US009886529B2

(12) **United States Patent**
Kannan et al.

(10) **Patent No.: US 9,886,529 B2**
(45) **Date of Patent: Feb. 6, 2018**

(54) **METHODS AND SYSTEMS FOR FEATURE RECOGNITION**

(71) Applicant: **GEOMETRIC LIMITED**, Vikhroli (W), Mumbai (IN)

(72) Inventors: **Thoguluva Ramamoorthy Kannan**, Chennai (IN); **Deepti Gupta**, Mumbai (IN)

(73) Assignee: **HCL Technologies Limited**, New Delhi (IN)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 772 days.

(21) Appl. No.: **14/471,666**

(22) Filed: **Aug. 28, 2014**

(65) **Prior Publication Data**

US 2016/0063136 A1 Mar. 3, 2016

(51) **Int. Cl.**
G06F 17/50 (2006.01)
G06T 17/10 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 17/50*** (2013.01); ***G06T 17/10*** (2013.01)

(58) **Field of Classification Search**
CPC G06F 17/50
USPC 703/1
See application file for complete search history.

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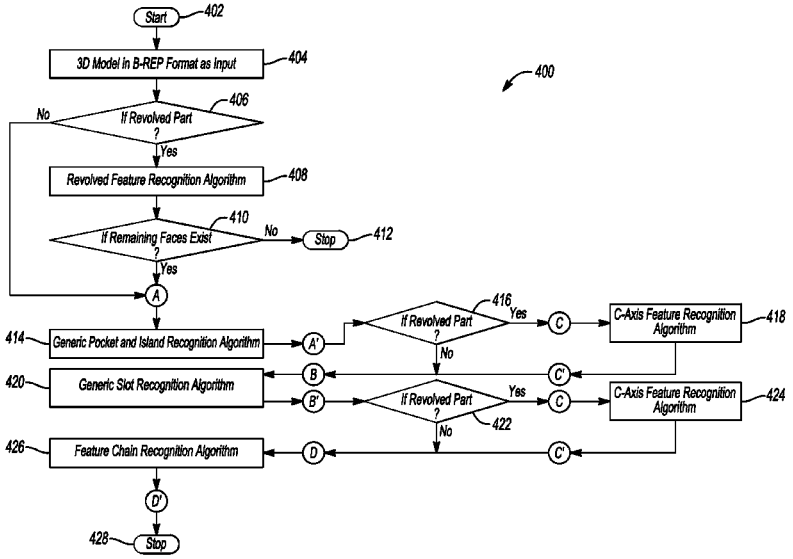
Primary Examiner — Timothy A Mudrick
(74) *Attorney, Agent, or Firm* — Brooks Kushman P.C.

(57) **ABSTRACT**

A computer-implemented product including instructions embodied in a non-transitory computer read-able medium that, when executed by a processor, cause the processor to receive input selecting one of a plurality of faces of a boundary representation model of an object. The computer-implemented product may include further instructions to identify boundary edges of the model outside the one of the faces not separated from the one of the faces by an intervening concave or convex edge. The boundary edges may define a perimeter of a topological feature containing the one of the faces. The computer-implemented product may include further instructions to identify a set of the faces including the one of the faces contained by the perimeter and generate output highlighting the boundary edges and set of the faces of the topological feature.

