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# An integrated feature based CAD/CAPP Optimization solution using .IGES data format

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***Abstract*— In today's globalized manufacturing environment, Computer Integrated Manufacturing (CIM) paradigm has been known as one of the effective enablers. Researchers believe that CIM paradigm can overcome the challenges like ever changing markets and customize oriented products. Of these dominant challenges, fulfilling the role as a bridge which joins the Computer Aided Design (CAD) and Computer Aided Process planning (CAPP) areas can be remarked. Although many solutions have been proposed in the area of CAPP, new research and solutions are still required, as it is believed that the CAPP is a complex engineering problem by facilitating the effective transformation of product design information. In this paper the dominant researches in the fields of CAPP integration with CAD have been investigated. Considering the lacks of the current researches, the paper proposes an effective solution based for integrating the CAD and CAPP areas. This integration is based on the concept of feature based design and manufacturing and benefits from the capability of enabling optimization in process planning area. The different aspects of the proposed solution has been discussed through a comprehensive case study. The capability of the proposed solution for integration with industrial optimization packages while marinating the integrity of the data is of the paper great achievements**

***Index Terms*— CAPP optimization, CAD, feature based process planning, Integration, .IGES**

## I. INTRODUCTION

In today's competitive globalized manufacturing environment, Computer Integrated Manufacturing (CIM) has been known as an effective enabler to overcome the requirements like ever changing markets and customize oriented products (ElMaraghy and Wiendahl 2009, Valilai and Houshmand 2014a). Through vast researches and solutions in CIM area, Computer aided process planning (CAPP) plays an important role (Xie and Tu 2011, Cay, *et al.* 1997, Behrokh, *et al.* 1999, Marri, *et al.* 1998). This role can be imagined as a bridge joining computer aided design (CAD) and computer aided manufacturing (CAM) area by facilitating the effective transformation of product design information into a set of manufacturing instructions consist of required machines, tools, setups, and operations (Ma, *et al.* 2000, Xu, *et al.* 2011, Dong, *et al.* 1997). Moreover, CAPP fulfills the paradigm of CAD and CAM integration as the critical phases of the product development process, resulting in modern digital manufacturing, which has been investigated to be vital to the competitiveness of manufacturing enterprises (Zhou 2007). Although CAPP's essential role as a link between design and manufacturing, new research and solutions are still required as it is believed that the CAPP is a complex engineering problem (Xu, *et al.* 2011). The scope of CAPP is vast and consist of functionalities vary from interpretation of design data, selection of machining operations, machine tools, cutting tools, datum and fixture to the calculation of cost and production time (Furth 1988, Chang and Wysk 2007, Steudely 1984).

One of the CAPP research and investigation topics which have been widely considered is known to be the "Feature" concept (Han, *et al.* 2000, Hyun and Requicha 1998, Sadaiah, *et al.* 2002). This concept facilitates the management of vast area of functionalities in CAPP from geometric analysis to the context of process planning of machined parts (Dong, *et al.* 1997, Chan and Case 1994, Han, *et al.* 2000). A Feature can be interpreted from different perspectives according to its related functionalities, e.g. design, machining, analysis, inspection assembly, etc. most common, a feature is characterized based on its shape in the product model or based on its required machining operation e.g. step, slot, pocket, hole, fillet (Lee, *et al.* 2007). Feature concept has been found to be an effective approach for the integration paradigm in which increases design and manufacturing efficiencies and bridging the gap between designs and manufacturing areas (Dong, *et al.* 1997). However, the feature concepts cannot success to enable the CAD/CAM integration unless they use integrated data structure to explain the areas of CAPP functionalities (Newman and Nassehi 2007, Houshmand and Valilai 2013b, Valilai and Houshmand 2013c).

Proceeding, the paper investigates the dominant researches in the fields of CAPP integration with CAD in section "Literature review". Moreover, the data integration approaches of the researches to enable the CAD/CAM integration are studied in section "Feature recognition". Discussing the merits and shortcomings of the researches, the paper proposes an effective solution based on feature based approach to fulfill the studied researches' shortcomings in section "Proposed idea". The contributions of the paper for

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data integration is discussed in section “Integrated CAD data structure”. The concepts of consolidation of process planning based on a feature based approach has been investigated in sections “Feature based data structure” and “The consolidated optimization module”. Finally, in section “
Case study”, the paper discusses a brief case study to elaborate the functionalities of the proposed solution.

