CNC systems. *The International Journal of Advanced Manufacturing Technology*. 2018. 94(1): 911-923.
30. Xu, L. M., Fan, F., Zhang, Z., Chen, Y., Hu, D. J. and Shi, L. Methodology and implementation of a vision-oriented open CNC system for profile grinding. *The*

International Journal of Advanced Manufacturing Technology. 2019. 100(5): 2123-2131.

31. Anugraha, R. A. and Ibrahim, M. R. Design and Develop of Open Architecture CNC Movement Control System for Analysing Precision Motion of EDM Machine. *International Journal of Integrated Engineering*. 2020. 12(3): 20 - 35.
32. Correa, J. E., Toombs, N. and Ferreira, P. M. A modular-architecture controller for CNC systems based on open-source electronics. *Journal of Manufacturing Systems*. 2017. 44: 317-323.
33. Al-Sahib, N. K. A. and Abdulrazzaq, H. F. Tool path optimization of drilling sequence in CNC machine using genetic algorithm. *Innov Syst Des Eng*. 2014. 5(1): 15-26.
34. Benhala, B. and Bouattane, O. GA and ACO techniques for the analog circuits design optimization. *Journal of Theoretical and Applied Information Technology*. 2014. 64(2): 413-419.
35. Liang, S. Y., Hecker, R. L. and Landers, R. G. Machining process monitoring and control: the state-of-the-art. *Journal of manufacturing science and engineering*. 2004. 126(2): 297-310.
36. Safaieh, M., Nassehi, A. and Newman, S. T. A novel methodology for cross-technology interoperability in CNC machining. *Robotics and Computer-Integrated Manufacturing*. 2013. 29(3): 79-87.
37. Newman, S. T., Nassehi, A., Xu, X. W., Rosso, R. S. U., Wang, L., Yusof, Y., Ali, L., Liu, R., Zheng, L. Y. and Kumar, S. Strategic advantages of interoperability for global manufacturing using CNC technology. *Robotics and Computer-Integrated Manufacturing*. 2008. 24(6): 699-708.
38. Yusof, Y., Newman, S., Nassehi, A. and Case, K. Interoperable CNC system for turning operations. *World academy of science, engineering and technology*. 2009. 34: 941-947.
39. Requicha, A. G. Representations for rigid solids: Theory, methods, and systems. *ACM Computing Surveys (CSUR)*. 1980. 12(4): 437-464.
40. Wang, K., Tang, M., Wang, Y., Estensen, L., Sollie, P. A. and Pourjavad, M. Knowledge-based CAD/CAPP/CAM integration system for manufacturing. *International Conference on Programming Languages for Manufacturing*. November 7. Boston: Springer. 2001. 406-415.
41. Xu, X., Wang, L. and Newman, S. T. Computer-aided process planning–A critical review of recent developments and future trends. *International Journal of Computer Integrated Manufacturing*. 2011. 24(1): 1-31.
42. Xu, X. W. and He, Q. Striving for a total integration of CAD, CAPP, CAM and CNC. *Robotics and Computer-Integrated Manufacturing*. 2004. 20(2): 101-109.
43. Mortenson, M. E. Geometric modeling. *Sawada," End effector design for robotic rňachining", 15th ISIR*. 1985. 3: 215-221.
44. Reintjes, J. F. Numerical control: making a new technologyed. *UK*: Oxford University Press. 1991.
45. Standardization, I. O. f. *Numerical control of machines Program format and definition of address words*. USA, 1982.
46. Xu, X. and Mao, J. A STEP-compliant collaborative product development system. *Proceedings of the 33rd international conference on computers and industrial engineering*. October 20. Turkey: ISCA. 2004. 25-27.

47. Organization, I. S. *Numerical control of machines: program format and definition of address words. Part 1: data Format for positioning, line motion and contouring control systems*. USA, 1982.
48. Latif, K. *New Technique for The Development of Open CNC Cell Controller based on ISO 14649 and ISO 6983*. PhD Universiti Tun Hussein Onn Malaysia; 2019.
49. Zhang, X., Nassehi, A. and Newman, S. T. Process comprehension for interoperable CNC manufacturing. *International Conference on Computer Science and Automation Engineering*. 10-12 June. China: IEEE. 2011. 225-229.
50. Xu, X. W. Realization of STEP-NC enabled machining. *Robotics and Computer-Integrated Manufacturing*. 2006. 22(2): 144-153.
51. Kramer, T. R. Evaluating manufacturing machine control language standards: an implementer's view. *Proceedings of the 2007 workshop on performance metrics for intelligent systems*. August 28-30. United States: Association for Computing Machinery. 2007. 267-274.
52. Benavente, J. C. T., Ferreira, J. C. E., Goulart, C. M. and Oliveira, d. V. G. A STEP-NC compliant system for the remote design and manufacture of mechanical components through the Internet. *International Journal of Computer Integrated Manufacturing*. 2013. 26(5): 412-428.
53. Shin, S.-J., Suh, S.-H. and Stroud, I. Reincarnation of G-code based part programs into STEP-NC for turning applications. *Computer-Aided Design*. 2007. 39(1): 1-16.
54. Kramer, T. and Xu, X. Advanced design and manufacturing based on STEPed. *London*: Springer-Verlag. 2009.
55. Hou, M. CAD/CAM integration based on machining features for prismatic parts. *Computer Science*. 2008. 4: 1-3.
56. Kržič, P., Stoić, A. and Kopač, J. STEP-NC: A new programming code for the CNC machines. *Strojniški vestnik*. 2009. 55(6): 406-417.
57. Weck, M., Wolf, J. and Kiritsis, D. STEP-NC—The STEP compliant NC programming interface evaluation and improvement of the modern interface. *International Intelligent Manufacturing System Forum*. 2001. 10: 1-5.
58. ISO. *Industrial Automation Systems and Integration–Physical Device Control–Data Model for Computerized Numerical Controllers–Part 1: Overview and Fundamental Principles*. USA, 14649-1. 2002.
59. Babu, K. S., Rao, D. D. N., Balakrishna, A. and Rao, C. S. Development of a Manufacturing database System for Step-NC data from express entities. *International Journal of Engineering Science and Technology*. 2010. 2(11): 6819-6828.
60. Xu*, X. W., Wang, H., Mao, J., Newman, S. T., Kramer, T. R., Proctor, F. M. and Michaloski, J. L. STEP-compliant NC research: the search for intelligent CAD/CAPP/CAM/CNC integration. *International Journal of Production Research*. 2005. 43(17): 3703-3743.
61. Hamilton, K., Hascoet, J.-Y. and Rauch, M. Implementing STEP-NC: Exploring possibilities for the future of advanced manufacturinged. *Berlin*: Springer. 2014.
62. Hardwick, M., Zhao, Y. F., Proctor, F. M., Nassehi, A., Xu, X., Venkatesh, S., Odendahl, D., Xu, L., Hedlind, M. and Lundgren, M. A roadmap for STEP-NC-enabled interoperable manufacturing. *The International Journal of Advanced Manufacturing Technology*. 2013. 68(5-8): 1023-1037.