20 Claims, 12 Drawing Sheets



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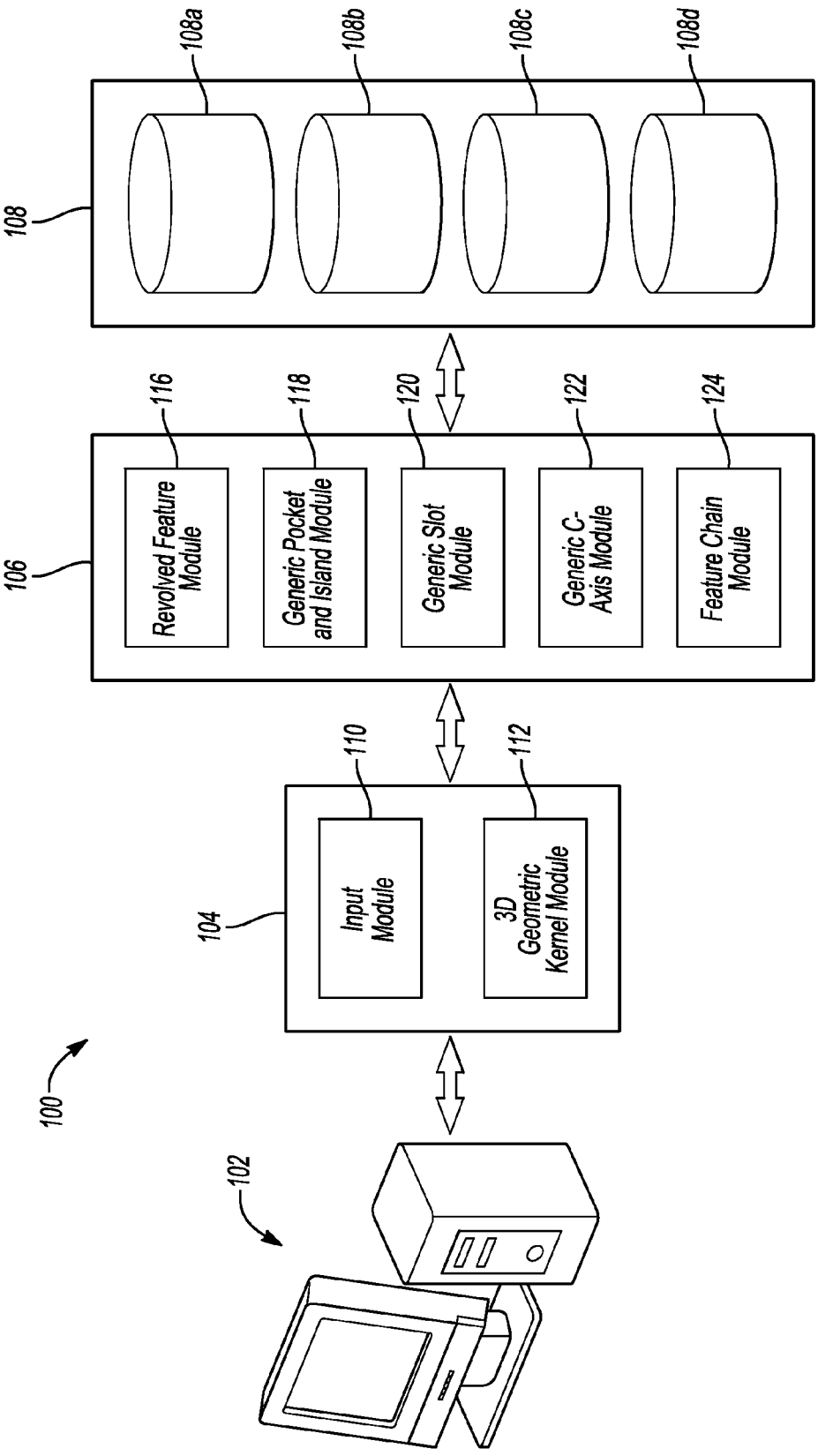

100
102
104
106
108
108a
108b
108c
108d
110
112
116
118
120
122
124
Input Module
3D Geometric Kernel Module
Revolved Feature Module
Generic Pocket and Island Module
Generic Slot Module
Generic C-Axis Module
Feature Chain Module