## II. Literature review

Considering the aim of the paper for integrating the CAD and CAPP areas, the literature has been investigated for algorithms which enable the integration of feature-based process planning. As researchers believe, the power of feature models in linking the CAD/CAPP domain is highly effective as it links the design features to feature types associated with manufacturing process models (Martti 1996). In this perspective, CAD will also be based on geometrical features and CAPP/CAM will be based on manufacturing features (Zhou, *et al.* 2007). The paper have studied the dominant research works and classified the results in the three groups as shown in

Table 1.

Table 1.Review of Important Micro CAPP Platform, Manufacturing Data Integration Platform and Integration of CAD/CAPP Platform

| Author's name | Contribution | Proposal of a Micro CAPP solution | proposal of a Manufacturing Data Integration solution | Data integration between CAD and CAPP |
|---|---|---|---|---|
| Lee, *et al.* 2007 | Integration System from Design Data to Automatic Computer-aided Process Planning (CAPP) | NO | NO | YES |
| Miao, *et al.* 2002 | Integrating CAD and CAM Modules in Commercial CAD/CAM Software | NO | NO | YES |
| Hou and Faddis 2006 | Tool Path Generation in an Integrated CAD/CAPP/CAM System Based on Machining Features | NO | NO | YES |
| Bianconi, *et al.* 2006 | Application Program Interface and data exchange integration between CAD/CAM/CAPP/CAX | NO | NO | YES |
| Gao, *et al.* 2005 | Feature Based CAD/CAPP Integration Through STEP File | NO | YES | YES |
| Sivakumar and Dhanalakshmi 2013 | Integration of CAD/CAM/ CAI through STEP file | NO | YES | YES |
| Valilai and Houshmand 2010 | Integration and Interoperable Platform for Collaborative CAD/CAPP/CAM/CNC Machining Systems based on STEP Standard | NO | YES | YES |
| Balakrishna, *et al.* 2006 | Integration between CAD/CAM/CAE in Product Development System Using STEP/XML | NO | YES | YES |
| Xu, *et al.* 2011 | Intelligent CAD/CAPP/CAM/CNC Integration Based on STEP-NC | NO | YES | YES |
| Valilai and Houshmand 2013c | Collaboration and Integration for CAD/CAM in New Product Development Based on Step Standard | NO | YES | YES |
| Garcia, *et al.* 2011 | Process Planning Based on Feature Recognition Method | YES | NO | NO |
| Dong, *et al.* 1997 | Integration of Feature Based Process Planning and Scheduling | YES | NO | NO |

In the first group, (Lee, *et al.* 2007, Miao, *et al.* 2002, Hou and Faddis 2006, Dartigues, *et al.* 2007) used CAD and CAPP data integration. In these investigations, the researchers developed efficient feature recognition algorithms in order to enable data integration between CAD and CAPP domains. However, the researchers neither proposed any solution to enable a standard data format for CAD design data nor considered any solution for the Micro CAPP application. In the second group, (Gao, *et al.* 2005, Sivakumar and Dhanalakshmi 2013, Valilai and Houshmand 2010, Balakrishna, *et al.* 2006, X. W. Xu, *et al.* 2005, Valilai and Houshmand 2013c) have proposed manufacturing data integration solutions. Moreover, the researchers investigated for frameworks that enable data integration between CAD and CAPP. In most of these methods, 3D designed parts data were maintained in a common standard data format such as STEP (Standard for the Exchange of Product model data), .IGES (*Initial Graphics Exchange Specification)*, DXF (Drawing Exchange Format). The CAD data, which usually included geometric entities like lines, circles, faces and points were used by CAPP for feature extraction operations. However, these investigations lacked for an efficient solution, which can lead from the extracted features to Process planning operations in micro CAPP.

In the third group, researchers like (Garcia, *et al.* 2011, Dong, *et al.* 1997) proposed solutions which enabled powerful feature recognition algorithms for detailed process planning automation in micro CAPP. However, these methods did not fulfill a standard data format for geometric 3D solid modeling nor they proposed data integration solutions among CAD and CAPP environments. Considering the aforementioned researches, this paper proposes a novel solution in which paradigms like data integration among CAD and CAPP environment, supporting process planning operations in micro CAPP in the form of famous .IGES standard data format and application of these standardized data in efficient features recognition and extraction environment can be achieved.