63. Rauch, M., Laguionie, R. and Hascoet, J.-Y. Achieving a STEP-NC enabled advanced NC programming environmented. *London*: Springer. 2009.
64. Sääski, J., Salonen, T. and Paro, J. Integration of CAD, CAM and NC with Step-NCed. *Finland*: Espoo, VTT. 2005.
65. Yusof, Y., Kassim, N. D. and Zamri Tan, N. Z. The development of a new STEP-NC code generator (GEN-MILL). *International Journal of Computer Integrated Manufacturing*. 2011. 24(2): 126-134.
66. Kassim, N., Yusof, Y. and Awang, M. Z. Reviewing iso 14649 through iso10303. *ARPN J. Eng. Appl. Sci*. 2016. 11(10): 6599-6603.
67. Zhang, Y., Xu, X., Bai, X. and Liu, Y. Understanding the STEP-NC data model for computer numerical control. *2nd International Conference on Advanced Computer Control*. 27-29 March. China: IEEE 2010.
68. Zivanovic, S. and Puzovic, R. Wire EDM machining simulations based on STEP-NC program. *Technical Gazette*. 2016. 23(6): 1831-1838.
69. Calabrese, F. and Celentano, G. Design and realization of a STEP-NC compliant CNC embedded controller. *2007 IEEE Conference on Emerging Technologies and Factory Automation (EFTA 2007)*. 25-28 September. Greece: IEEE. 2007. 1010-1017.
70. Ridwan, F., Xu, X. and Liu, G. A framework for machining optimisation based on STEP-NC. *Journal of Intelligent Manufacturing*. 2012. 23(3): 423-441.
71. Srivastava, D. and Komma, V. R. Development of STEP AP224 Extractor for Interfacing Feature Based CAPP to STEP-NC (AP238). *International Journal of Automation and Computing*. 2019. 16(5): 655-670.
72. Zhang, X., Nassehi, A., Safaieh, M. and Newman, S. T. Process comprehension for shopfloor manufacturing knowledge reuse. *International Journal of Production Research*. 2013. 51(23-24): 7405-7419.
73. Pobozniak, J. and Sobieski, S. Extension of STEP-NC data structure to represent manufacturing process structure in CAPP system. *Procedia Manufacturing*. 2017. 11: 1692-1699.
74. Richard, J. and Stark, J. Standardisation of the manufacturing process: the STEP-NC project. *Computer Science*. 2002. 1: 10-11.
75. Rodriguez, E. and Alvares, A. J. Implementation of the STEP-NC and MTConnect Standards for Additive Manufacturing. *10th Brazilian Congress on Manufacturing Engineering*. 2019. Brazil. 2019. 1-5.
76. Denkena, H. K., Tönshoff, J., Selle, A., Storr, S., Heusinger, S. and Rogers, G. Offline-Berechnung der Zerspankräfte in der NC-Programmierung. *Vorhersage der Zerspankräfte beim HSC-Schlichtfräsen*. 2002. 22(92): 581-587.
77. Hu, P., Han, Z., Fu, H. and Han, D. Architecture and implementation of closed-loop machining system based on open STEP-NC controller. *The international journal of advanced manufacturing technology*. 2016. 83(5-8): 1361-1375.
78. Bonnard, R., Mognol, P. and Hascoët, J. Y. Rapid prototyping project description in STEP-NC model. *6th CIRP International Seminar on Intelligent Computation in Manufacturing Engineering*. 15 Jun. Italy. 2008. 357-362.
79. Wang, H., Xu, X. and Tedford, D. J. An adaptable CNC system based on STEP-NC and function blocks. *International Journal of Production Research*. 2007. 45(17): 3809-3829.
80. Kramer, T. and Proctor, F. Feature-based process planning based on STEP. *Advanced Design and Manufacturing Based on STEP*. 2009. 5: 23-48.

81. Yusof, Y. STEP-NC-compliant systems for the manufacturing environment. *lathe*. 2009. 15: 1-24.
82. Ridwan, F., Xu, X. W. and Liu, G. Generic Feed-Rate Optimization Based on a Predicted Power Force Model. *Proceedings of the 6th CIRP-Sponsored International Conference on Digital Enterprise Technology*. 14-16 December. Berlin: Springer. 2010. 401-417.
83. Hua-bing, O. and Bin, S. Research on the Conversion from Design Features to Machining Features Faced on STEP-NC. *2011 Third International Conference on Measuring Technology and Mechatronics Automation*. 6-7 Jan. China: IEEE. 2011. 103-106.
84. Lei, P., Zheng, L., Xiao, W., Li, C. and Wang, D. A closed-loop machining system for assembly interfaces of large-scale component based on extended STEP-NC. *The International Journal of Advanced Manufacturing Technology*. 2017. 3: 1-27.
85. Thilmany, J. Beyond step. *Mechanical Engineering Magazine Select Articles*. 2007. 129(10): 41-43.
86. Yusof, Y., Tan, N. Z. Z., Kassim, N. and Nawi, N. M. ISO14649 code generator for intelligent manufacture for STEP-NC compliant machining. *Proceedings of the Asia Pacific Industrial Engineering and Management Systems Conference (APIEMS2009)*. 22 March. China: APIEMS. 2009. 14-16.
87. Verma, A. K. and Rajotia, S. A review of machining feature recognition methodologies. *International Journal of Computer Integrated Manufacturing*. 2010. 23(4): 353-368.
88. Zhao, Y. *An integrated process planning system for machining and inspection*. Ph.D 2009.
89. Nassehi, A., Liu, R. and Newman, S. T. A new software platform to support feature-based process planning for interoperable STEP-NC manufacture. *International Journal of Computer Integrated Manufacturing*. 2007. 20(7): 669-683.
90. Wang, H.(2009). *New control strategy for CNC machines via STEP-NC. ResearchSpace@ Auckland*. Retrieved on January 31, 2009, from https://studylib.net/doc/5536443/new-control-strategy-for-cnc-machines-via-step-nc.
91. Storr, A., Pritschow, G., Heusinger, S. and Azotov, A. Workingstep planning for turning with STEP-NC: planning methods for user support. *IWF Zeitschrift fur Wirtschaftlichen Fabrikbetrieb*. 2002. 97(7-8): 390.
92. Brecher, C., Vitr, M. and Wolf, J. Closed-loop CAPP/CAM/CNC process chain based on STEPand STEP-NC inspection tasks. *International Journal of Computer Integrated Manufacturing*. 2006. 19(6): 570-580.
93. Allen, R. D., Harding, J. A. and Newman, S. T. The application of STEP-NC using agent-based process planning. *International Journal of Production Research*. 2005. 43(4): 655-670.
94. Newman, S. T., Allen, R. D. and Rosso, R. S. U. CAD/CAM solutions for STEP-compliant CNC manufacture. *International Journal of Computer Integrated Manufacturing*. 2003. 16(7-8): 590-597.
95. Rosso, R. S. U., Newman, S. T. and Rahimifard, S. The adoption of STEP-NC for the manufacture of asymmetric rotational components. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*. 2004. 218(11): 1639-1644.

96. Rosso, R. S. U. *STEP compliant CAD/CAPP/CAM system for rotational asymmetric parts*. Ph.D. Loughborough University; 2005.
97. Ali, L., Newman, S. T. and Petzing, J. Development of a STEP-compliant inspection framework for discrete components. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*. 2005. 219(7): 557-563.
98. Yusof, Y., Case, K., Newman, S. T. and Xu, X. W. A STEP-compliant system for turning operationsed. *London*: Springer. 2007.
99. Yusof, Y. and Case, K. STEP compliant CAD/CAPP/CAM system for turning operations. *Proceedings of the world congress on engineering and computer science*. October 22 - 24. USA: WCECS. 2008. 22-24.
100. Cuenca, S., Jimeno-Morenilla, A., Martínez, A. and Maestre, R. Hardware approach to tool path computation for STEP-NC enabled CNC: A case study of turning operations. *Computers in Industry*. 2011. 62(5): 509-518.
101. Valente, A., Carpanzano, E., Nassehi, A. and Newman, S. T. A STEP compliant knowledge based schema to support shop-floor adaptive automation in dynamic manufacturing environments. *CIRP Annals-Manufacturing Technology*. 2010. 59(1): 441-444.
102. Rauch, M., Laguionie, R., Hascoët, J.-Y. and Xu, X. Enhancing CNC manufacturing interoperability with STEP-NC. *Journal of Machine Engineering*. 2009. 9(4): 26-37.
103. Laguionie, R., Rauch, M. and Hascoët, J.-Y. Simulation and optimization in a multi-process environment using STEP-NC. *IEEE International Conference on Control and Automation*. 9-11 December. New Zealand: IEEE. 2009. 2384-2391.
104. Aciu, R.-M. and Ciocarlie, H. G-code optimization algorithm and its application on printed circuit board drilling. *9th IEEE International Symposium on Applied Computational Intelligence and Informatics*. 15-17 May. Romania: IEEE. 2014. 43-47.
105. Ahmad, R. and Plapper, P. Generation of safe tool-path for 2.5 D milling/drilling machine-tool using 3D ToF sensor. *CIRP Journal of Manufacturing Science and Technology*. 2015. 10: 84-91.
106. Danjou, C., Le Duigou, J. and Eynard, B. Closed-loop Manufacturing, a STEP-NC Process for Data Feedback: A Case Study. *Procedia CIRP*. 2016. 41: 852-857.
107. Bonnard, R., Hascoët, J.-Y., Mognol, P., Zancul, E. and Alvares, A. J. Hierarchical object-oriented model (HOOM) for additive manufacturing digital thread. *Journal of Manufacturing Systems*. 2019. 50: 36-52.
108. Rodriguez, T., Montemurro, M., Le Texier, P. and Pailhès, J. Structural displacement requirement in a topology optimization algorithm based on isogeometric entities. *Journal of Optimization Theory and Applications*. 2020. 184(1): 250-276.
109. Kramer, T. R., Huang, H. M., Messina, E., Proctor, F. M. and Scott, H. A feature-based inspection and machining system. *Computer-Aided Design*. 2001. 33(9): 653-669.
110. Montiel-Ross, O., Medina-Rodriguez, N., Sepulveda, R. and Melin, P. Methodology to optimize manufacturing time for a CNC using a high performance implementation of ACO. *International Journal of Advanced Robotic Systems*. 2012. 9(121): 1-10.

