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Simulation Program for 4th Axis CNC Machining in NX CAM System

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ABSTRACT

This paper presents the development of a simulation program to improve the process planning and simulation for 4th axis machining in NX CAM systems. A customised graphical user interface (GUI) was developed to enhance the simulation process planning and reduce the dependency on the user's experience while developing the machining program in NX CAM systems. The simulation operation was recorded using a journaling tool available in NX CAM while visual basic programming was utilised to customise the code. The results indicate that the developed programs are capable of optimising the 4th axis machining simulation by reducing the processing steps and time with minimum process planning tasks.

Keywords: Visual Basic programming (VB); computer-aided manufacturing (CAM); simulation; 4th axis machining; process planning.

INTRODUCTION

In the real industry, planning of machining processes is the most important thing to be considered in order to increase operational efficiencies. Milling operation is widely used in the manufacturing sector due to its flexibility of machining approach and high precision in terms of geometrical accuracy. Most milling operation is handled by an experienced machinist to machine the standard or custom parts based on the customer's request. For the process parameter, it does not have a fixed value and depends on the features of the part to be machined. Commonly, machining parameters are determined based on the machinist's experience or can be referred to a machining handbook. However, process parameters determination indirectly affects the time required to develop machining process planning. Experienced machinists utilise minimal time to build the process planning based on their experience in developing machining operations. For machinists who are lack of experience, it definitely delays the process. Consequently, process planning optimisation is an effective approach to develop efficient machining with an optimal strategy.

In the manufacturing industries, simulation can be defined as the routines for pre-evaluation processes for selected machining operations. Before the actual machining operation, the simulation model for the desired machining operation is developed first in order to study the behaviour of the processes virtually. By doing this, the problem or issue in the machining operation can be identified at the early stages during simulation [1]. In general, machining simulation can be executed in most CAM systems. Analysis conducted during simulations allows CAM systems to be a design tool for developing a new process planning [2]. Various types of machining scenarios can be thoroughly analysed without involving the risk of tool collision and wastage of the workpiece. To develop a machining simulation, selection of operation and process planning are the most important aspects to be considered. In CNC machining, these two criteria indirectly affect the overall operation processing time, operation cost, and machining procedure efficiency [3]. For example, if machining operations require recurring processes to be analysed, the consistency of procedures and input parameters is very important to be carefully controlled so that the obtained results are accurate. By implementing the correct and reliable process steps in the planning phase, high-quality machining results can be achieved [4]. The latest development in machining simulation systems proposed the integration of independent programming to execute certain functions in CAD/CAM systems [5].

Through the proposed approach, custom programs can be developed to control machining operations during the planning stages. This article discussed the development of a customised machining simulation application by integrating Visual Basic Programming in NX CAM system. In the manufacturing section, NX CAM offered various mill type operations including mill planar, mill contour, and millmulti-axis. However, this study is focusing on Mill Contour setup because the operation is adaptable to various kind of surfaces. In 4^{th} axis machining, the cutting tool engages the workpiece in various orientation and thus need to deal with planar and contour surfaces. This is considered as an optimum mill set up in the nature of 4^{th} axis machining within the NX CAM systems. The application aims to generate machining operation with minimum process planning tasks. The paper is organized in the following way: Section 2 provides a review of the previous researches in applying the programming tools within CAD/CAM systems for simulation data management, modelling development, and process planning optimisation. Section 3 briefly discusses the back-end program architecture, design framework, and methodology to develop the proposed program in this paper. The implementation of the developed machining simulation on selected models is described in section 4. Finally, the conclusion was drawn, and suggestions made for future research development.

PROCESS PLANNING OVERVIEW

The generation of detail planning in the manufacturing industry is an important process in order to produce a part that meets the geometry requirements and design specification Scallan [6]. Process planning is related to the method to fabricate the parts in terms of tools, fixtures, machinery, operating sequences, and assemblies. These methods have been traditionally done by process planners and documented in routing sheets. All these are the main factors contributing to labour-intensiveness, time-consumption, and relying heavily on a process planner's experience [7].

Classification of Process Planning

In general, process planning can be defined as an engineering activity to determine the appropriate procedures for the process of transforming raw materials into a product determined by the engineering design [8]. Once the procedure has been finalised, the task shifts to a process planner where he must be efficient and complete the task on schedule. Therefore, it is important to ensure that the machining processes of these parts are in the right specification, high geometric accuracy, with the minimum possible cost, and completed on time. In the CNC machining processes, there are various types of data and information required which is one of the factors that contribute to the complexity of process planning. All the data and information should be carefully assessed so that it meets the product requirements and specifications. Therefore, the use of various aid-supports such as CAD/CAM and CAPP are needed in order to obtain an optimal machining process. Process planning is classified into two categories: manual process planning (MPP) and computer-aided process planning (CAPP). At present, there are two general approaches to MPP, which are traditional and workbook, while in CAPP approach, there are variant and generative approaches. Each of these approaches is associated with specific planning techniques. Figure 1 shows the classification approach to represent process planning.