Fig-1

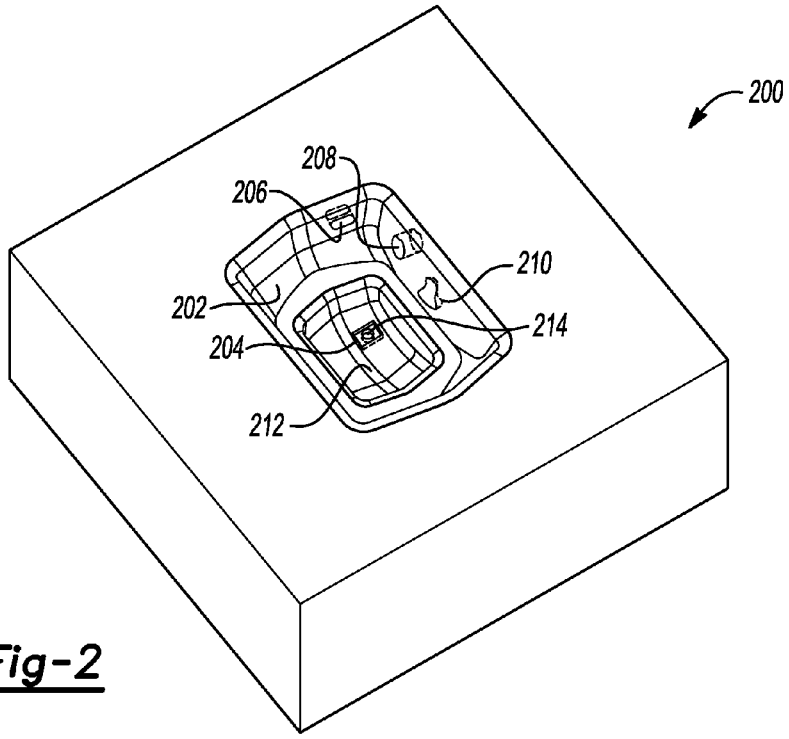
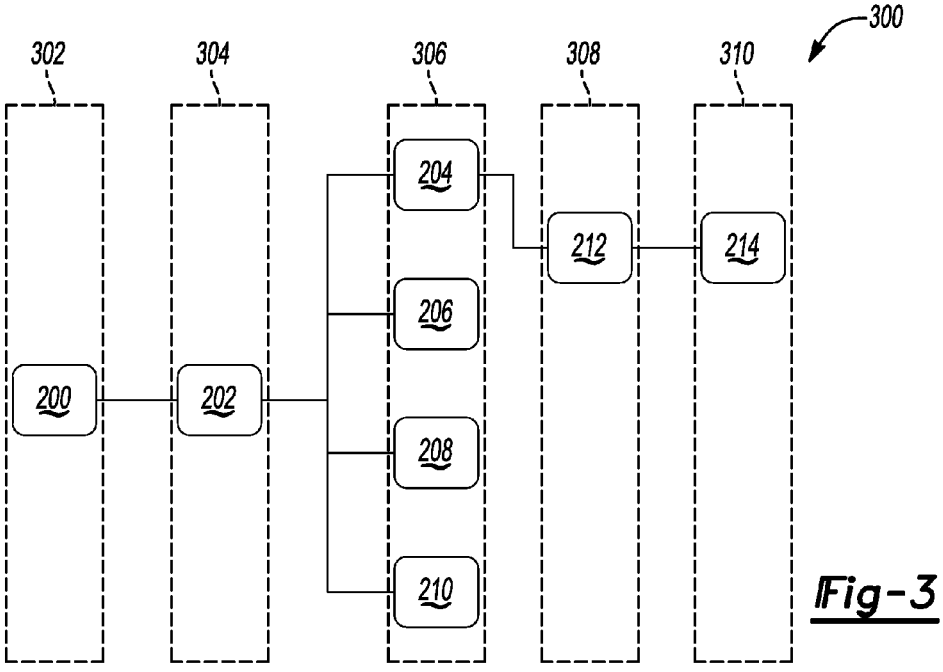

200
208
206
210
202
214
204
212

Fig-2


300
302
304
306
308
310
204
212
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206
200
202
208
210