111. Shin, S.-J., Woo, J. and Rachuri, S. Predictive analytics model for power consumption in manufacturing. *Procedia Cirp*. 2014. 15: 153-158.
112. Lu, Y., Choi, S. and Witherell, P. Towards an integrated data schema design for additive manufacturing: Conceptual modeling. *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*. 2015. USA: ASME. 2015.
113. Shin, S.-J., Woo, J., Kim, D. B., Kumaraguru, S. and Rachuri, S. Developing a virtual machining model to generate MTConnect machine-monitoring data from STEP-NC. *International Journal of Production Research*. 2016. 54(15): 4487-4505.
114. Jones, B. A., Shand, M. G. and McLaughlin, L. *System and method for creating and utilizing a construction aid*. Patent 9,982,986. 2018.
115. Pistorius, J. M., Bodach, M., Fulton, J., Mathew, S. and Petty, N. L. *Verification system for manufacturing processes*. Patent 2019.
116. Fattori, C. C., Dobrianskyj, G. M., Junqueira, F., Santos Filho, D. J. and Miyagi, P. E. Description of productive processes in a collaborative environment. *IECON 2011-37th Annual Conference of the IEEE Industrial Electronics Society*. 7-10 Nov. Australia: IEEE. 2011. 379-384.
117. Souza, F. J., Ferreira, J. C. E., Martin, C. A. and Gascho, W. F. Remote machining of prismatic parts through the internet in a cnc machine compliant with the step-nc standard. *23rd ABCM International Congress of Mechanical Engineering*. 2015. Brazil. 2015. 6-11.
118. Ferreira, J. C. E., Benavente, J. C. T. and Inoue, P. H. S. A web-based CAD/CAPP/CAM system compliant with the STEP-NC standard to manufacture parts with general surfaces. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*. 2017. 39(1): 155-176.
119. Toquica, J. S., Alvares, A. J. and Bonnard, R. A STEP-NC compliant robotic machining platform for advanced manufacturing. *The International Journal of Advanced Manufacturing Technology*. 2018. 95(9-12): 3839-3854.
120. Rodriguez, E. and Alvares, A. J. A STEP-NC implementation approach for additive manufacturing. *Procedia Manufacturing*. 2019. 1(1): 1-8.
121. Suh, S. H., Lee, E. S., Kim, H. C. and Cho, J. H. Geometric error measurement of spiral bevel gears using a virtual gear model for STEP-NC. *International Journal of Machine Tools and Manufacture*. 2002. 42(3): 335-342.
122. Gizaw, M., Rani, A. M. A. and Yusof, Y. STEP based product data model for turn-mill operations. *2011 National Postgraduate Conference*. 19-20 Sept. Malaysia: IEEE. 2011. 1-4.
123. Alizadehdehkohneh, P. and Razfar, M. R. Setup Planning Automation of Turned Parts Based on STEP-NC Standard. *International Journal of Mechanical and Industrial Engineering (IJMTE)*. 2011. 1(2): 1-6.
124. Mokhtar, A. and Houshmand, M. Introducing a roadmap to implement the universal manufacturing platform using axiomatic design theory. *International Journal of Manufacturing Research*. 2010. 5(2): 252-269.
125. Tan, J., Zhang, C. and Liang, X. Research on STEP-NC Based Machining and On-Machine Inspecting Simulation System. *International Conference on Computational Intelligence and Software Engineering*. 11-13 December. China: IEEE. 2009. 1-4.
126. Tan, J., Zhang, C., Liu, R. and Liang, X. Study on framework of STEP-NC controller with on-machine inspection. *International Conference on Artificial*

Intelligence and Computational Intelligence. 7-8 Noveber. China: IEEE. 2009. 40-44.

127. Shu, Q., Gong, G. and Sun, A. Implementation of CAM system integration between STEP-NC and UG. *Third International Conference on Intelligent Networks and Intelligent Systems*. 1-3 Nov. China: IEEE. 2010. 657-660.
128. Huang, X. Enhancing STEP-NC compliant CNC controller for distributed and reconfigurable environment in production line. *International Conference on Computer, Mechatronics, Control and Electronic Engineering*. 24-26 Aug. China: IEEE. 2010. 106-109.
129. Han, J., Du, J. and Yan, X. A New Network Collaborative Manufacturing Based on the STEP-NC. *International Conference on Computational Aspects of Social Networks*. 26-28 Sept. China: IEEE. 2010. 620-623.
130. Yongsheng, L. and Tingbiao, J. Information extraction system model based on STEP-NC program. *International Technology and Innovation Conference 2009 (ITIC 2009)*. 12-14 October. China: IET. 2009.
131. Igari, S., Tanaka, F. and Onosato, M. Development of process planning and machining system for machine-independent STEP-NC data. *IEEE International Conference on Control and Automation*. 9-11 December. New Zealand: IEEE. 2009. 1241-1247.
132. Rashid, M. F. F. A., Harun, W. S. W., Ghani, S. A. C., Mohamed, N. M. Z. N. and Rose, A. N. M. Optimization of Multi-Pass Pocket Milling Parameter using Ant Colony Optimization. *Advanced Materials Research*. 2014. 1043: 65-70.
133. Yusof, Y. and Latif, K. New Interpretation Module for Open Architecture Control Based CNC Systems. *Procedia CIRP*. 2015. 26: 729-734.
134. Nguyen, T. T., Pham, H. T. and Nguyen, T. H. M. Tool path optimization in CNC punching machine for sheet metal manufacturing. *Proceedings - 2017 International Conference on System Science and Engineering, ICSSE 2017*. 2017. 6: 381-386.
135. Zavalnyi, G. Z. Y. L. and Xiao, W. Optimization of the STEP-NC compliant online toolpath generation for T- spline surfaces using convolutional neural network and random forest classifier. *International Multi-Conference on Engineering and Technology Innovation*. 2–6 November 2018. Taiwan: IOP Conference Series: Materials Science and Engineering. 2019.
136. Patil, S. and Anasane, S. S. Development of 3-Axis Micro-Step Resolution Desktop CNC Stage for Machining of Meso-and Microscale-Featuresed. *Singapore*: Springer. 2020.
137. Storr, S. and Heusinger, S. STEP-NC–Grundlage einer CAD. *NC-Prozesskette Das STEP-NC-Prozessmodell für die Drehbearbeitung*. 2002. 5.
138. Suh, S.-H., Lee, B.-E., Chung, D.-H. and Cheon, S. U. Architecture and implementation of a shop-floor programming system for STEP-compliant CNC. *Computer-Aided Design*. 2003. 35(12): 1069-1083.
139. Pobożniak, J. Algorithm for ISO 14649 (STEP-NC) feature recognition. *Management and Production Engineering Review*. 2013. 4: 50–58.
140. Danjou, C., Le Duigou, J. and Eynard, B. Closed-loop manufacturing process based on STEP-NC. *International Journal on Interactive Design and Manufacturing (IJIDeM)*. 2017. 11(2): 233-245.
141. Toquica, J. S., Zivanovic, S., Bonnard, R., Rodriguez, E., Alvares, A. J. and Ferreira, J. C. E. STEP-NC-based machining architecture applied to industrial robots. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*. 2019. 41(8): 314.