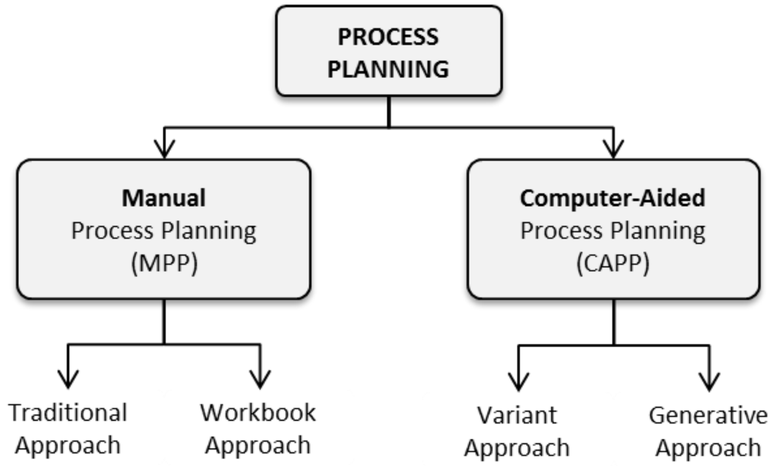

Figure 1. Classification of process planning.

Manual process planning (MPP) is totally based on the machining planner's experiences, skills, and knowledge in terms of machining equipment, processes, and tooling. In the traditional approach, process planning is performed manually by experienced process planners in manufacturing background to decide on the type of material and processes to be used [9]. The tools feed, and speeds recommended for the particular processes are referred to manual worksheets. All the procedures and operations are documented in the process planning template called Routing Sheet [6]. In some companies, process plans are manually classified and stored in workbooks [10]. The workbook approach is a derivative of the traditional approach.

A sequence of operations for the manufacture of certain types of parts is loaded in the workbook. When the required process has been identified in terms of drawing interpretation and manufacturing, the operation sequences are selected in the workbook and incorporated into the process plan. The need for shorter processing time and chasing the customer's demands have led the industry to initiate automation in production cycles [9]. Computer-Aided Process Planning (CAPP) is a system where computers are used to replace human intervention in order to produce good process plans at an optimum time [11]. The basic concept of CAPP is to automate the process planning activities, where time and efforts were reduced and result in a high process plan consistency.

The variant process planning approach, also called retrieval approach, can be described as an advanced manual approach where the standard plan is retrieved and modified by a computer to suit a given part [10]. The plan is displayed for review and printed as a routing sheet. It includes information such as the type of machines and tool to be used, the sequences of the manufacturing operations, speed, feed, and time consumed for each sequence. The generative process planning approach is a nearly automated approach to process planning. The plans are developed by a computer in terms of decision logic, formulae, algorithm, and geometric analysis. However, the generative process planning approach is complicated because it contains detail information about the geometry and dimension of the part. This approach is capable of developing new standard plans instead of using and modifying an existing plan as in the variant approach [7]. Basically, in the development of product designs and manufacturing, process planning plays an important role in improving product performance and reducing time consumption [12]. The implementation of CAPP has been studied by the generation of CNC codes in CAM software [13]. The algorithm is developed to generate the tool path and integrate the same with commercial software.

Basics of Process Planning Procedure

A basic process planning procedure is illustrated in Figure 2. The brief description of each activity is explained clearly afterwards. Each activity involves various methods in the retrieval of information, decisions, and information selection. Macro-process planning refers to the selection of the optimal sequence of different process steps, set-ups, and the selection of machine. Micro-process planning, also known as operations planning, aimed at optimising each individual operation regarding tool use, machining parameters, and tool paths [14]. There are different attempts to improve the level of process planning, especially through automation. Most of the automation attempts are aimed at the micro-process planning stage.

A process planning is started from drawing interpretation. A thorough analysis of the drawing was carried out before beginning with the actual planning. Process planners should consider the materials in terms of type and properties, geometry, features, tolerances, surface finishes, and quality. In machining process selection, a production planner needs to make an early decision on the production technology to be used. When the decision has been finalised, the process planner takes over the task of making decisions on the sub-processes and sequences. The next procedure is the machine tool selection. The selected processes and operations affect the suitability in machine selection. Each machine has different features and specifications, including the number of axes, machine stability, number of tools, maximum spindle speed, work area space, and etc. Sometimes, freedom of choice is very limited and specified. For the selection of blank or workpieces, it depends on the planned volume of production (either low or high). If the volume of production is low, then, the small blank is reasonable, but as long as the production volumes are high, then, a large blank was used. It is a matter of a trade-off between blank cost and machining cost.

