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Research Article

Development of Web based Tool Path Generator (W-TPG)

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Abstract

Rapid developments in Information Technology (IT) are throwing new opportunities for industries & individuals. Internet of Things (IoT), Social manufacturing becoming popular day by day and are allowing individuals to develop custom components & tools. Contemporarily, individuals no more need to be confined with proprietary applications and conditions over simple needs. Also knowledge on standards & standard file formats allows these individuals to share tools and information via web. STEP-NC (ISO 14649) is an enhancement to STEP (ISO 10303) for operating NC machines and helps in following a common platform of file formats, throughout CAD/CAM/CAPP/NC manufacturing chain rather than depending on multiple disconnected file formats from proprietary applications. In this regard, an attempt is made to develop a Web based Tool Path Generator (W-TPG) based on open platform. Various milling operations namely face milling, drilling and pocket finishing, identified from the example1 of ISO14649 part11 are considered for developing the modules. Key parameters that influence the tool path are identified from the STEP-NC file and can be entered at the GUI for regenerating and simulate the tool path. Developed algorithms helps for building a complete web based STEP-NC manufacturing as future scope.

Keywords: *STEP-NC, ISO14649, Open Source, web applications, Simulation*

1. Introduction

In the era of Information Technology (IT), right information at right time for right person becomes the key for success for mankind as well as machines. Numerical Control (NC) machines were evolved in 1950's and since then many organizations like International Standards Organization (ISO), Electronic Industries Alliance (EIA) etc are working towards standardization of input file format for NC machines. EIA released its standard RS-274 in 1980 called as G&M Code based program for operating CNC. ISO released its relevant first standard version with number ISO 6983 in 1982 (www.iso.org). Rapid developments in IT provides new opportunities to industries to oblige new concepts of collaborative works, concurrent engineering, Product lifecycle management (PLM) etc. Free and open-source software (FOSS) decreases software costs enables custom build tools with better security and stability. Internet of Things (IoT) is the network of physical objects like devices, buildings, vehicles which are embedded with sensors, related electronics & software. Objects are connected with network to collect and exchange data for operations. Web of Things (WoT), act as application layer and simplifies the creation and operations of IOT applications via web. With a goal of building global infrastructure and smart manufacturing, IoT encourages use of WoT and FOSS (D. Uckelmann *et al*, 2011). Social manufacturing is another new trend that allows individuals to be part of design & research. Leveraging open systems, democratizing the systems of production to engage more diverse actors are going to help social manufacturing (www.iftf.org).

In this regard an attempt is made to develop a 'Web based Tool Path Generator (W-TPG)' for prismatic components on open source platform. Basic milling features defined in example1 of ISO 14649-part11 (ISO 14649, Part 11, 2004) are considered for development and testing. The individual GUI's are developed where users are allowed to provide stock dimensions, and required manufacturing information. Independent feature GUIs generate tool paths using parametric based on interactive parametric modeling concept. 'OpenJSCAD', an open source web platform with combination of Java Scripting and OpenSCAD is identified to be suitable for the development of OWTG. STEP-NC file format along with tool path viewers developed at various STEP-NC projects are briefed in chapter2. Base open software selection criteria for W-

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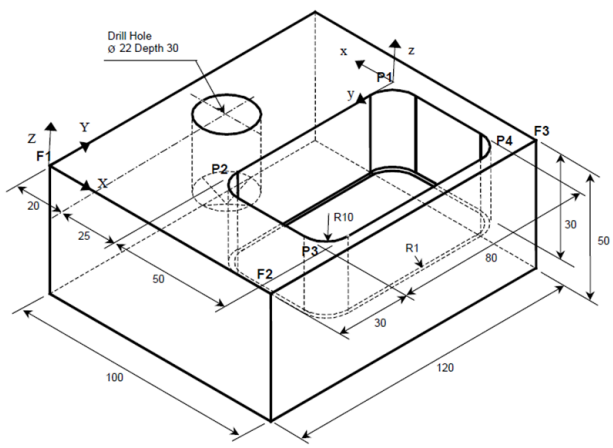
TPG are explained in chapter3. Methodology along with developed GUI's are well explained with flow charts and diagrams subsequently in chapters 4 & 5. Future scope and integration possibilities of W-TPG for complete STEP-NC manufacturing platform is discussed in chapter6.