142. Hardwick, M. and Loffredo, D. Lessons learned implementing STEP-NC AP-238. *International Journal of Computer Integrated Manufacturing*. 2006. 19(6): 523-532.
143. Minhat, M., Xu, X. and Vyatkin, V. STEPNCMillUoA: a CNC system based on STEP-NC and Function Block architecture. *International Journal of Mechatronics and Manufacturing Systems*. 2009. 2(1-2): 3-19.
144. Wang, H., Xu, X., Zhang, C. and Hu, T. A hybrid approach to energy-efficient machining for milled components via STEP-NC. *International Journal of Computer Integrated Manufacturing*. 2017. 4: 1-15.
145. Yusof, Y. and Case, K. Design of a STEP compliant system for turning operations. *Robotics and Computer-Integrated Manufacturing*. 2010. 26(6): 753-758.
146. Xiao, W., Zheng, L., Huan, J. and Lei, P. A complete CAD/CAM/CNC solution for STEP-compliant manufacturing. *Robotics and Computer-Integrated Manufacturing*. 2015. 31: 1-10.
147. Elias, D. M., Yusof, Y. and Minhat, M. CNC machine system via STEP-NC data model and LabVIEW platform for milling operation. *Open Systems (ICOS), 2013 IEEE Conference on*. 2-4 Dec. Malaysia: IEEE. 2013. 27-31.
148. Kassim, N., Yusof, Y., Bahrudin, I. A., Mohd Hanifa, R., Nor, M., Hadri, M., Aziz, A., Rahman, A. and Othman, Z. H. Information Structure of STEP Convertor of STEP-CNC Mapping System. *Applied Mechanics and Materials*. 2015. 773: 38-42.
149. Xiao, S. An open-architecture embedded manufacturing control system. *2010 International Conference on Measuring Technology and Mechatronics Automation*. IEEE. 2010. 517-520.
150. Dharmawardhana, M., Ratnaweera, A. and Oancea, G. STEP-NC Compliant Intelligent CNC Milling Machine with an Open Architecture Controller. *Applied Sciences*. 2021. 11(13): 6223.
151. Ramesh, R., Jyothirmai, S. and Lavanya, K. Intelligent automation of design and manufacturing in machine tools using an open architecture motion controller. *Journal of Manufacturing Systems*. 2013. 32(1): 248-259.
152. Wu, H., Zhang, C., Li, G. and Wang, B. Windows XP embedded based open architecture computer numerical control system. *2006 2nd IEEE/ASME International Conference on Mechatronics and Embedded Systems and Applications*. IEEE. 2006. 1-6.
153. Pritschow, G., Altintas, Y., Jovane, F., Koren, Y., Mitsuishi, M., Takata, S., Van Brussel, H., Weck, M. and Yamazaki, K. Open controller architecture–past, present and future. *CIRP Annals*. 2001. 50(2): 463-470.
154. Pritschow, G., Daniel, C., Junghans, G. and Sperling, W. Open system controllers–a challenge for the future of the machine tool industry. *CIRP annals*. 1993. 42(1): 449-452.
155. Brecher, C., Verl, A., Lechler, A. and Servos, M. Open control systems: state of the art. *Production Engineering*. 2010. 4(2-3): 247-254.
156. Nacsa, J. Comparison of three different open architecture controllers. *IFAC Proceedings Volumes*. 2001. 34(10): 115-119.
157. Ueno, S., Chino, S., Hoshino, Y. and Uneme, M. Development of the Standard Application Program Interface (API) for Open FA controller in Japan. *Proc. of the 15th Annual Meeting, ASPE*. 2000. 296-299.
158. Ueno, S., Mitsuishi, M., Muto, K. and Takata, S., *Standard API for Open-architecture CNC and It's Application to HMI and Operation Monitoring*, in

Initiatives of Precision Engineering at the Beginning of a Millennium. 2002, Springer. 789-793.

159. Yang, W. and Zhanbiao, G. An open CNC controller based on LabVIEW software. *2010 International Conference on Computer Application and System Modeling (ICCASM 2010)*. IEEE. 2010. V4-476-V4-479.

160. Proctor, F. M. and Michaloski, J. Enhanced machine controller architecture overviewed.: US Department of Commerce, National Institute of Standards and Technology. 1993.

161. Zheng, J.-m., Zhao, W. and Li, Z. Open EDM CNC system based on RT Linux. *COMPUTER INTEGRATED MANUFACTURING SYSTEMS-BEIJING-*. 2005. 11(8): 1179.

162. HAN, Z.-y., WANG, Y.-z. and FU, H.-y. Development of a PC-based open architecture software-CNC system. *Chinese Journal of Aeronautics*. 2007. 20(3): 272-281.

163. Park, S., Kim, S.-H. and Cho, H. Kernel software for efficiently building, re-configuring, and distributing an open CNC controller. *The International Journal of Advanced Manufacturing Technology*. 2006. 27(7): 788-796.

164. Li, P., Hu, T. and Zhang, C. A unified communication framework for intelligent integrated CNC on the shop floor. *Procedia Engineering*. 2011. 15: 840-847.

165. Roach, R. A., Argibay, N., Allen, K., Balch, D. K., Beghini, L. L., Bishop, J. E., Boyce, B., Brown, J. A., Burchard, R. L. and Chandross, M. E., *Born qualified grand challenge LDRD final report*. 2018, Sandia National Lab.(SNL-NM), Albuquerque, NM (United States); Sandia ….

166. Soori, M., Arezoo, B. and Habibi, M. Tool deflection error of three-axis computer numerical control milling machines, monitoring and minimizing by a virtual machining system. *Journal of Manufacturing Science and Engineering*. 2016. 138(8).

167. Ghani, J. A., Choudhury, I. A. and Hassan, H. H. Application of Taguchi method in the optimization of end milling parameters. *Journal of materials processing technology*. 2004. 145(1): 84-92.

168. Liang, M., Yeap, T., Hermansyah, A. and Rahmati, S. Fuzzy control of spindle torque for industrial CNC machining. *International Journal of Machine Tools and Manufacture*. 2003. 43(14): 1497-1508.

169. Lim, E. M. and Menq, C.-H. Integrated planning for precision machining of complex surfaces. Part 1: cutting-path and feedrate optimization. *International Journal of Machine Tools and Manufacture*. 1997. 37(1): 61-75.

170. Li, Z. Z., Zhang, Z. H. and Zheng, L. Feedrate optimization for variant milling process based on cutting force prediction. *The International Journal of Advanced Manufacturing Technology*. 2004. 24(7-8): 541-552.

171. Henriques, E. Towards the integration of process and production planning: an optimisation model for cutting parameters. *The International Journal of Advanced Manufacturing Technology*. 2006. 28(1-2): 117-128.

172. Satishkumar, S., Asokan, P. and Kumanan, S. Optimization of depth of cut in multi-pass turning using nontraditional optimization techniques. *The International Journal of Advanced Manufacturing Technology*. 2006. 29(3-4): 230-238.

173. Zhang, J., Liang, S. Y., Yao, J., Chen, J. M. and Huang, J. L. Evolutionary optimization of machining processes. *Journal of Intelligent Manufacturing*. 2006. 17(2): 203-215.