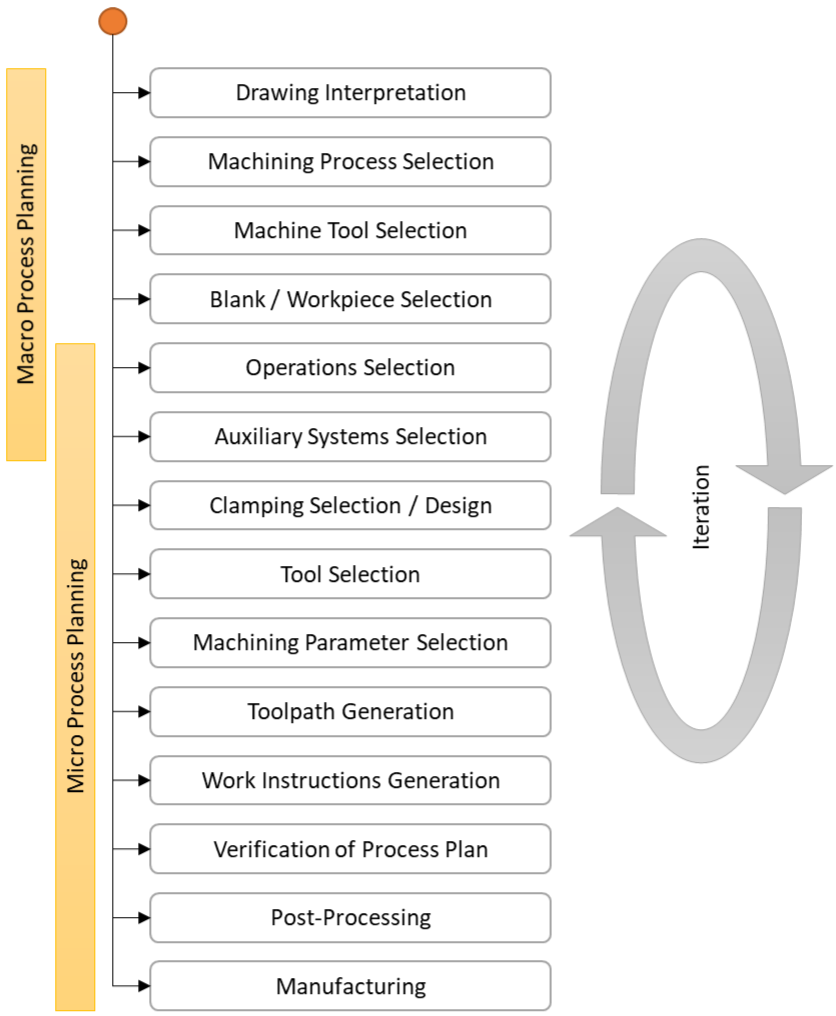

Figure 2. General process planning task.

The next procedure is the selection of the auxiliary system. Most of the machine tools work with other systems in the manufacturing system. For example, machine tools can be a part of a production line or flexible manufacturing system (FMS) and delivered by robots or other automated equipment. For the cutting tools selection, it greatly affects the machining processes in terms of cost, time, and the possibility of achieving the specified dimensions and characteristics. In the meantime, there is an interconnection between the cutting tool, machining parameters, tool path, and cutting processes. Normally, the tools are supplied with a variety of materials, coating, and micro/macro geometry.

The selection of the cutting tools affects the machined parts' surface finish and the resulting forces on the workpieces which lead to vibrations. The main factors to consider for the tool selection are tool geometry, tool life, and material removal rate (MRR). However, in order to reduce the level of complexity in process planning, minimising the use of different tools is the best way. In addition, it can also optimise the time for a tool change, setup time, and operating costs. The next procedure is the selection of the machining parameters. This procedure is closely related to machining time and machining cost. Generally, the process parameter includes spindle speed, feed rate, and depth of cut. The value to be set for each parameter is different and depends on the process to be implemented. For the tool path generation procedure, it can be implemented through two methods, manually on the CNC machine or through the CAM application. Generating tool path is a part of the procedure in the entire machining strategy which is related to machining parameters and tools geometry. It is important to know how certain features can be machined to prevent errors in the machining operation. In the meantime, defining the machining strategies for complex geometry is also important, where optimal cutting conditions throughout the process must be considered. Normally, CNC machines have been programmed to define constraints for certain process design. The output of this step is the generation of NC programs.

The verification of the process plan is essential to ensure that the intended product is executed correctly, smoothly, and according to specifications. Basically, the verification process is done by simulation methods using CAM systems or directly to the machine controller. Geometrical accuracy and collision detection can also be performed with a simulation which depends on the degree of complexity of the machining processes. This can be executed through other simulation software, for example, Vericut which can optionally be embedded together with the common CAM systems. Basically, the software simulates the cutting operation by processing .clsf file generated from NX CAM. Then, it assesses the volume removed and detect collision based on the selected machine type. The simulation processes usually do not provide detail information on the performance of the continuous machining operation therefore, the process is always subject to variations. In conclusion, the simulation here can be an effective tool in which the machined concepts can be valued virtually. The process planning then continues with the post-processing step before proceeding with the manufacturing operation.

The Adaptability of Programming Code in CAD/CAM systems

Based on the recent developments in CAD/CAM technology, several improvements have been established to minimise dependency on experienced machinists to build machining process planning [3][5]. In this section, recent research on the integration of programming codes within the CAD/CAM system is reviewed. Generally, this method highly depends on the purpose and optimisation in the intended process. Therefore, a brief review of these methods is also included. Shao Wei [15] developed a digital management program called "unified digitization system" for the part parameters based on UG (Unigraphics NX) platform. The existing data management systems are incapable of controlling and managing the product design data or information consistently.

In the modern industries, a platform in terms of digital management that has the capability to keep the synchronized data, including the data of product design and manufacturing processes, is required. Palekar [16] developed a Master Model application to improvise the updating process for assembly models. The application was developed to address the problems associated with parts assemblage in NX CAM systems. The process of information updating for parts assembly that has hundreds of sub-assemblies components is a very critical part in the modern CAD/CAM industry. The Application Programming Interfaces (API) has been used to develop the program within Microsoft Visual Studio. For programming purpose, the combination of journaling tools and VB.net has been employed. The user entered the necessary input into the program, then, the input was transferred to NX using excel files. The master model application managed to reduce the product life cycle time and percentage of error generation during NX parts assembly information update processes. Zbiciak [17] worked out an application to automate the engineering task in NX CAM environment that used to generate a 3D design for gear wheel models. The application is known as generator module.

The main function of the module is to develop and model the spur and helical gears. The program was developed using NX modelling function by manipulating the vector graphics to generate a journaling code for customisation. According to the simulation results, the generator module managed to facilitate the constructional process design within minimum time and process planning. The main advantage of the application is the capability to reduce the modelling time compared to manual simulation methods. Gawai [17] developed a customisation software to design a solid shaft coupling assembly model using Unigraphics (NX) and Knowledge-Fusion (KF) Programming. Knowledge-Fusion (KF) is an integrated tool that permits the NX end user to extend the NX capabilities by increasing the design speed and intelligently control their own functions as needed by the developer [19]. The customised software was used to automate the design process for shaft coupling modelling, where it was managed to decrease the processing time and effectively simplify the modelling process planning. Siddesh [20] introduced an automation method to generate CAD models in CATIA systems using programming application. Standard user form was used as an interface in the macro method and was able to help users interact with the CAD model. It contains a labelled text box and a commands button to start the design process. The user just needs to enter the value into the box, then, press the "create spring" button. Using the proposed system, the time required to generate the CAD model for repetitive work can be reduced up to 90%.