2. Background

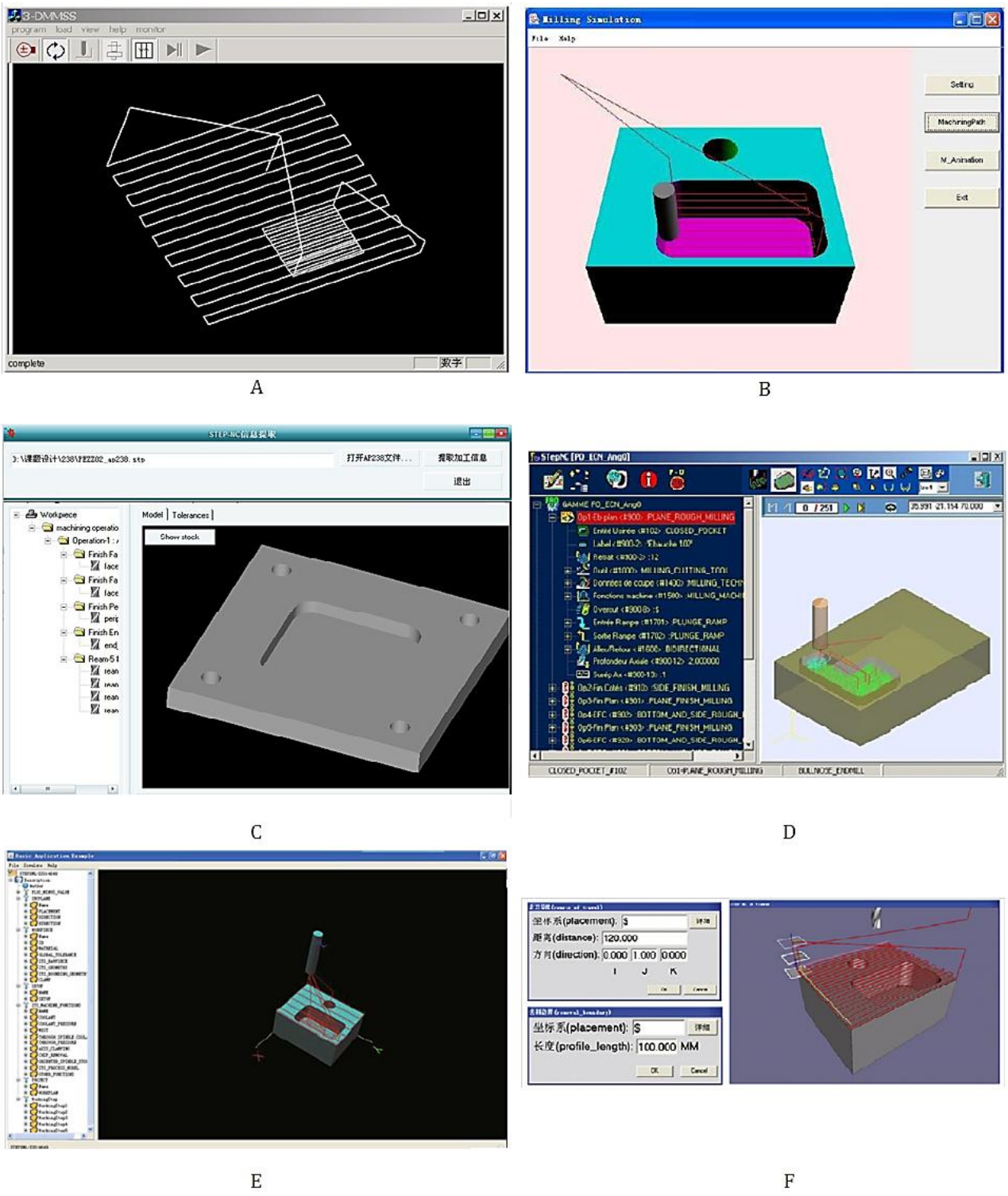
Majority of the industries use commercial software systems for CAD/CAM/CAPP needs of manufacturing chain. These applications are operated on diverse file formats and need to convert into standard file formats like IGES, STEP, etc. for interoperability. These conversions are prone to loss of information and constraining benefits from collaborative and concurrent engineering techniques. International Standards Organization (ISO) identified the need for common standard platform to eliminate data loss across various stages of CAD/CAM/CAPP/CNC chain via a new big standard ISO 10303 known as 'STandard for the Exchange of Product model data (STEP)' since 1984 (Introduction to ISO 10303, NIST Tech Note:2002). Another standard, ISO 14649 is also being developed exclusively for working with Computer Numerical Control (CNC) Machines which is well harmonized with STEP and is well known as STEP-NC. Since the beginning of 21st century many countries participated towards realizing STEP-NC machine. Many researchers developed many tool path generation and visualization modules based on STEP-NC. Few are mentioned as follows. It's been observed that many research efforts made at machine level using ARM (ISO 14649) data model on Milling Machine. ISO14649 model is Application Reference Model (ARM) for STEP-NC and are the best to work with machine related activities. AP238 Application Interpreted Model (AIM) is best for interoperability and concurrent works like Design integration, MRP, PDM, PLM etc. Example part1 of ISO 14649-part11 is being considered by many researchers for base application/platform development because of its simplicity and coverage of many milling operations (fig.1).