174. Shin, Y. C. and Joo, Y. S. Optimization of machining conditions with practical constraints. *The International Journal of Production Research*. 1992. 30(12): 2907-2919.
175. Sönmez, A. İ., Baykasoğlu, A., Dereli, T. and Fılız, İ. H. Dynamic optimization of multipass milling operations via geometric programming. *International Journal of Machine Tools and Manufacture*. 1999. 39(2): 297-320.
176. Agapiou, J. S. The optimization of machining operations based on a combined criterion, part 1: the use of combined objectives in single-pass operations. *TRANSACTIONS-AMERICAN SOCIETY OF MECHANICAL ENGINEERS JOURNAL OF ENGINEERING FOR INDUSTRY*. 1992. 114: 500.
177. Shunmugam, M. S., Reddy, S. V. B. and Narendran, T. T. Selection of optimal conditions in multi-pass face-milling using a genetic algorithm. *International Journal of Machine Tools and Manufacture*. 2000. 40(3): 401-414.
178. Palanisamy, P., Rajendran, I. and Shanmugasundaram, S. Optimization of machining parameters using genetic algorithm and experimental validation for end-milling operations. *The International Journal of Advanced Manufacturing Technology*. 2007. 32(7-8): 644-655.
179. Wang, Z. G., Rahman, M., Wong, Y. S. and Sun, J. Optimization of multi-pass milling using parallel genetic algorithm and parallel genetic simulated annealing. *International Journal of Machine Tools and Manufacture*. 2005. 45(15): 1726-1734.
180. Baskar, N., Asokan, P., Saravanan, R. and Prabhaharan, G. Selection of optimal machining parameters for multi-tool milling operations using a memetic algorithm. *Journal of Materials processing technology*. 2006. 174(1): 239-249.
181. Kassim, N. *The Development of New Step-NC Mapping System for Step-NC Integration*. Ph.D. Universiti Tun Hussein Onn Malaysia; 2015.
182. Zarei, O., Fesanghary, M., Farshi, B., Saffar, R. J. and Razfar, M. R. Optimization of multi-pass face-milling via harmony search algorithm. *Journal of materials processing technology*. 2009. 209(5): 2386-2392.
183. Rao, R. V. and Pawar, P. J. Parameter optimization of a multi-pass milling process using non-traditional optimization algorithms. *Applied soft computing*. 2010. 10(2): 445-456.
184. Yildiz, A. R. A new hybrid differential evolution algorithm for the selection of optimal machining parameters in milling operations. *Applied Soft Computing*. 2013. 13(3): 1561-1566.
185. Li, Y. and Frank, M. C. Machinability analysis for 3-axis flat end milling. *Journal of manufacturing science and engineering*. 2006. 128(2): 454-464.
186. Al-Kindi, G. and Zughaer, H. An approach to improved CNC machining using vision-based system. *Materials and Manufacturing Processes*. 2012. 27(7): 765-774.
187. El-Midany, T. T., Elkeran, A. and Tawfik, H. Optimal CNC plunger selection and toolpoint generation for roughing sculptured surfaces cavity. *Journal of manufacturing science and engineering*. 2006. 128(4): 1025-1029.
188. Suh, S.-H. and Lee, J.-J. Five-axis part machining with three-axis CNC machine and indexing table. *Journal of manufacturing science and engineering*. 1998. 120(1): 120-128.
189. Liu, C., Li, Y., Wang, W. and Shen, W. A feature-based method for NC machining time estimation. *Robotics and Computer-Integrated Manufacturing*. 2013. 29(4): 8-14.

190. Lasemi, A., Xue, D. and Gu, P. Recent development in CNC machining of freeform surfaces: a state-of-the-art review. *Computer-Aided Design*. 2010. 42(7): 641-654.
191. Mattson, M. CNC programming: principles and applicationsed. *US*: Delmar Cengage Learning. 2009.
192. Suneel, T. S. and Pande, S. S. Intelligent tool path correction for improving profile accuracy in CNC turning. *International Journal of Production Research*. 2000. 38(14): 3181-3202.
193. Zhang, Y., Xu, X. and Liu, Y. Numerical control machining simulation: a comprehensive survey. *International Journal of Computer Integrated Manufacturing*. 2011. 24(7): 593-609.
194. De Lacalle, L. N. L., Lamikiz, A., Sanchez, J. A. and Salgado, M. A. Toolpath selection based on the minimum deflection cutting forces in the programming of complex surfaces milling. *International Journal of Machine Tools and Manufacture*. 2007. 47(2): 388-400.
195. Jones, M. T. Artificial intelligence: a systems approached. *USA*: Jones & Bartlett Learning. 2008.
196. El-Mounayri, H., Kishawy, H. and Tandon, V. Optimized CNC end-milling: A practical approach. *International Journal of Computer Integrated Manufacturing*. 2002. 15(5): 453-470.
197. Zhong, Y. Structuralism? Functionalism? Behaviorism? Or mechanism? Looking for a better approach to AI. *International Journal of Intelligent Computing and Cybernetics*. 2008. 1(3): 325-336.
198. Agrawal, R. K., Pratihar, D. K. and Choudhury, A. R. Optimization of CNC isoscallop free form surface machining using a genetic algorithm. *International Journal of Machine Tools and Manufacture*. 2006. 46(7-8): 811-819.
199. Chan*, F. T. S., Wong, T. C. and Chan, L. Y. A genetic algorithm-based approach to machine assignment problem. *International journal of production research*. 2005. 43(12): 2451-2472.
200. Holland, J. H. Adaptation in natural and artificial systems: an introductory analysis with applications to biology, control, and artificial intelligenceed. *USA*: MIT press. 1992.
201. Man, K.-F., Tang, K.-S. and Kwong, S. Genetic algorithms: concepts and applications [in engineering design]. *IEEE transactions on Industrial Electronics*. 1996. 43(5): 519-534.
202. Langevin, A., Soumis, F. and Desrosiers, J. Classification of travelling salesman problem formulations. *Operations Research Letters*. 1990. 9(2): 127-132.
203. Laporte, G. The traveling salesman problem: An overview of exact and approximate algorithms. *European Journal of Operational Research*. 1992. 59(2): 231-247.
204. Qudeiri, J. E. A., Raid, A.-M., Jamali, M. A. and Yamamoto, H. Optimization hole-cutting operations sequence in CNC machine tools using GA. *2006 International conference on service systems and service management*. 25-27 October. France: IEEE. 2006. 501-506.
205. McCulloch, W. S. and Pitts, W. A logical calculus of the ideas immanent in nervous activity. *The bulletin of mathematical biophysics*. 1943. 5(4): 115-133.
206. Karayel, D. Prediction and control of surface roughness in CNC lathe using artificial neural network. *Journal of materials processing technology*. 2009. 209(7): 3125-3137.

207. Liang, P. and Bose, N. K. Neural network fundamentals with graphs, algorithms and applicationsed. *USA*: Mac Graw-Hill. 1996.
208. Ghosh, N., Ravi, Y. B., Patra, A., Mukhopadhyay, S., Paul, S., Mohanty, A. R. and Chattopadhyay, A. B. Estimation of tool wear during CNC milling using neural network-based sensor fusion. *Mechanical Systems and Signal Processing*. 2007. 21(1): 466-479.
209. Yang, J. and Zhuang, Y. An improved ant colony optimization algorithm for solving a complex combinatorial optimization problem. *Applied Soft Computing*. 2010. 10(2): 653-660.
210. Ülker, E., Turanalp, M. E. and Halkaci, H. S. An artificial immune system approach to CNC tool path generation. *Journal of Intelligent Manufacturing*. 2009. 20(1): 67-77.
211. Castro, L. N., De Castro, L. N. and Timmis, J. Artificial immune systems: a new computational intelligence approached. *London*: Springer. 2002.
212. Li, Z., Zhang, Y. and Tan, H.-Z. IA-AIS: An improved adaptive artificial immune system applied to complex optimization problems. *Applied Soft Computing*. 2011. 11(8): 4692-4700.
213. Wang, X.-L., Cheng, J.-H., Yin, Z.-J. and Guo, M.-J. A new approach of obtaining reservoir operation rules: Artificial immune recognition system. *Expert Systems with Applications*. 2011. 38(9): 11701-11707.
214. Dorigo, M. and Blum, C. Ant colony optimization theory: A survey. *Theoretical computer science*. 2005. 344(2-3): 243-278.
215. Dorigo, M., Maniezzo, V. and Colorni, A. Ant system: optimization by a colony of cooperating agents. *IEEE Transactions on Systems, man, and cybernetics, Part B: Cybernetics*. 1996. 26(1): 29-41.
216. Mohan, B. C. and Baskaran, R. A survey: Ant Colony Optimization based recent research and implementation on several engineering domain. *Expert Systems with Applications*. 2012. 39(4): 4618-4627.
217. Dorigo, M. and Stützle, T. Ant Colony Optimizationed. *Berlin*: Springer. 2004.
218. Dorigo, M. *Optimization, learning and natural algorithms*. Ph. D. Politecnico di Milano; 1992.
219. Kennedy, J. and Eberhart, R. Particle swarm optimization. *Proc. IEEE International Conference on Neural Networks*. 27 November -1 December. Australia: IEEE. 1995. 1942-1948.
220. Shi, X. H., Liang, Y. C., Lee, H. P., Lu, C. and Wang, Q. X. Particle swarm optimization-based algorithms for TSP and generalized TSP. *Information processing letters*. 2007. 103(5): 169-176.
221. Kanan, H. R. and Faez, K. An improved feature selection method based on ant colony optimization (ACO) evaluated on face recognition system. *Applied Mathematics and Computation*. 2008. 205(2): 716-725.
222. Li, J. G., Yao, Y. X., Gao, D., Liu, C. Q. and Yuan, Z. J. Cutting parameters optimization by using particle swarm optimization (PSO). *Applied Mechanics and Materials*. 2008. 10: 879-883.
223. Chen, C. J. and Tseng, C. S. The path and location planning of workpieces by genetic algorithms. *Journal of Intelligent Manufacturing*. 1996. 7(1): 69-76.
224. Dereli, T., Filiz, I. H. and Baykasoglu, A. Optimizing cutting parameters in process planning of prismatic parts by using genetic algorithms. *International Journal of Production Research*. 2001. 39(15): 3303-3328.