In addition, the proposed method also improves the consistency of the design model and reduces the probability of human error. Benaouali [21] developed a procedure to automate the integration between Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE) which is used to design and analyse aircraft wings. The proposed procedures are developed using Graphic Interactive Programming (GRIP) automation tool which is available in the Siemens NX software. The main purpose of the integration is to eliminate the repetitive cost effort and to simplify the optimisation procedure. Nafis [5] developed a machining simulation program to improvise the manufacturing process planning for CNC Rapid Manufacturing (CNC-RM) applications. This simulation tool is intended to apply the automation approach to handle machining process planning. A customised program has been developed using visual basic programming and incorporated with the NX platform. It equipped with simple Graphical User Interfaces (GUI) that has a few inputs to be defined by the user. The simulation results show that the developed program managed to build a complete machining operation and successfully minimised the time spent on process planning by up to 79% compared to the manual simulation approach.

METHODOLOGY

Code Development Procedure

In this study, a visual basic programming language was used as a basis for graphical user interfaces (GUI) development and code customisation. The developed GUI was embedded with codes generated from the journal tools available in the CAM NX system. Journaling is a tool that is available inside NX CAM which allows users to record, edit, and replay all the interaction during NX sessions [22]. In general, the development of the

simulation program can be viewed in two phases- development phase and application phase.
Figure 3 shows the procedure of journaling code recording and customisation.

The development phase is a procedure on how the process of coding development is executed. All the tasks in this phase are performed manually. It starts with opening the NX CAM software, then, proceed to the "create a model" process by importing the model or parts into the NX system. Next, the journal tool function is activated to record all the user's interaction while developing the machining program. Journal tool recorded all the tasks, starting from constructing the machining program, simulating the machining operation, until exporting the simulation results into excel files. Once all the required instructions have been completed, then, the journaling tools function is stopped. The recorded code was converted to visual basic (VB) script files before being imported into visual basic programming application. These are the general processes performed to develop the programs in the machining planning stages.

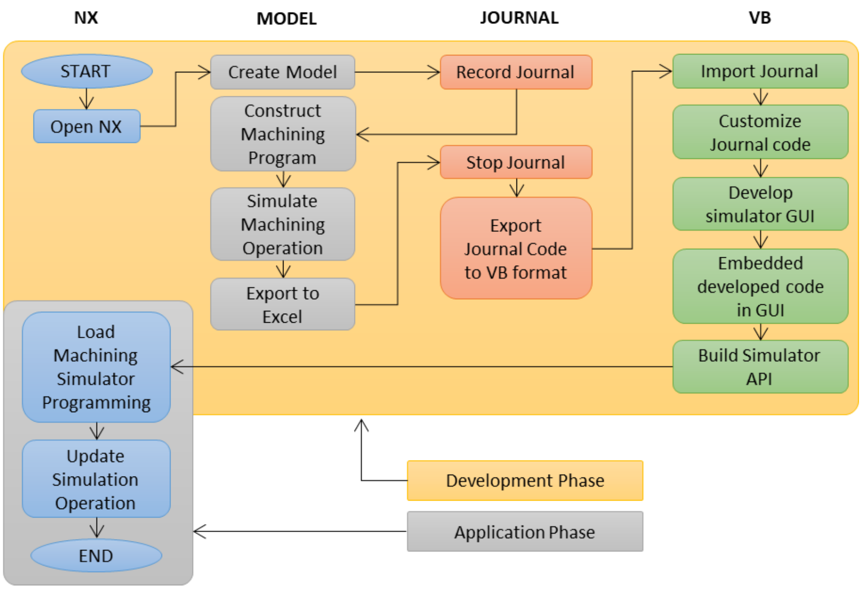

Figure 3. Journaling and code customisation procedure.

In the Visual Basic software, there are three methods that have been employed in order to modify the code recorded from journaling; these are grouped code, replacement code, and simulation instruction code. The first method (grouped code) is executed by identifying the task that used the same data input value, then, group these codes together using specified variables. This is intended to simplify the code referring processes.

Figure 4 shows the grouped method for 'workpiece diameter' input used in the developed programs. The value of the workpiece diameter is useful to determine the other task values, such as the value of the cutting depth level, and the value of the cutting area extension. Through this method, the input parameter is utilised for several tasks to generate operations efficiently.

In the meantime, the second method (replacement code) is used to modify the journaling codes by removing the 'code stickiness' from the original codes as shown in Figure 5. The purpose of replacement is to ensure the customised code is universal and applicable to any CAD model. The original codes indicate that the parts were defined as "Unparameterized Features (0)" where these are the parts used during the journaling recording procedures. However, if the original codes are used for the other different parts, unexpected errors might occur. To avoid the error, code replacements are required to enable this program for all types of model. Replacement code has been equipped with pop-out selection, where the users are allowed to select the desired parts or model effectively. For the third method (simulation instruction code), a custom code has been developed to perform simulation routines for repeated operations. The instruction code was developed to run a series of machining simulations virtually by repeating the analysis automatically without user intervention. The simulation instruction code is depicted in Figure 6.