Since the beginning of 21st century, many researchers across globe made their efforts towards realizing STEP-NC manufacturing platform. Tool path generation and viewer is part of the chain to simulate before manufacturing. Xiaoming along with others developed a 3-D milling machining simulation system (3-DMMSS) based on C++ programming (X. Zhu *et al*, 2006). Raphael L et al from IRCCyn developed toolpath programming in intelligent STEP-NC manufacturing platform PosSFP (L. Raphael *et al*, 2008). Algorithms were developed and tested without simulation GUI. Junzhe Tan et al developed on machine inspection (OMI) simulation modules using JAVA & JAVA3D (J.Tan *et al*, 2009). Qiling Shu et al from Shenyang Ligong Uni of China implemented a CAM system for integration of STEP-NC with UniGraphics (UG) using APIs (Q.Shu *et al*, 2010). Mattieu Rauch from France with others from South Korea made an international effort in developing an advanced STEP-NC controller for intelligent machining processes on SPAIM platform (M. Rauch *et al,* 2012). Works performed for Delphi based tool for geometric modeling, DellCAM power mill for tool path generation based on ISO 14649. Yu Zhang et al from School of Mech Engg & Automation, china along with Prof Xun Xu from Auckland Uni, Newzealand made their efforts in developing STEP-NC based High level machining simulator (Y Zhang *et al*, 2012). Wenlei Xiao et al from Beihang University of China made their efforts to customize CATIA using C++ programming techniques for geometric modeling as well as tool path generation based on STEP-NC (W Xiao *et al*, 2015). (Fig.2) shows various tool path viewers developed as part of various STEP-NC systems as mentioned.




```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION(('ISO 14649-11 EXAMPLE 1', 'SIMPLE PRORGRAM WITH A PLANAR_FACE, A
POCKET, AND A ROUND_HOLE'),'1');
FILE_NAME('EXAMPLE1.STP','2002-02-02',('YONG TAK HYUN','JOCHEN WOLF'),('WZL, RWTH-
AACHEN'),$,'ISO 14649',$);
FILE_SCHEMA(('MACHINING_SCHEMA','MILLING_SCHEMA'));
ENDSEC;
DATA;
#1= PROJECT('EXECUTE EXAMPLE1',#2,(#4),$,$,$);
#2= WORKPLAN('MAIN WORKPLAN',(#10,#11,#12,#13,#14),$,#8,$);
#4= WORKPIECE('SIMPLE WORKPIECE',#6,0.010,$,$,$,(#66,#67,#68,#69));
#6= MATERIAL('ST-50','STEEL',(#7));
#7= PROPERTY_PARAMETER('E=200000N/M2');
#8= SETUP('SETUP1',#71,#62,(#9));
#9= WORKPIECE_SETUP(#4,#74,$,$,());
#10= MACHINING_WORKINGSTEP('WS FINISH PLANAR FACE1',#62,#16,#19,$);
#11= MACHINING_WORKINGSTEP('WS DRILL HOLE1',#62,#17,#20,$);
#12= MACHINING_WORKINGSTEP('WS REAM HOLE1',#62,#17,#21,$);
#13= MACHINING_WORKINGSTEP('WS ROUGH POCKET1',#62,#18,#22,$);
#14= MACHINING_WORKINGSTEP('WS FINISH POCKET1',#62,#18,#23,$);
#16= PLANAR_FACE('PLANAR FACE1',#4,(#19),#77,#63,#24,#25,$,());
#17= ROUND_HOLE('HOLE1 D=22MM',#4,(#20,#21),#81,#64,#58,$,#26);
#18= CLOSED_POCKET('POCKET1',#4,(#22,#23),#84,#65,(),$,#27,#35,#37,#28);
-----------------------------------------------------------------------
-----------------------------------------------------------------------
-----------------------------------------------------------------------
-----------------------------------------------------------------------
#124= CARTESIAN_POINT('P4',(-50.000,0.000,0.000));
#125= CUTTING_COMPONENT(80.000,$,$,$);
#126= CUTTING_COMPONENT(90.000,$,$,$);
#127= CUTTING_COMPONENT(100.000,$,$,$);
ENDSEC;
END-ISO-10303-21;
```