## 3. IGES Format

IGES has been recognized as one of the common standards for geometric data exchange of CAD objects (Kahrs 1995). The .IGES data structure can be divides into five sections, which appear in the following order: Start section, Global section, Directory Entry section, Parameter data Entry section and Terminate section. Two main important sections in the .IGES data structure are Directory Entry section and Parameter data Entry section. Directory Entry section consists of all entities forming the geometric model of the parts. These entities can be geometric objects like straight lines, points, planes, arcs, composite curves (Abouel Nasr and Kamrani 2006). Moreover, in Parameter data Entry section, the detailed data describing the entities in Directory Entry section are described.

This research uses .IGES data structure for its new feature recognition mechanism. Through this mechanism, the algorithm considers the part geometric data in the form of .IGES data structure and looks for geometric objects in the .IGES file to form the design features.

### I. Feature recognition

In computer integrated manufacturing and computer process planning, product data management in different manufacturing disciplines is indispensable. One of the well-known solutions for product data management is the application of features concepts. A feature can be defined as a general shape of a part clearly related to the manufacturing process (Lee, *et al.* 2007) also it can be described as a geometric form that created on the surfaces or initial 3D, 2D part in the manufacturing process such as hole, step, slot, pocket, etc. (Abouel Nasr and Kamrani 2006). Different solutions have been proposed in the area of feature recognition. Some of the well-known solutions are syntactic pattern recognition approach, geometric decomposition approach, expert system rules/logic approach and graph-based approach. But among existing approaches, two types of feature recognition methods have been considered by the researchers being known as graph-based method and hint-based method. Graph-based solutions had been vastly used through 1980's due to their well-established techniques of graph algorithms (Rahmani and Arezoo 2007). If the boundary representation (B-Rep) of a component is used for CAD geometric modeling, faces can be considered as nodes of the graph and face to face relationships form the links of the graph (Xun 2009). In the graph-based feature recognition, a graph represents the topology and geometry of the part (connection of faces) is created. The graph is often recognized, for example the edges are marked as concave or convex (Joshi and Chang 1988, Verma and Rajotia 2004). This graph is then analyzed to extract subsets of nodes and arcs that match with any predefined template. Moreover, Hint-based methods search for the effects of the features on the geometric shape known as hints. This makes them strong especially in case of intersecting features. By application rules, the hints detection occurs based on geometry and topology of faces. Usually, models for feature definition base on hints are modelled as packages as feature recognition algorithm (JungHyun, *et al.* 2000, Rahmani and Arezoo 2007).

## 4. Proposed idea

According to a literature review and dominant researches, this paper focuses on three domains including a) Integration between CAD and CAPP, b) standard data format for geometric 3D solid modeling and c) process planning automation in micro CAPP. Figure 1 shows the overall architecture to support the three scopes. This architecture covers the overviewed researches' gap with following functionalities.

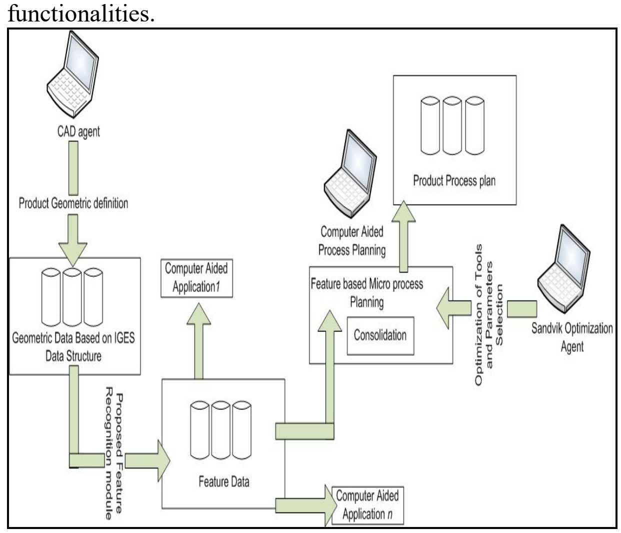


Figure 1. The overall architecture of the proposed solution

## 5. Integrated CAD data structure

In the first part of the architecture, the part design data is introduced through CAD software and it is represented as a solid model assuming that the B-Rep technique is used. The architecture requires that the CAD software can generate an .IGES data file for representing the geometrical information of the part which is one of the common features of the CAD solutions. The .IGES file is then imported to the framework and the data of the geometric content is extracted. The procedure for geometric data extraction from .IGES file format as shown in Figure 2.