225. Castelino, K., D'Souza, R. and Wright, P. K. Toolpath optimization for minimizing airtime during machining. *Journal of Manufacturing Systems*. 2003. 22(3): 173-180.
226. Cus, F. and Balic, J. Optimization of cutting process by GA approach. *Robotics and Computer-Integrated Manufacturing*. 2003. 19(1-2): 113-121.
227. Oysu, C. and Bingul, Z. Application of heuristic and hybrid-GASA algorithms to tool-path optimization problem for minimizing airtime during machining. *Engineering Applications of Artificial Intelligence*. 2009. 22(3): 389-396.
228. Qudeiri, J. A., Yamamoto, H. and Ramli, R. Optimization of operation sequence in CNC machine tools using genetic algorithm. *Journal of Advanced Mechanical Design, Systems, and Manufacturing*. 2007. 1(2): 272-282.
229. Saravanan, R. and Janakiraman, V. Study on reduction of machining time in CNC turning centre by genetic algorithm. *International Conference on Computational Intelligence and Multimedia Applications (ICCIMA 2007)*. 13-15 December. India: IEEE. 2007. 481-486.
230. Savas, V. and Ozay, C. The optimization of the surface roughness in the process of tangential turn-milling using genetic algorithm. *The International Journal of Advanced Manufacturing Technology*. 2008. 37(3-4): 335-340.
231. Liu, M., Ding, X., Yan, Y. and Ci, X. Study on optimal path changing tools in CNC turret typing machine based on genetic algorithm. *International Conference on Computer and Computing Technologies in Agriculture*. 22-25 October. Berlin: Springer. 2010. 345-354.
232. Zuperl, U. and Cus, F. Optimization of cutting conditions during cutting by using neural networks. *Robotics and Computer-Integrated Manufacturing*. 2003. 19(1-2): 189-199.
233. Zuperl, U., Cus, F., Mursec, B. and Ploj, T. A hybrid analytical-neural network approach to the determination of optimal cutting conditions. *Journal of Materials Processing Technology*. 2004. 157: 82-90.
234. Mahdavinejad, R. A., Khani, N. and Fakhrabadi, M. M. S. Optimization of milling parameters using artificial neural network and artificial immune system. *Journal of Mechanical Science and Technology*. 2012. 26(12): 4097-4104.
235. Ghaiebi, H. and Solimanpur, M. An ant algorithm for optimization of hole-making operations. *Computers & Industrial Engineering*. 2007. 52(2): 308-319.
236. Wu, J. and Yao, Y. A modified ant colony system for the selection of machining parameters. *2008 Seventh International Conference on Grid and Cooperative Computing*. 24-26 October. China: IEEE. 2008. 89-93.
237. Cus, F., Balic, J. and Zuperl, U. Hybrid ANFIS-ants system based optimisation of turning parameters. *Journal of Achievements in Materials and Manufacturing Engineering*. 2009. 36(1): 79-86.
238. Abbas, A. T., Aly, M. F. and Hamza, K. Optimum drilling path planning for a rectangular matrix of holes using ant colony optimisation. *International Journal of Production Research*. 2011. 49(19): 5877-5891.
239. Medina-Rodríguez, N., Montiel-Ross, O., Sepúlveda, R. and Castillo, O. Tool Path Optimization for Computer Numerical Control Machines based on Parallel ACO. *Engineering Letters*. 2012. 20(1): 1-8.
240. Wang, S. G., Wang, Y. J., Wu, G. X. and Fu, Y. L. Application of intelligence fusion algorithm in path optimization problem. *Applied Mechanics and Materials*. 2012. 151: 632-636.

241. Onwubolu, G. C. and Clerc, M. Optimal path for automated drilling operations by a new heuristic approach using particle swarm optimization. *International Journal of Production Research*. 2004. 42(3): 473-491.
242. Zuperl, U., Cus, F. and Gecevska, V. Optimization of the characteristic parameters in milling using the PSO evolution technique. *Strojniski vestnik*. 2007. 53(6): 354-368.
243. Xi, J. and Liao, G. Cutting parameter optimization based on particle swarm optimization. *2009 Second International Conference on Intelligent Computation Technology and Automation*. 10-11 October. China: IEEE. 2009. 255-258.
244. Prakasvudhisarn, C., Kunnapapdeelert, S. and Yenradee, P. Optimal cutting condition determination for desired surface roughness in end milling. *The International Journal of Advanced Manufacturing Technology*. 2009. 41(5-6): 440-448.
245. Srinivas, J., Giri, R. and Yang, S.-H. Optimization of multi-pass turning using particle swarm intelligence. *The International Journal of Advanced Manufacturing Technology*. 2009. 40(1-2): 56-66.
246. Zheng, L. Y. and Ponnambalam, S. G. Optimization of multipass turning operations using particle swarm optimization. *7th International Symposium on Mechatronics and its Applications*. 20-22 April. United Arab Emirates: IEEE. 2010. 1-6.
247. Hsieh, H.-T. and Chu, C.-H. Improving optimization of tool path planning in 5-axis flank milling using advanced PSO algorithms. *Robotics and Computer-Integrated Manufacturing*. 2013. 29(3): 3-11.
248. Klancnik, S., Brezocnik, M., Balic, J. and Karabegovic, I. Programming of CNC milling machines using particle swarm optimization. *Materials and manufacturing processes*. 2013. 28(7): 811-815.
249. Raja, S. B. and Baskar, N. Application of particle swarm optimization technique for achieving desired milled surface roughness in minimum machining time. *Expert Systems with Applications*. 2012. 39(5): 5982-5989.
250. Kanna, S., Tovar, A., Wou, J. and El-Mounayri, H. DETC2014-34884. *8th International Conference on Micro- and Nanosystems*. August 17–20. USA: ASME. 2016. 1-6.
251. Mehne, H. H. and Mirjalili, S. A parallel numerical method for solving optimal control problems based on whale optimization algorithm. *Knowledge-Based Systems*. 2018. 151: 114-123.
252. Balic, J. and Korosec, M. Intelligent tool path generation for milling of free surfaces using neural networks. *International Journal of Machine Tools and Manufacture*. 2002. 42: 1171-1179.
253. Weng, S.-S. and Liu, Y.-H. Mining time series data for segmentation by using Ant Colony Optimization. *European Journal of Operational Research*. 2006. 173(3): 921-937.
254. Zhang, X. and Tang, L. A new hybrid ant colony optimization algorithm for the vehicle routing problem. *Pattern Recognition Letters*. 2009. 30(9): 848-855.
255. Chen, W.-J. Combination of LabVIEW and Improved Ant Colony Algorithms for Optimization Path Design of Pneumatic Robot Manipulator. *International Journal of Science and Engineering Investigations*. 2012. 1(5): 33-39.