Fig.1 Example1 work piece of ISO14649-part11 & STEP-NC Sample file (ISO 14649-Part11: 2004)



A. 3DMMS (X Zhu *et al*, 2006), B. OMI Simulation System (J Tan *et al*, 2009),
C. STEP-NC interface (Q Shu *et al*, 2010), D. SPAIM-StepNC (M Rauch *et al*, 2012),
E. STEP-NC system (Y Zhang *et al*, 2012), and F. STEP-CNC prototype (W Xiao *et al*, 2015)

Fig.2 GUIs of various Tool path Simulators developed at various STEP-NC systems

3. Application considerations

It's been observed that most of the STEP-NC platforms utilized one or more proprietary applications and no considerable effort is made for web control. Proprietary software is mostly under restrictive copyright and the source code is usually hidden and users need to depend on costlier customization over simple changes. On the other side, FOSS is freely licensed and allows anyone to study and edit the software in any way, and the source code is openly shared. Open source applications encourage people to

voluntarily improve the platform. Development of web modules based on open source technologies; promote the implementation of STEP-NC manufacturing across globe to a greater extent. Open standards & open source enables the interoperability with positive impact on innovation, growth and competitiveness (F Almeida *et al*, 2015).

In this regard, an attempt is made to develop an open web based tool path generator & viewer. Web tools are programmed individually for different manufacturing features considered from Example 1 (Fig.1) for planar machining, drilling, Pocket finishing. In the present work, these tools are developed for manual inputs that are defined at STEP-NC file of Example1, and are going to be automated with other modules of the platform in future. Selection of proper base application plays key role in the success & future integration and various key factors considered are discussed as under.

3.1 Application features

Base application should be an open source application with web graphical user interface and with an ability to generate geometric models. Back end support of object oriented programming helps for the development of the system.

3.2. Comparison of various open source CAD editing applications

Many systems like Webgl, OpenSCAD, OpenJSCAD, were explored for the compatibility with requirements. Most of the systems available in market are designed for STEP and doesn't support STEP-NC format. Table 1 shows the comparison of familiar open source systems designed for CAD applications. Though there are many open-source CAD editors supporting many file formats, OpenJSCAD is identified as base application for satisfying all the needs of W-TPG. Conversion capability to STL, X3D formats is added advantage to support rapid prototyping works

3.3. Platform for OWTG

Following section explains the features of the platform selected i.e OpenJSCAD for OWTG with reasons.

3.3.1. OpenJSCAD

OpenJSCAD is a combination of OpenSCAD & Javascript to provide web browser support for features of OpenSCAD. It is being developed and maintained by team of members with MIT license providing permissive free software license for all users. Platform works both offline and online web browser with command line interface with programming guide and is identified to be best for the development of WTPG.

3.3.2. CAD features

Platform works on constructive solid geometry (CSG) approach. 2D/3D Primitives, 2D/3D Transformations, Extrude, Properties, Colors, mathematical functions etc along with parametric modeling.