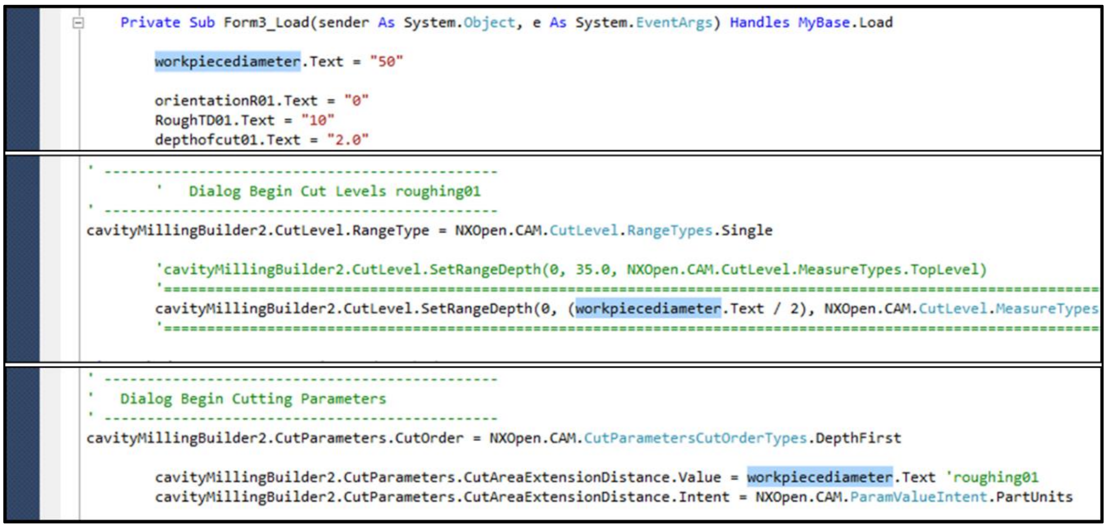

Figure 4. User input, cutting depth and cutting extension.

Figure 5. Code stickiness replacement.

```
Private Sub roughing4simulation()

    Dim a As Integer
    Dim b As Integer
    Dim c As Integer

    Dim totalCuttingLength As Double
    Dim totalCuttingTime As Double
    Dim MRR As Double

    Dim saveData(360, 4) As Double
    Dim cData As Integer = 1

    a = textbox1.Text
    b = textbox2.Text
    c = textbox3.Text

    For nilai As Integer = a To b Step c
        roughing4_tekan(nilai, totalCuttingLength, totalCuttingTime, MRR)

        saveData(cData, 1) = nilai 'nilai
        saveData(cData, 2) = totalCuttingLength 'totalCuttingLength
        saveData(cData, 3) = totalCuttingTime '/ 1000 'totalCuttingTime
        saveData(cData, 4) = MRR * totalCuttingTime

        System.Threading.Thread.Sleep(1000)
        Application.DoEvents()

        cData = cData + 1

    Next
    WriteValueToExcel_roughing4(cData, saveData)

    Me.Close()
   Form1.Close()

End Sub
```

Figure 6. Simulation instruction code.

RESULTS AND DISCUSSION

Graphical User Interface (GUI)

The customised Graphical User Interface (GUI) has been developed to assist the process planning task for machining simulation operations. This simulation program was designed using Visual Studio 2010 on a Windows Form Application template. A previous customised journaling code was embedded inside the GUI to complete this program. Figure 7shows the front-end interfaces of the Roughing Simulation program. It is equipped with several drop-down lists, text box, and radio-button options that have been programmed with a certain range of values for specific parameters. The input of this GUI is divided into everal categories, including workpieces diameter, cutting parameters (spindle speed, feed rate, depth of cut), cutting orientation set, cutting tools size, and simulation analysis for cutting orientations. The user only needs to enter the information inside the input area before proceeding to generate the machining program by pressing the RUN button. This program offered different approach in machining setup apart of the standard database available in NX CAM. It is equipped with built-in custom programs that allows user to simulate a few numbers of experiments with minimal setup.