256. Bahar, B., M. F. Miskon, N. A. Bakar, A. Z. Shukor and Ali, F. On Boostrap Prediction Intervals for Autoregressive Model. *Australian Journal of Basic and Applied Sciences*. 2014. 8(6): 385-389.
257. Ab Rashid, M. F. F., Mohamed, N. M. Z. N., Rose, A. N. M., Ghani, S. A. C. and Harun, W. S. W. Implementation of Ant Colony Optimization Algorithm to Minimize Cost of Turning Process. *Applied Mechanics & Materials*. 2014. 695: 558–561.
258. M Diwekar, U. and H Gebreslassie, B. Efficient Ant Colony Optimization (EACO) Algorithm for Deterministic Optimization. *International Journal of Swarm Intelligence and Evolutionary Computation*. 2015. 05(01): 1-9.
259. Yue, Y. m. and Wang, X. An Improved Ant Colony Optimization Algorithm for Solving TSP. *International Journal of Multimedia and Ubiquitous Engineering*. 2015. 10(12): 153-164.
260. Zainal, N., Zain, A. M., Radzi, N. H. M. and Othman, M. R. Glowworm swarm optimization (GSO) for optimization of machining parameters. *Journal of Intelligent Manufacturing*. 2016. 27(4): 797-804.
261. Yıldız, B. S. and Yıldız, A. R. Moth-flame optimization algorithm to determine optimal machining parameters in manufacturing processes. *Materials Testing*. 2017. 59(5): 425-429.
262. Stojadinovic, S. M., Majstorovic, V. D., Durakbasa, N. M. and Sibalija, V. T. Ants colony optimisation of a measuring path of prismatic parts on a cmm. *Metrology and Measurement Systems*. 2016. 23(1): 119-132.
263. Rao, R. V., Rai, D. P. and Balic, J. A multi-objective algorithm for optimization of modern machining processes. *Engineering Applications of Artificial Intelligence*. 2017. 61: 103-125.
264. Abhishek, K., Kumar, V. R., Datta, S. and Mahapatra, S. S. Parametric appraisal and optimization in machining of CFRP composites by using TLBO (teaching–learning based optimization algorithm). *Journal of Intelligent Manufacturing*. 2017. 28(8): 1769-1785.
265. Jing, J., Feng, P., Wei, S. and Zhao, H. Investigation on surface morphology model of Si3N4 ceramics for rotary ultrasonic grinding machining based on the neural network. *Applied Surface Science*. 2017. 396: 85-94.
266. Sangwan, K. S. and Kant, G. Optimization of machining parameters for improving energy efficiency using integrated response surface methodology and genetic algorithm approach. *Procedia CIRP*. 2017. 61(1): 517-522.
267. Abhishek, K., Kumar, V. R., Datta, S. and Mahapatra, S. S. Application of JAYA algorithm for the optimization of machining performance characteristics during the turning of CFRP (epoxy) composites: comparison with TLBO, GA, and ICA. *Engineering with Computers*. 2017. 33(3): 457-475.
268. Shukla, A., Agarwal, P., Rana, R. S. and Purohit, R. Applications of TOPSIS algorithm on various manufacturing processes: a review. *Materials Today: Proceedings*. 2017. 4(4): 5320-5329.
269. Shukla, R. and Singh, D. Selection of parameters for advanced machining processes using firefly algorithm. *Engineering Science and Technology, an International Journal*. 2017. 20(1): 212-221.
270. Santhanakrishnan, M., Sivasakthivel, P. S. and Sudhakaran, R. Modeling of geometrical and machining parameters on temperature rise while machining Al 6351 using response surface methodology and genetic algorithm. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*. 2017. 39(2): 487-496.

271. Johari, N. F., Zain, A. M., Mustaffa, N. H. and Udin, A. Machining parameters optimization using hybrid firefly algorithm and particle swarm optimization. *The 6th International Conference on Computer Science and Computational Mathematics (ICCSCM 2017)*. 4–5 May. Malaysia: IOP Publishing. 2017. 12005.

272. Mohanty, C. P., Mahapatra, S. S. and Singh, M. R. An intelligent approach to optimize the EDM process parameters using utility concept and QPSO algorithm. *Engineering Science and Technology, an international journal*. 2017. 20(2): 552-562.

273. Saw, L. H., Ho, L. W., Yew, M. C., Yusof, F., Pambudi, N. A., Ng, T. C. and Yew, M. K. Sensitivity analysis of drill wear and optimization using Adaptive Neuro fuzzy–genetic algorithm technique toward sustainable machining. *Journal of Cleaner Production*. 2018. 172: 3289-3298.

274. Sen, R., Choudhuri, B., Barma, J. D. and Chakraborti, P. Optimization of wire EDM parameters using teaching learning based algorithm during machining of maraging steel 300. *Materials Today: Proceedings*. 2018. 5(2): 7541-7551.

275. Ram Prabhu, T., Savsani, V., Parsana, S., Radadia, N., Sheth, M. and Sheth, N. Multi-Objective Optimization of EDM Process Parameters by Using Passing Vehicle Search (PVS) Algorithm. *Defect and Diffusion Forum*. 2018. 382: 138-146.

276. Hajimiri, H., Abedini, V., Shakeri, M. and Siahmargoei, M. H. Simultaneous fixturing layout and sequence optimization based on genetic algorithm and finite element method. *The International Journal of Advanced Manufacturing Technology*. 2018. 97(9-12): 3191-3204.

277. Rao, R. V., Rai, D. P. and Balic, J. Optimization of abrasive waterjet machining process using multi-objective jaya algorithm. *Materials Today: Proceedings*. 2018. 5(2): 4930-4938.

278. Majumder, A., Das, A. and Das, P. K. A standard deviation based firefly algorithm for multi-objective optimization of WEDM process during machining of Indian RAFM steel. *Neural Computing and Applications*. 2018. 29(3): 665-677.

279. Zhang, X. X., Wang, Z. C. and Chen, H. Y. Optimization of Milling Parameters for Titanium Alloys Based on Support Vector Machine (Machine Learning) and Ant Colony Optimization Algorithm. *Key Engineering Materials*. 2018. 770: 262-267.

280. Wang, R., Zhao, J., Liu, F., Gao, C., Xie, L., Meng, X., Sun, Y. and Liu, C.(2018). *New optimization method for SPS-ALPHA Mark-II based on improved ACO algorithm*. *Northwestern Polytechnical University*. Retrieved on January 31, 2018, from https://en.nwpu.edu.cn/info/1175/2798.htm.

281. Pandey, A. K. Computer aided Genetic Algorithm based Optimization of Electrical Discharge Drilling in Titanium alloy (Grade-5) Sheet. *Materials Today: Proceedings*. 2019. 18: 4869-4881.

282. Stojadinović, S. M. and Majstorović, V. D. Ant Colony Optimisation of the Measuring Path of PMPs on a CMMed. *Cham*: Springer. 2019.

283. Shaomin, L., Deyuan, Z., Daxi, G., Zhenyu, S. and Hui, T. Modeling and drilling parameters optimization on burr height using harmony search algorithm in low-frequency vibration-assisted drilling. *The International Journal of Advanced Manufacturing Technology*. 2019. 101(9-12): 2313-2325.

284. Azadi Moghaddam, M. and Kolahan, F. Modeling and optimization of the electrical discharge machining process based on a combined artificial neural

network and particle swarm optimization algorithm. *Scientia Iranica*. 2019. 27(3): 1206-1217.

285. Singh, M., Ramkumar, J., Rao, V. R. and Balic, J. Experimental investigation and multi-objective optimization of micro-wire electrical discharge machining of a titanium alloy using Jaya algorithm. *Advances in Production Engi*. 2019. 14(2): 251-263.

286. Hazir, E. and Ozcan, T. Response surface methodology integrated with desirability function and genetic algorithm approach for the optimization of CNC machining parameters. *Arabian Journal for Science and Engineering*. 2019. 44(3): 2795-2809.

287. Satpathy, M. P. and Routara, B. C. Modeling and Optimization of Ultrasonic Machining Process Using a Novel Evolutionary Algorithmed. *India*: IGI Global. 2019.

288. Deris, A. M., Zain, A. M., Sallehuddin, R. and Sharif, S. Modeling and Optimization of Electric Discharge Machining Performances using Harmony Search Algorithm. *ELEKTRIKA-Journal of Electrical Engineering*. 2019. 18(3-2): 56-61.

289. Wang, H., Zhong, R. Y., Liu, G., Mu, W., Tian, X. and Leng, D. An optimization model for energy-efficient machining for sustainable production. *Journal of Cleaner Production*. 2019. 232: 1121-1133.

290. Ebadinezhad, S. DEACO: Adopting dynamic evaporation strategy to enhance ACO algorithm for the traveling salesman problem. *Engineering Applications of Artificial Intelligence*. 2020. 92: 36-49.

291. Zhu, C. and Tang, F. Laser Processing Path Planning Based on GA Improved ACO. *2020 12th International Conference on Measuring Technology and Mechatronics Automation (ICMTMA)*. 2020. Thailand: IEEE. 2020. 80-84.

292. Ahammed, T., Qudeiri, J. A., Mourad, A.-H., Ziout, A. and Safieh, F. Intelligent Sequence Optimization Method for Hole Making Operations in 2M Production Lineed. *Cham*: Springer. 2020.

293. Dandge, S. and Chakraborty, S. Selection of Machining Parameters in Ultrasonic Machining Process Using CART Algorithmed. *Singapore*: Springer. 2020.

294. Kumar, M. and Khatak, P. Development of a Discretization Methodology for 2.5 D Milling Toolpath Optimization Using Genetic Algorithmed. *Singapore*: Springer. 2020.