Table 2.

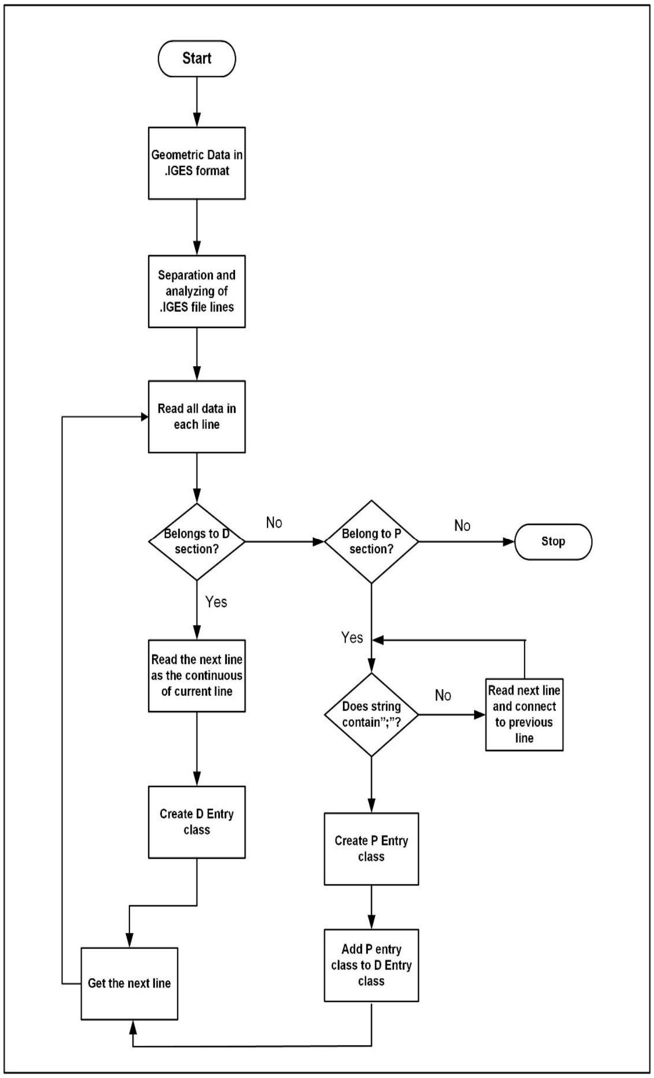


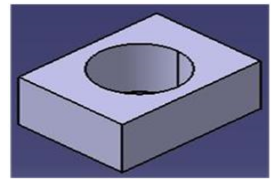
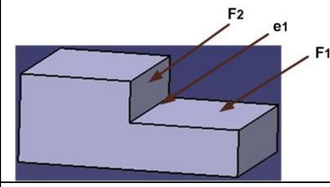
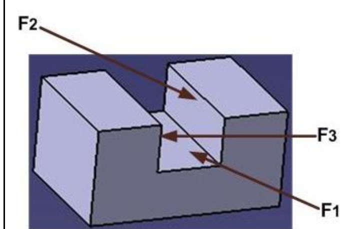

Figure 2. The procedure for geometric data extraction from .IGES file format

## 6. Feature based data structure

In the second part of the architecture, the proposed framework consists of a feature recognition application, which analyses the B-Rep geometrical information related to the part design. All entities in the directory section and parameter section long with proper subsets that contain all geometric objects like points, vertices, lines, faces are extracted in the proposed module. The architecture applies this module to extract the design features on the part. The architecture extracts the design features by applying a hint-based approach. The feature recognition rules are able to recognize common features like Slot (through), Hole (through), Step (through). The related feature recognition procedures are described in

Table 2. Feature extraction procedures proposed in the architecture

| Features | Algorithm for Feature Extraction | Feature Shape |
|---|---|---|

| | | |
|---|---|---|
| Hole through | For every edge in the list, If edge is a closed loop and is inner<br>Then create a new HOLE THROUGH object with the edge as the circle suface and look for the similar edge in the list |  |
| Step through | For every inner edge (e1) of type line in the edge list<br>If face f2 is a adjacent to face f1.<br>If two common faces(face1 and face 2) of the edge (e1) orthogonal to each other<br>And the angle between f2 and f1 is 90.<br>Then faces f1 and f2 form a step<br>Create a new step T object and add to feature list<br>End for |  |
| Slot through | For every two inner edges of type line in the edge list.<br>If face f2 adjacent to face f1 and face f3 is adjacent to face f1.<br>If the two edges have a common face(face1) connected to them and inner edge count of the outer loop of the face equals two.<br>And face f2 and face f3 are perpendicular to the common face(facef1) and parallel to each other with inner edge count of their outer loops equal one.<br>The faces f1, f2 and f3 form a slot.<br>Create a new slot T object and add to feature list.<br>End for |  |