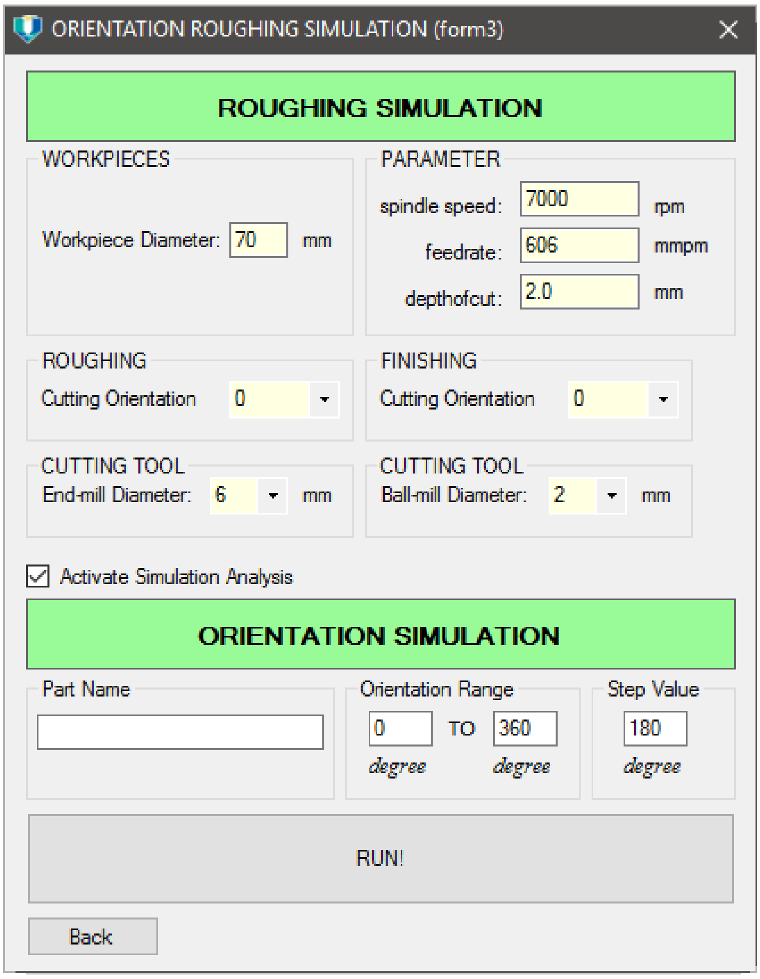

Figure 7. Rough simulation of CAM GUI.

Simulation Program Procedure

The roughing simulation program was used to investigate the optimum cutting orientations and to generate the required machining operation. The process planning procedure of the developed program is shown in Figure 7. At first, the selected CAD model is imported into the NX CAM system; then, the simulation program is called from the installation location inside the windows. Once the program was activated, the first GUI was pop-out to provide a selection for machining operations. After selecting the desired operation, a window form for parameter insertion appears (Figure 8). In this form, the user fills up all the required parameters to construct a machining operation. Next, the user needs to define the geometrical models which are parts model (CAD), workpieces (blank), check block (cutting boundary), and cutting area (machined surfaces) through a series of selection windows. Then the program executes the simulation where it develops the cutting operations based on the ranges of orientation set up by the user earlier. In each orientation, cutting length and time data is recorded and finally published in the Excel file format.

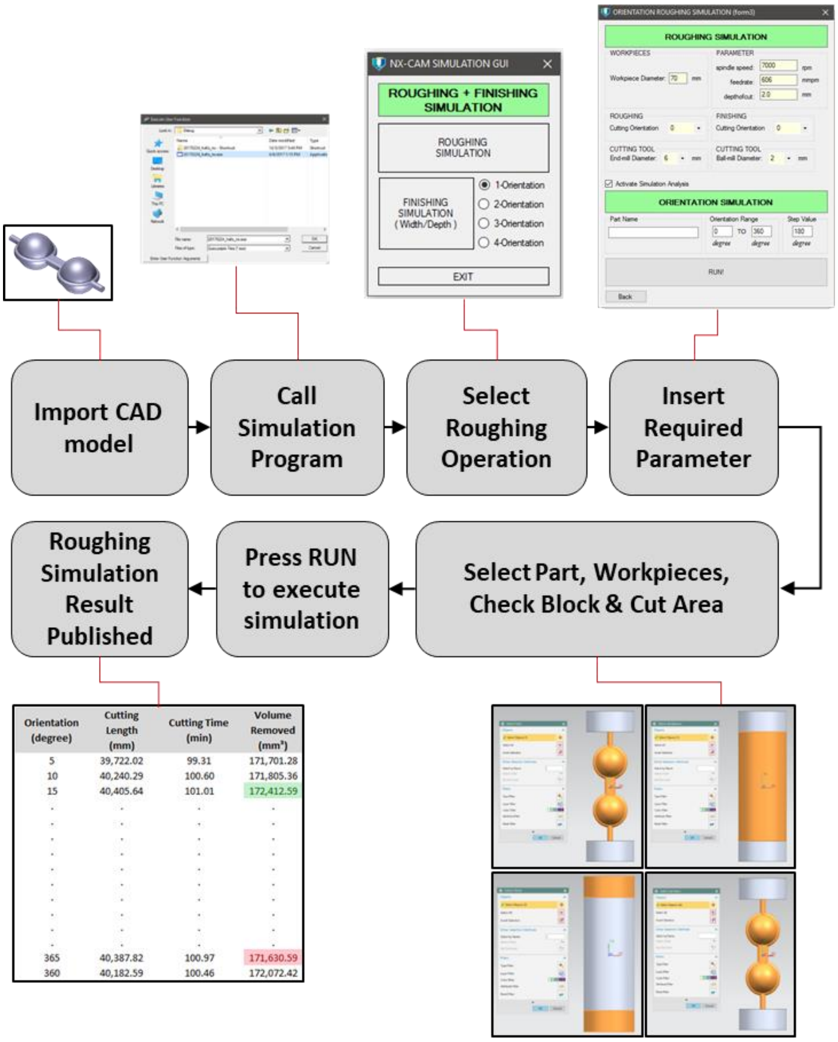

Figure 8. Simulation program process planning.

Comparison of Simulation Approaches

To illustrate the overview of the simulation operation, the differences in process planning between manual simulation approach and the proposed approaches can be seen in Figure 9. The manual simulation approach is a manual method that is typically used to build machining programs and requires significant user intervention and effort to execute the repetitive processes [12]. Some parameters and settings for each operation need to be changed in order to run the simulations with several constant parameters. In this study, certain levels of automation are expected to be embedded in the operation of build-up routines. The proposed approach is an improvised method by developing a custom application to build a machining program in NX with the addition of several automation elements.