3.3.3. Program features

OpenJSCAD is object oriented and allows users to use JavaScript programming concepts and libraries. Interactive Parametric Modeling allows users to develop custom tools for developing CAD/CAM models with user input values at web interface.

Table.1 Comparison of Various open source CAD editors

(www.freecadweb.org) (www.librecad.org) (www.openscad.org), (www.openjscad.org) (www.qcad.org), (www.solvespace.com)

Application and developer	Latest release with version number	Field of application	License type	Import formats	Export formats	Web interface
FreeCAD by Juergen Riegel	April 18, 2016, 0.16	3D	LGPL	U3D,SVG,DXF,OBJ, BRep,STEP,IGES	U3D,SVG,DXF,OBJ,BRep,STEP,IGES	Not available
LibreCAD	January 10, 2016, Version 2.0.9	2D	GNU-GPL	DWG, DXF	DXF, JPEG, PNG, SVG, BMP	Not available
OpenSCAD by Marius Kintel, Clifford Wolf	March 10, 2015, 2015.03	2D / 3D parametric	GNU-GPL	DXF, STL, OFF	PNG, DXF, STL, OFF	OpenJscad
QCad by RibbonSoft	June 17, 2013, Version 3.1	2D	GNU-GPL	IFC, DXF, DWG	IFC, DXF, DWG	Not available
SolveSpace by Jonathan-Westhues	August 11, 2013, v.2.0	2D / 3D parametric	GNU-GPL	Not identified	STEP,OBJ,STL,DXF,HPGL,SVG,EPS,PDF	Not available

4. Programming Methodology

This chapter explains the input parameters and flow chart of the programs developed for face milling, drilling & pocket finishing with the help of flowcharts. One needs to understand the schema of STEP-NC file format to identify the influencing parameters for tool path generation for various machining operations from the respective data models. Further understanding of individual operations or entities can be understood from the respective data models available at ISO manuals (www.iftf.org) (ISO14649-Part 111:2004). For

example every STEP-NC file includes 'PROJECT' entity as the top level entity, which calls for other entities like 'WORKPLAN', 'WORKPIECE', owner, etc. Actual machining operations are represented as 'WORKINGSTEPs' and are related to 'WORKPLAN'. Entire information is stored into respective entity values following the data model and these values to be interpreted properly for developing any real time systems or implementations.

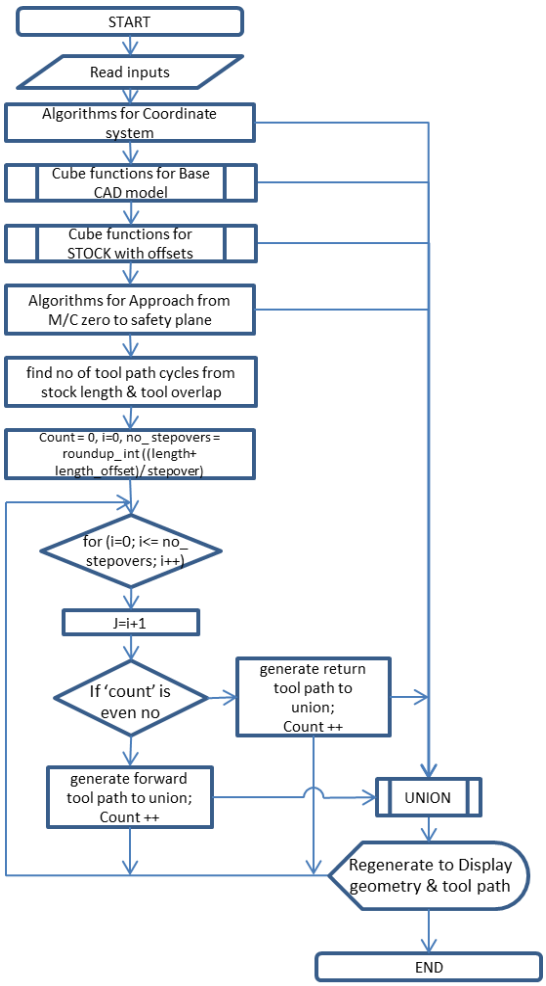


Fig.3 Flowchart for generating tool path for face milling over stock

4.1 Face milling feature

Face milling is the most common milling operation and is performed on flat surfaces or faces of stock. Present work deals with finishing operation of face milling and is performed in single pass over the face. Programming is flexible enough for adding depth of cut when needed. In addition to the regular parameters, stock offsets also be incorporated at GUI and tool path is generated accordingly. Major parameters identified from STEP-NC file for face milling module are stock dimensions, security plane height, over cut length, tool diameter, tool progress overlap, Machine zero position. All the parameters are identified at the STEP-NC file at (Fig.3) shows the flowchart of the program written for the development of module.