## 7. THE CONSOLIDATED OPTIMIZATION MODULE

In the third part of the proposed architecture, the recognized features which were extracted from the part are used and by interpreting the parameters related to those feature, the micro process planning mechanism is run. The micro process planning mechanism then applies the Sandvik© optimization agent and proposes the optimal machining parameters. The optimal machining parameters are then transferred to the feature based micro process planning mechanism and are consolidated with the geometric feature data as described in Table 3.

Table 3. Sandvik© optimization procedures proposed in the architecture

| | | **Sandvik© Parameters** | |
|---|---|---|---|
| **Features** | **Parameters Objective** | **Input** | **Output** |
| Hole | Drill Diameter<br>Hole Depth | Drill Diameter<br>Hole Depth | Net Power<br>Feed Force<br>Torque<br>Metal Removal Rate<br>Cutting Time Per Hole<br>Hole Depth |
| Step | Cutting Diameter<br>MAX Ap Finishing<br>MAX Ap Roughing<br>High<br>Roughing Number | Cutting Diameter<br>Inscribed Circle<br>Number of effective edges<br>Cutting Depth<br>Machined Diameter of the work piece<br>Unmachined Diameter of the work piece | Cutting Speed<br>Spindle Speed<br>Feed Speed<br>Vfm<br>Cutting power for removal of chips(pc)<br>Metal removal of rate<br>Cutting torque |
| | Cutting Diameter<br>MAX Ap Finishing | Feed per cutting edge(fz)<br>Maximum chips thickness(hex) | Cutting Speed<br>Spindle Speed |

| | | | |
|---|---|---|---|
| Slot | MAX Ap Roughing<br>High<br>Roughing Number | Average chips thickness(hm)<br><br>Cutting Diameter<br>Inscribed Circle<br>Number of effective edges<br>Cutting Depth<br>Machined Diameter of the work piece<br>Unmachined Diameter of the work piece | Feed Speed<br>Vfm<br>Cutting power for removal of chips(pc)<br>Metal removal of rate<br>Cutting torque |

## 8. Case Study

For validation of the proposed architecture, a comprehensive case study has been designed to investigate the capabilities of the architecture. The case study considers a product design phase in which the geometric data of the product is defined. In this phase, a part design has been declared using a CAD software package as shown in Figure 3. In this stage, the part geometric is defined by the operator. Then, the CAD software connects to the proposed architecture and delivers the CAD data in the format of .IGES data structure. The .IGES based CAD data of the designed part is shown Figure 4.