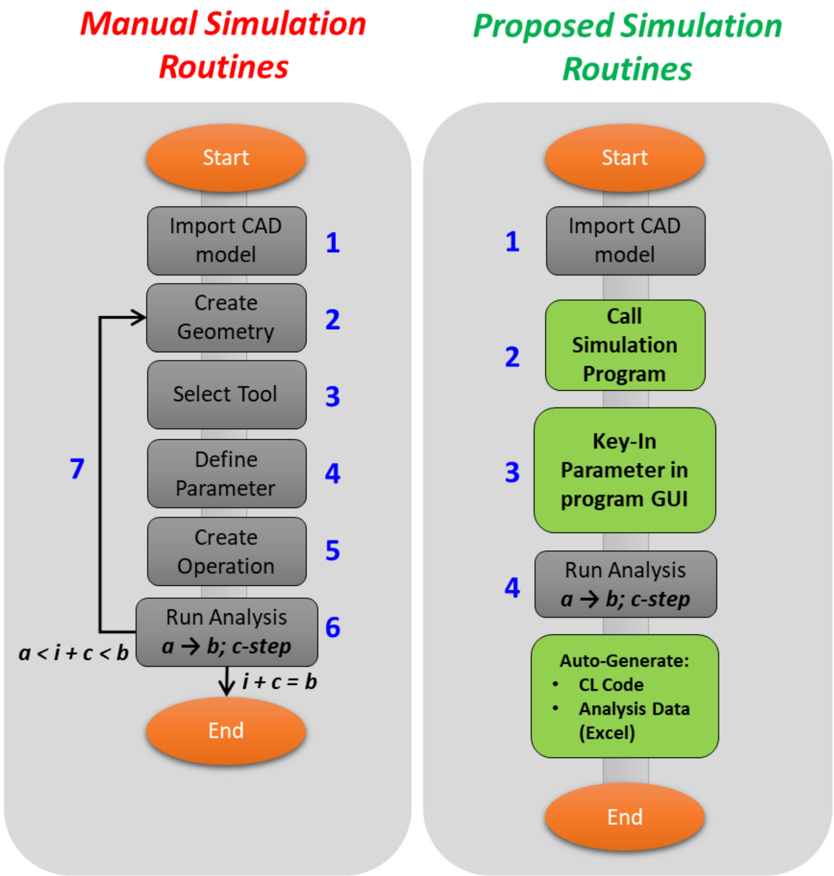

Figure 9. Comparison of simulation approaches.

The simulation runs continuously without requiring users' intervention between the part geometry in 4th axis machining operations. Consequently, if there are many parts geometries involved in one operation, the program automatically loops the simulation to the next operation efficiently. Journaling program codes are recorded through the tool in NX CAM, starting from "Create Geometry" (level-2) to "Create Operation" (level-5). Some parameters values that need to be set in each level have been simplified and grouped in the GUI program window. Through this method, the proposed approach has managed to reduce the processing step from 6 steps to just 3 steps. The proposed simulation application was validated by executing machining processes on several CAD models as shown in Figure 10. The selected models vary in terms of geometry and size. Each model needs different cutting orientation and cutting parameters.

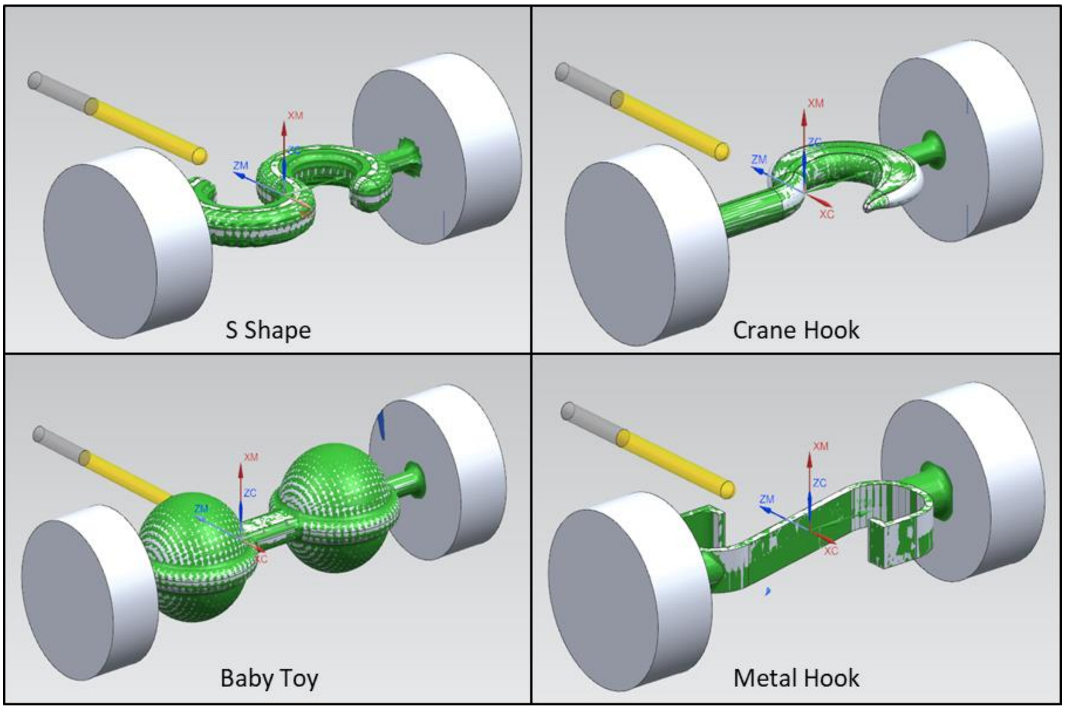

Figure 10: CAD model for simulation validation

The simulation application manages to develop a machining operation efficiently, including roughing and finishing operations. Table 1 reveals the results of processing time for machining program developments in NX CAM systems. The total operation column indicates the machining operation executed for each model, consisting of four cutting orientations in the roughing operation and two cutting orientations in the finishing operation. The processing time (min) columns indicate the comparison of the time spent to build the machining operations by the manual simulation and proposed approaches.