4.2 Drilling feature

Drilling is another common operation which is also specified in STEP-NC example file is considered as another needy as part of the present work. Module takes stock dimensions, hole position, security plane height, tool diameter, Machine zero position etc. as input parameters. (Fig.4) shows the flowchart of the program written for the development of module. JSCAD features used for planar milling module were also used for drilling module as well.

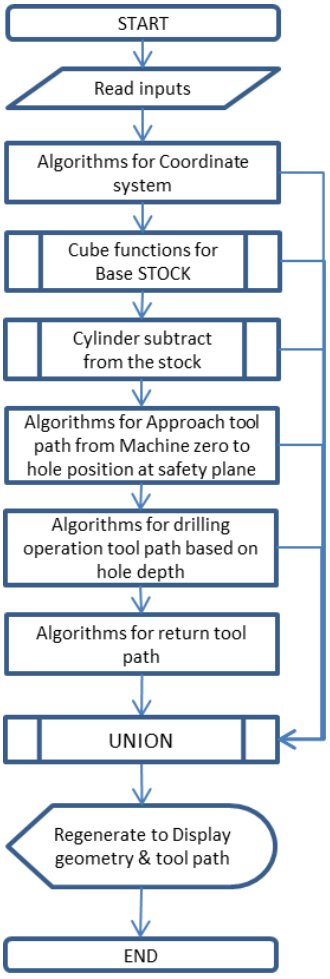


Fig.4 Flowchart for generating tool path with for drilling operation over stock

4.3 Pocket finishing feature

Another machining operation mentioned in the example1 of STEP-NC shown in (Fig.1) is pocket finishing where the stock is already with a rough pocket to be operated again for final finishing operation. Stock dimensions, Pocket dimensions,

pocket position, tool dia, fillet radius, security plane, etc to be considered for the module. (Fig.5) shows the flowchart of the program written for development of module. JSCAD features used for planar milling module were also used for pocket finishing module as well.

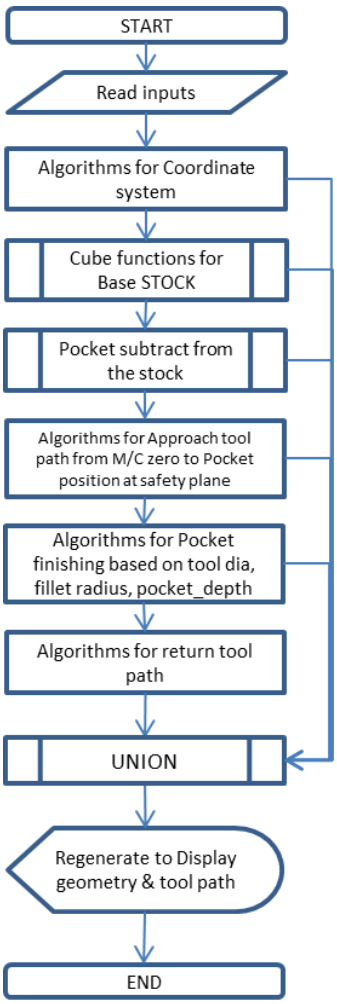


Fig.5 Flowchart for generating tool path for Pocket finishing operation over pocket

5. Developed GUI

This chapter explains the final GUI's of the developed individual modules for aforementioned milling operations.

5.1 Stock & tool path generation for face-milling

Inbuilt CAD features like BLOCK, CYLINDER, etc., transformation functions; application of color for differentiating tool bit, geometry, offset and tool path; along with CSG features like UNION etc are used for real useful output for the user. (Fig.6) shows the final GUI of the module where user modifies the inputs to generate the tool path.