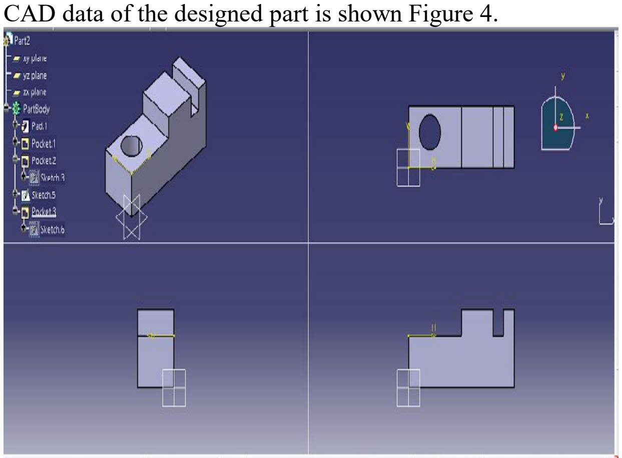


Figure 3. The case study part

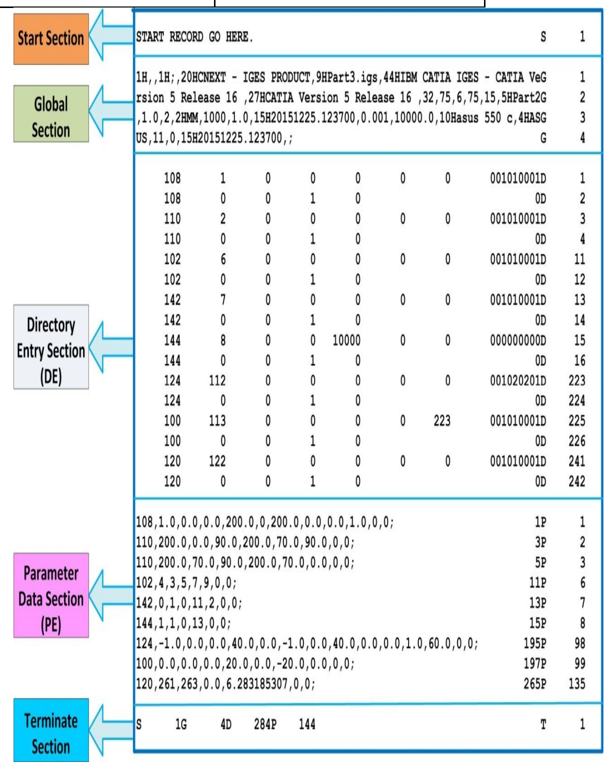



Figure 4. The .IGES CAD data

In the second phase, a module has been developed for feature recognition by the application of an object oriented software package. In the first step, the .IGES file should is read and all geometric data is extracted line by line through the directory and parameter data sections as it was discussed in procedure shown in Figure 4 . In the directory section, all entities are extracted. These entities can include geometric objects like points, lines, vertices and faces. The entities are coded as shown in Table 4. These entities are keys for explaining point, lines, and other geometric objects. For example the entity coded as type 100 is a circle and entity coded as type110 is straight line as shown in Table 4. The solution has retrieved all circles, straight lines and composite curves from the CAD data. Straight lines, circles and composite curves are entities related to the design features of the designed part. The architecture then delivers all the geometric entities to the main module with their subsets, which consist of all points, lines, vertices and faces. Proceeding, all lines, composite curves and circle are sent to the top module with their subsets including start points, end points, vertices and faces as shown as Figure 5.

Table 4. Curve and Surface Entities

| Entity Type Number | Entity Description |
|---|---|
| 108 | Plane |

| | |
|---|---|
| 110 | Straight Line |
| 102 | Composite Curve |
| 142 | Curve on Parametric Surface |
| 144 | Trimmed Parametric Surface |
| 124 | Transformation Matrix |
| 100 | Circular Arc |
| 120 | Surface of Revolution |

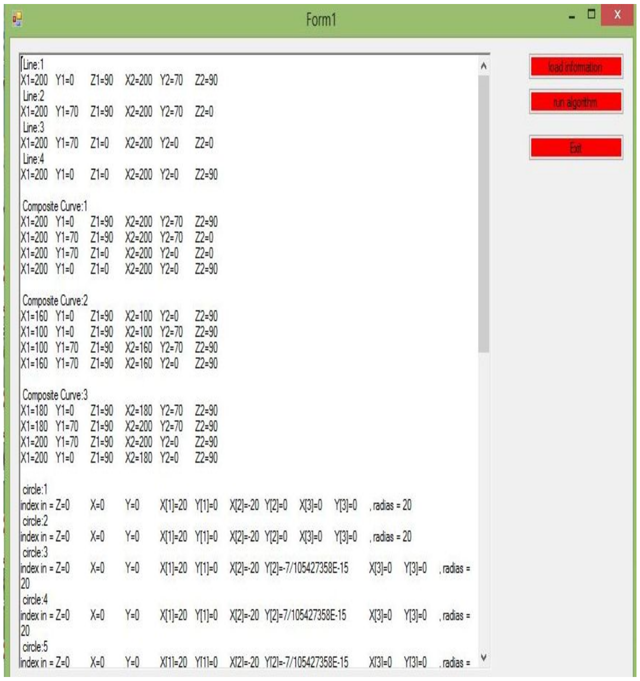



Figure 5. The extracted geometric information of the case study part

After the geometric data of the part is interpreted, the solution starts to execute its feature recognition procedure. As mentioned in section "Feature based data structure", this procedure uses the geometric interpreted data and recognizes the machining features of the part. The extracted features are defined based on the developed procedures described in Table 2. Figure 6 shows the extracted feature of the case study part like hole, slot and step. The extracted features are then delivered to the architecture for future application.