295. Zaretalab, A., Haghighi, S. S., Mansour, S. and Sajadieh, M. S. An integrated stochastic model to optimize the machining condition and tool maintenance policy in the multi-pass and multi-stage machining. *International Journal of Computer Integrated Manufacturing*. 2020. 33(3): 211-228.

296. Zuperl, U. and Cus, F. Combined Intelligent and Adaptive Optimization in End Milling of Multi-layered 16MnCr5/316Led. *Singapore*: Springer. 2020.

297. Dorigo, M., Gambardella, L. M., Birattari, M., Martinoli, A., Poli, R. and Stützle, T. Ant Colony Optimization and Swarm Intelligenceed. *Belgium*: ANTS 2006.

298. Serpell, M. and Smith, J. Initial application of ant colony optimisation to statistical disclosure control. *Proceedings of the 15th annual conference on Genetic and evolutionary computation*. 2013. Netherlands: Association for Computing Machinery. 2013. 97-104.

299. Deneubourg, J. L., Aron, S., Goss, S. and Pasteels, J. M. The self-organizing exploratory pattern of the argentine ant. *Journal of insect behavior*. 1990. 3(2): 159-168.
300. Dorigo, M. and Stützle, T. From Real to Artificial Ants. *Ant Colony Optimization*. 2018. 7: 1-24.
301. Blum, C. Ant colony optimization: Introduction and recent trends. *Physics of Life reviews*. 2005. 2(4): 353-373.
302. Bullnheimer, B., Hartl, R. F. and Strauss, C. A new rank based version of the Ant System. A computational study. *Adaptive Information Systems and Modelling in Economics and Management Science*. 1997. 3: 15-20.
303. Stützle, T. and Hoos, H. H. MAX–MIN ant system. *Future generation computer systems*. 2000. 16(8): 889-914.
304. Monmarché, N., Venturini, G. and Slimane, M. On how Pachycondyla apicalis ants suggest a new search algorithm. *Future generation computer systems*. 2000. 16(8): 937-946.
305. Dréo, J. and Siarry, P. Continuous interacting ant colony algorithm based on dense heterarchy. *Future Generation Computer Systems*. 2004. 20(5): 841-856.
306. Bilchev, G. and Parmee, I. C. The ant colony metaphor for searching continuous design spaces. *AISB workshop on evolutionary computing*. April 3–4. UK: Springer. 1995. 25-39.
307. Socha, K. and Dorigo, M. Ant colony optimization for continuous domains. *European journal of operational research*. 2008. 185(3): 1155-1173.
308. Praveen, V., Keerthika, P., Sarankumar, A. and Sivapriya, G. A Survey on Various Optimization Algorithms to Solve Vehicle Routing Problem. *2019 5th International Conference on Advanced Computing & Communication Systems (ICACCS)*. 15-16 March 2019. India: IEEE. 2019. 134-137.
309. Halim, A. H. and Ismail, I. Combinatorial optimization: comparison of heuristic algorithms in travelling salesman problem. *Archives of Computational Methods in Engineering*. 2019. 26(2): 367-380.
310. Guo, Z., Wang, M., Wu, J., Tao, F., Chen, Q., Wang, Q., Ouyang, Q., Shi, J. and Zou, X. Quantitative assessment of zearalenone in maize using multivariate algorithms coupled to Raman spectroscopy. *Food chemistry*. 2019. 286: 282-288.
311. Stiitzle, T. and Hoos, H. The MAX-MIN ant system and local search for the traveling salesman problem. *Proceedings of IEEE international conference on evolutionary computation*. 13-16 April. USA: IEEE. 1997. 309-314.
312. Gutjahr, W. J. A graph-based ant system and its convergence. *Future generation computer systems*. 2000. 16(8): 873-888.
313. Guntsch, M. and Middendorf, M. Applying population based ACO to dynamic optimization problems. *International Workshop on Ant Algorithms*. September 10-12. Berlin: Springer. 2002. 111-122.
314. Bianchi, L., Gambardella, L. M. and Dorigo, M. An ant colony optimization approach to the probabilistic traveling salesman problem. *International Conference on Parallel Problem Solving from Nature*. September 7–11. Spain: Springer. 2002. 883-892.
315. Socha, K. ACO for continuous and mixed-variable optimization. *International Workshop on Ant Colony Optimization and Swarm Intelligence*. 5-8 September. Berlin: Springer. 2004. 25-36.

316. Gajpal, Y. and Abad, P. An ant colony system (ACS) for vehicle routing problem with simultaneous delivery and pickup. *Computers & Operations Research*. 2009. 36(12): 3215-3223.
317. Shojaeipour, S. A Novel Method for Automated Tool Path Optimisation for CNC Machining Operations. *Solid State Phenomena*. 2010. 166: 357-362.
318. Yun, H.-Y., Jeong, S.-J. and Kim, K.-S. Advanced harmony search with ant colony optimization for solving the traveling salesman problem. *Journal of Applied Mathematics*. 2013. 2013: 1-8.
319. Eskandari, L., Jafarian, A., Rahimloo, P. and Baleanu, D. A Modified and Enhanced Ant Colony Optimization Algorithm for Traveling Salesman Problemed. *Cham*: Springer. 2019.
320. Mavrovouniotis, M., Bonilha, I. S., Müller, F. M., Ellinas, G. and Polycarpou, M. Effective ACO-Based Memetic Algorithms for Symmetric and Asymmetric Dynamic Changes. *2019 IEEE Congress on Evolutionary Computation (CEC)*. 10-13 June 2019. New Zealand: IEEE. 2019. 2567-2574.
321. Singh, N. J. and Mediratta, S. R. Quadrative Assignment Problems (QAP) using Ant Colony Optimization (ACO). *International Journal of Applied Engineering Research*. 2019. 14(21): 3996-4000.
322. Chandra, I. and Riadi, J. *Cognitive Ant Colony Optimization : A New Framework in Swarm Intelligence Cognitive Ant Colony Optimization : A New Framework in Swarm Intelligence*. Ph.D. University of Salford; 2014.
323. Dorigo, M., Bonabeau, E. and Theraulaz, G. Ant algorithms and stigmergy. *Future Generation Computer Systems*. 2000. 16(8): 851-871.
324. Martinez, C., Castillo, O. and Montiel, O. Comparison between ant colony and genetic algorithms for fuzzy system optimizationed. *Berlin*: Springer. 2008.
325. Deb, K. and Padhye, N. Development of efficient particle swarm optimizers by using concepts from evolutionary algorithms. *Proceedings of the 12th annual conference on Genetic and evolutionary computation*. 10 July. USA Association for Computing Machinery. 2010. 55-62.
326. Rini, D. P., Shamsuddin, S. M. and Yuhaniz, S. S. Particle swarm optimization: technique, system and challenges. *International journal of computer applications*. 2011. 14(1): 19-26.
327. Abdullah, H., Ramli, R., Wahab, D. A. and Qudeiri, J. A. Minimizing machining airtime motion with an ant colony algorithm. *ICIC Express Letters*. 2016. 10(1): 161-165.
328. Dewil, R., Küçükoğlu, İ., Luteyn, C. and Cattrysse, D. A critical review of multi-hole drilling path optimization. *Archives of Computational Methods in Engineering*. 2019. 26(2): 449-459.
329. Latif, K., Adam, A., Yusof, Y. and Kadir, A. Z. A. A review of G code, STEP, STEP-NC, and open architecture control technologies based embedded CNC systems. *The International Journal of Advanced Manufacturing Technology*. 2021. 1-18.
330. Pacheco, N. d. O., Harbs, E., Rosso, R. S. U., Hounsell, M. d. S. and Ferreira, J. C. E. Application of The Step-NC Standard in a Computer Numerical Controlled Machining Device. *ABCM Symposium Series in Mechatronics*. 2012. 5: 713-723.
331. Dalavi, A., Pawar, P. and Singh, T. Determination of optimal tool path in drilling operation using Modified Shuffled Frog Leaping Algorithm. *International Journal for Engineering Modelling*. 2019. 32(2-4 Regular Issue): 33-44.

332. Karuppusamy, N. S. and Kang, B.-Y. Minimizing airtime by optimizing tool path in computer numerical control machine tools with application of A* and genetic algorithms. *Advances in Mechanical Engineering*. 2017. 9(12).