Table 1. The processing time required to construct a machining operation programs using manual simulation and proposed approaches.

Model	Total operations	Manual approach (min)	Proposed approach (min)	Improvement rate (%)
Baby toy	4 roughing 4 finishing	16.78	2.98	82.2%
Crane hook	4 roughing 4 finishing	14.48	2.38	83.5%
Alphabet S	4 roughing 4 finishing	16.27	2.45	84.9%
Metal hook	4 roughing 4 finishing	15.82	2.80	82.3%

In the manual simulation approach, the processing time is recorded based on the manual method for constructing machining operations in NX CAM, while the proposed approach is based on the developed simulation programs. As we can see from the manual simulation approach, the time spent was recorded between 15.82 min and 16.78 min.

However, the time recorded for the proposed approach was very much lower, ranging from 2.38 min to 2.98 min. This clearly shows that the proposed approach manages to reduce the time spent by up to 84.9% compared to manual simulation process planning. Indirectly, these results show the effectiveness of the designed program to carry out machining operations more effectively and consistently.

CONCLUSION

This paper has discussed the integration of visual basic programming in NX Computer-Aided Manufacturing (CAM) system for application in 4th axis machining. From the study, the developed applications managed to execute, control, and develop machining simulation programs efficiently with minimum processing steps. The results show that the proposed approach successfully reduced the processing time by up to 84.9%. In this paper, some of the simulation program development are described in order to generate machining operations for four-axis milling. In future works, the development of machining routines for roughing and finishing operations in four-axis milling will be addressed. This includes the experimental analysis to ensure the simulations data are according to the real machining data. Subsequently, the machining routines should resolve the parameters optimisation accordingly.

REFERENCES

[1] Staffan A. A study of process planning for metal cutting. Chalmers University of Technology. 1652-8891; 2009.
[2] Carson B, Nicol N. Chapter 1: Introduction to Simulation in Discrete-Event System Simulation. 5th ed. Prentice Hall; 2010. Retrieved from http://ece.ut.ac.ir/Classpages/S86/ECE462/slides/Chapter1.pdf.
[3] Matthew F. Implementing rapid prototyping using CNC machining (CNC-RP) through a CAD/CAM interface. In: Proceedings of the Solid Freeform Fabrication, pp. 112-123; 2007.
[4] Jie Z, Zhang D, Chang Z. 3D model based machining process planning. Advanced Materials Research. 2011; 301-303: 534-544.
[5] Nafis M, Case K, Watts D. Rapid process planning in CNC machining for rapid manufacturing applications. International Journal of Mechanical Engineering and Robotic Research 2017; 6(2): 118–121.
[6] Scallan P. Process Planning: The design / manufacture interface. Elsevier Science & Technology Books. 2002.
[7] Kalpakjian S. Computer-aided manufacturing: manufacturing engineering and technology. 5th ed. Upper Saddle River, NJ: Pearson Education.; 2006.
[8] Scallan P. Process planning: CAD/CAM & DFM. Butterworth-Heinemann; 2003.
[9] Rao N. CAD/CAM Principles and Applications. 3rd ed. New Delhi: McGraw Hill Education India; 2010.
[10] Jahan D, Kabir G. Development of computer aided process planning (CAPP) for rotational parts. Global Journal of Researches in Engineering 2010; 10(4): 16–24.
[11] Staffan A. Methods for improving performance of process planning for CNC machining; an approach based on surveys and analytical models. Chalmers University of Technology. 2012.

[12] Bahaley S, Maldhure B. Computer aided process planning of a ginning machine component. International Journal of Innovative and Emerging Research in Engineering 2015. 2(1): 179-186.

[13] Turley S, Diederich D, Jayanthi B, Datar A, Ligetti C, Finke D. Automated Process Planning and CNC-Code Generation. In: Industrial and System Engineering Research Conference, pp. 2138–2145; 2015.

[14] Elmaraghy H. Reconfigurable process plans for responsive manufacturing systems in digital enterprise technology. Boston: Springer; 2007. p 35–44.

[15] Wei S, Chong L, Jing Y, Ying W, Junjie G. A digital management system of part processing parameter based on UG. In: IEEE International Conference of. Mechatronics Automotive, pp. 2055–2059; 2014.

[16] Palekar J, Khairnar. Master model automation using nx unigraphics customization. International. Journal. of Engineering Development Research 2014; 2(2): 2184–2189,

[17] Zbiciak M, Grabowik C, Janik W. An automation of design and modelling tasks in NX Siemens environment with original software – generator module. In: 9^{th} World Congress on Computational Mechanics Conference, pp. 1-6; 2015;

[18] Gawai U, Wavale S, Katkam V. Software development (customization) in UG/NX 4.0 for coupling module using knowledge fusion programming. Interantional Journal of Science Engineering Technology Research 2015; 4(8): 1421–1426.

[19] Siemens. Knowledge Fusion (KF). 2018. Retrieved from http://www.daasolutions .com /expertise/nxcustomization/knowledgefusion/

[20] Siddesh S, Suresh BS. Automation of generating CAD Models. Journal of Mechanical Engineering Automotive 2015; 5(1): 55–58.

[21] Benaouali A, Kachel S. An automated CAD/CAE integration system for the parametric design of aircraft wing structures. Journal of Theoretical and Applied Mechanics 2017; 55(2): 447–459.

[22] Siemens. Getting Started with SNAP. Siemens Product Lifecycle Management Software Inc, 2014.