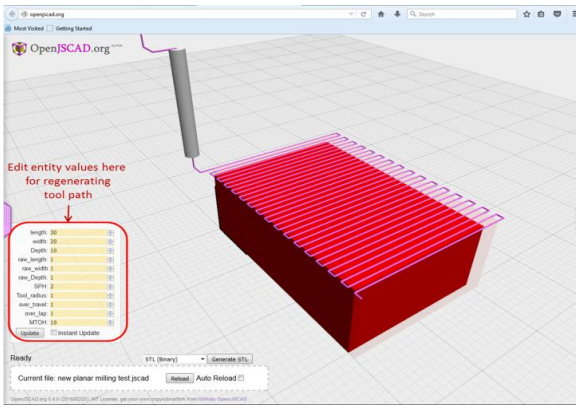


Fig.6 GUI for simulating face milling over web

5.2 Stock & tool path generation for drilling

The developed GUI for drilling operation allows user to edit relevant input parameters and to update the tool path accordingly for user verification (Fig.7).

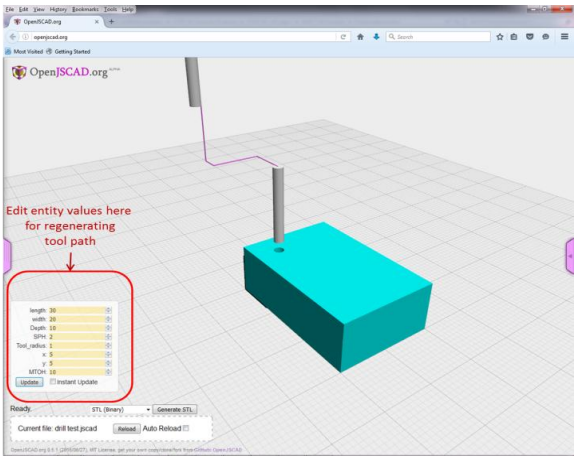


Fig.7 GUI for simulating drilling operation over web

5.3 Stock & tool path generation for Pocket finishing

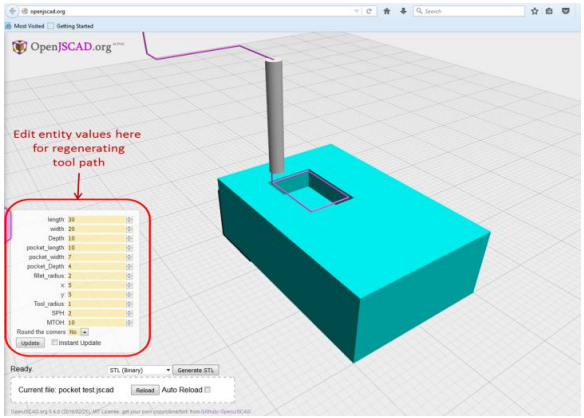


Fig.8 GUI for simulating pocket finishing over web

GUI for pocket finishing allows user to edit all the relevant input parameters related to pocket finishing operation and then to regenerate the corresponding tool path (Fig.8).