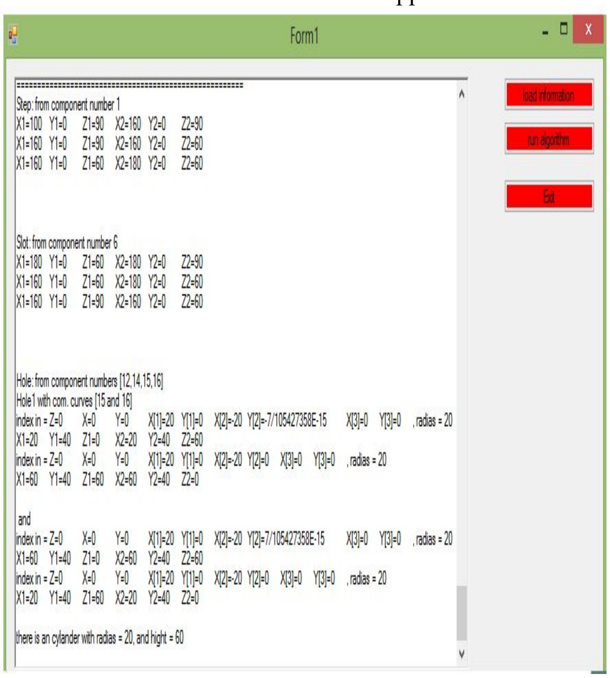



Figure 6. The extracted feature representations

In the third phase, the recognized features, which were extracted from the designed part, are considered. As each feature has definite parameters which are necessary for process planning as described in Table 3, the solution is designed to define these parameters. The solution prepares the required parameters of each extracted feature and then sent those parameters to the micro process planning module. Afterward, the micro process planning mechanism applies the Sandvik© optimization agent and proposes the optimal machining parameters. As described in section "The consolidated optimization module", the Sandvik© optimization agent is designed to propose the optimal machining parameters for each machining feature. The proposed optimal machining parameters are then transferred back to the solution and are consolidated with the geometric feature data as shown as Figure 7 based on the feature type.

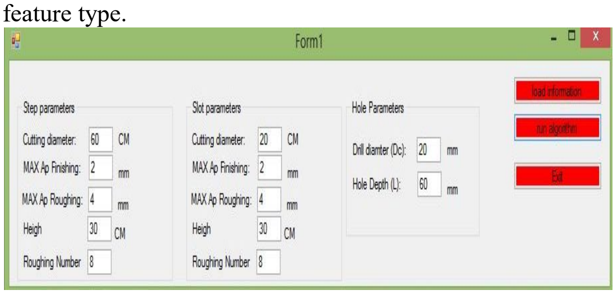



Figure 7. The consolidated micro process planning and the feature geometric data

## CONCLUSION

Nowadays, manufacturing enterprises have faced with the paradigm of globalization in which challenges like integration and worldwide distributed collaboration. Computer Integrated Manufacturing (CIM) has been introduced as one of the most powerful enablers to achieve globalization paradigm. In CIM concept, Computer Aided concepts are vastly considered. Through the CAX, Computer Aided Process Planning (CAPP) is known as one of the challenging scopes playing a critical role in the phases of the product development process, resulting in modern digital manufacturing. Of these dominant challenges for CAPP, the role as a bridge which joins the Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) areas can be remarked. Although many solutions have been proposed in the area of CAPP, new research and solutions are still required, as it is believed that the CAPP is a complex engineering problem by facilitating the effective transformation of product design information. In this paper the dominant researches in the fields of CAPP integration with CAD were investigated. The findings of this research showed the capabilities of the feature based design and process planning as a valuable research area to overcome the shortcomings of the studied papers. Proposing a feature based approach, the paper have proposed an effective solution based for integrating the CAD and CAPP areas. This integration benefited from the capability of enabling optimization in process planning area. The proposed solution consisted of three main modules. One for maintain the integrity of geometric data, the second one for the feature recognition and the last for optimizing the process planning parameters. The different aspects of the proposed solution has been discussed through a comprehensive case study. The capability of the proposed solution for integration with industrial optimization packages while marinating the integrity of the data is of the paper great achievements. For further researches, the paper proposes consideration of more advanced standard especially ISO 10303 (STEP). Also, the paper proposes the extension of the paper's proposed solution to support more advanced CAPP optimization modules and procedures.

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