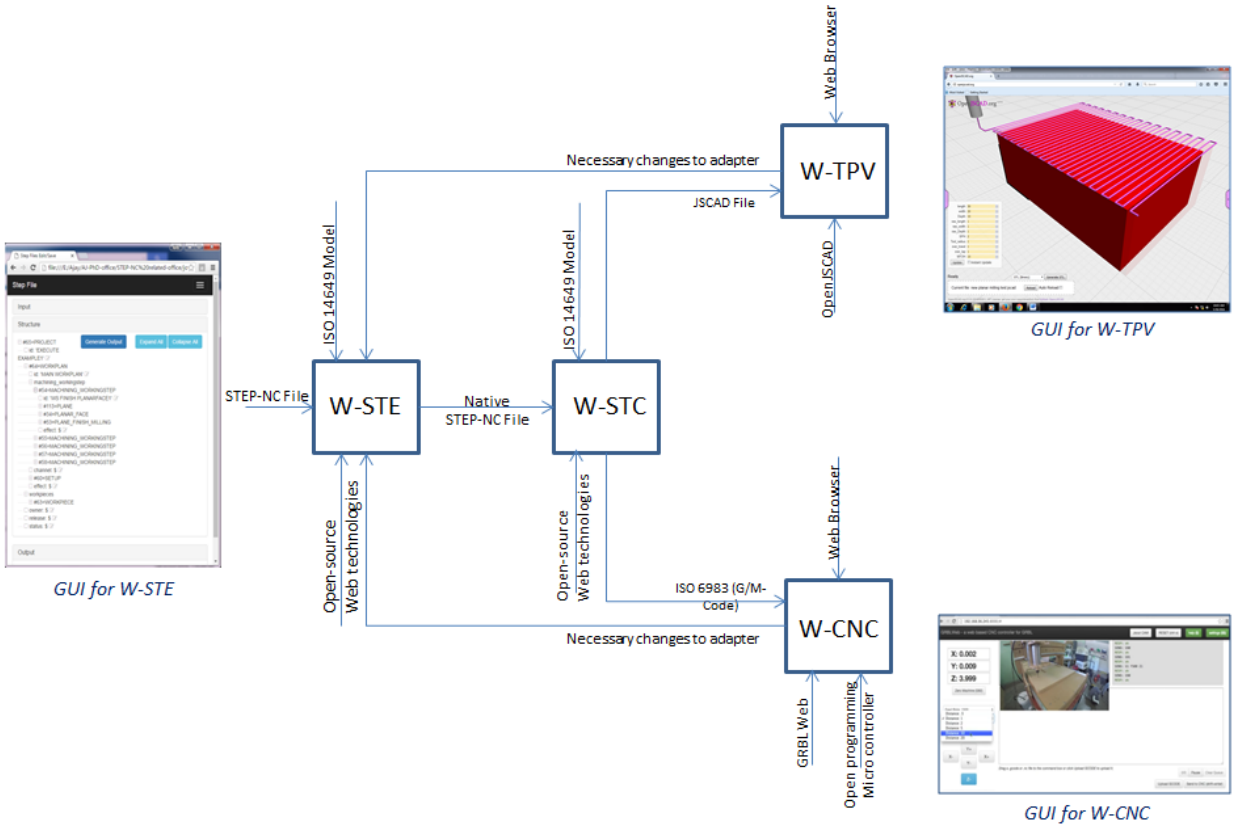


Fig.9 Frame work of developing 'Open Web - StepNC manufacturing platform (OW-StepNC)'

6. Future scope of W-TPG

All the three selected machining operations are part of the STEP-NC example file shown in (Fig.1). Present work helps in using the developed algorithms for automatic tool path generation as part of Open Web-StepNC (OW-StepNC) manufacturing system. (Fig.9) shows the framework of the developing system. Entire system is an integration of four different modules designed towards availing a complete web based STEP-NC manufacturing. Web based STep-nc Editor (W-STE) is designed for importing any STEP-NC file and then to show the tree view structure allowing user to understand the file and various manufacturing operations called as working steps. The module also allows user to edit and create a new STEP-NC file called as 'native STEP-NC' file according to shop floor needs. Second module helps in converting the native STEP-NC file information into two different file formats namely NC file (G/M code), JSCAD file (tool path simulator). These two files are fetched by the third and fourth modules W-TPV & W-CNC which are basically open source tools namely OpenJSCAD & GRBLWeb. All modules are designed to work on web using open softwares to be in line with IoT & social manufacturing concepts.

Present work helps in understanding the generation of tool paths according to the inputs, and to know what programming functions are suitable for generating the JSCAD files. These programs are embedded at W-STC which reads the input parameters directly from STEP-NC file and to generate corresponding JSCAD file which later viewed at W-TPV.

Conclusion

Following points are concluded from the present work.

1. A Web based Tool Path Generator (W-TPG) is developed as part of a complete open web STEP-NC manufacturing platform.
2. The application allows tool path generation and view possibilities for different milling operations namely for face milling, drilling, and pocket finishing operations.
3. Application allows user to edit the parameters which affect the tool path and can regenerate the tool path accordingly at the GUI.
4. OpenJSCAD, an open source web platform with combination of Java Scripting and SCAD is identified to be suitable for developing CAD/CAM web applications.
5. Developed application proved that users can build custom programs according to their need and throwing new opportunities for 'social manufacturing' and Internet of Things (IoT).

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