Fig-3

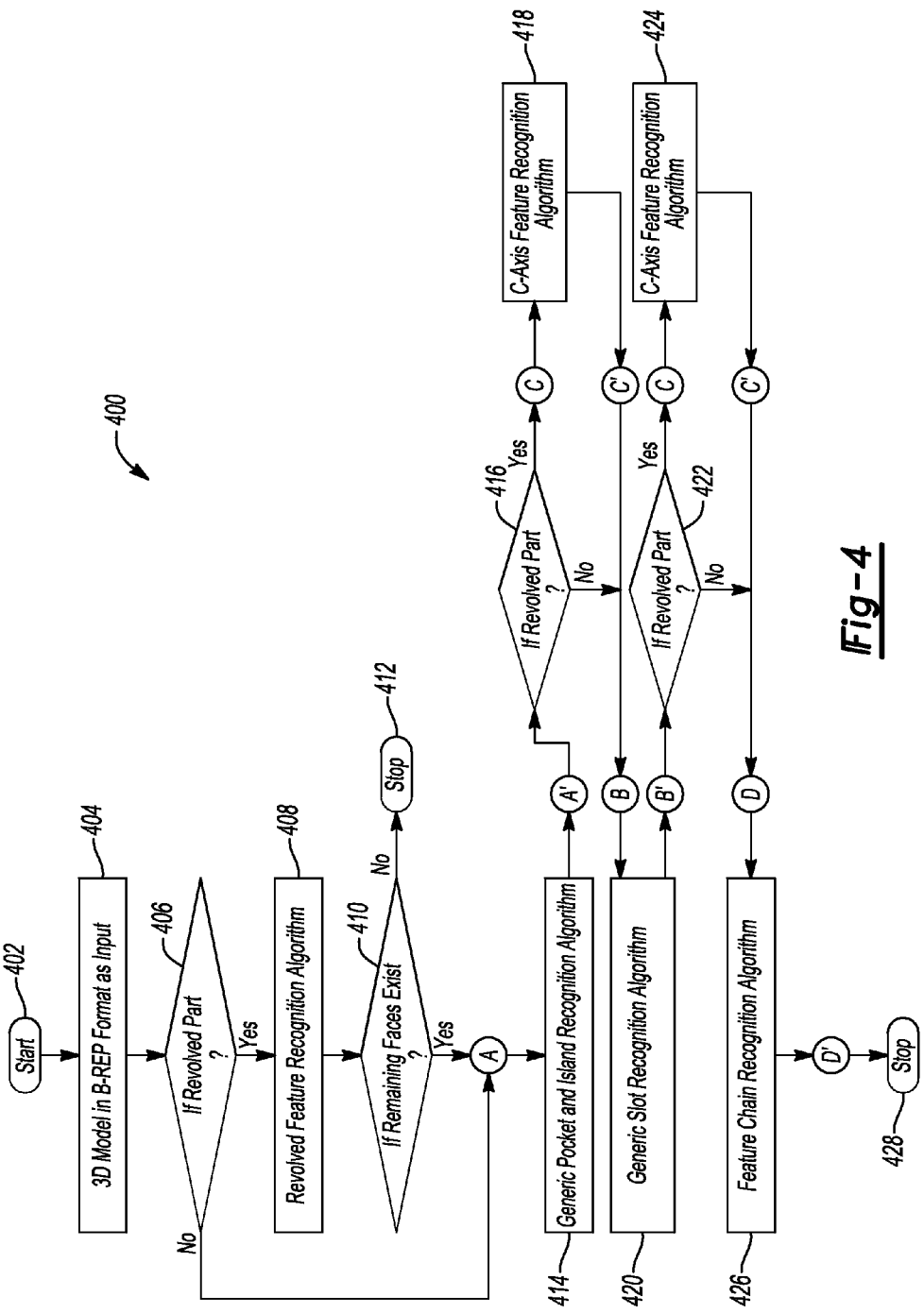
400
Start
402
3D Model in B-REP Format as Input
404
If Revolved Part ?
406
Yes
No
Revolved Feature Recognition Algorithm
408
If Remaining Faces Exist ?
410
No
Stop
412
Yes
A
A'
Generic Pocket and Island Recognition Algorithm
414
If Revolved Part ?
416
Yes
No
C
C-Axis Feature Recognition Algorithm
418
B
B'
Generic Slot Recognition Algorithm
420
If Revolved Part ?
422
Yes
No
C
C-Axis Feature Recognition Algorithm
424
D
D'
Feature Chain Recognition Algorithm
426
Stop
428

Fig-4

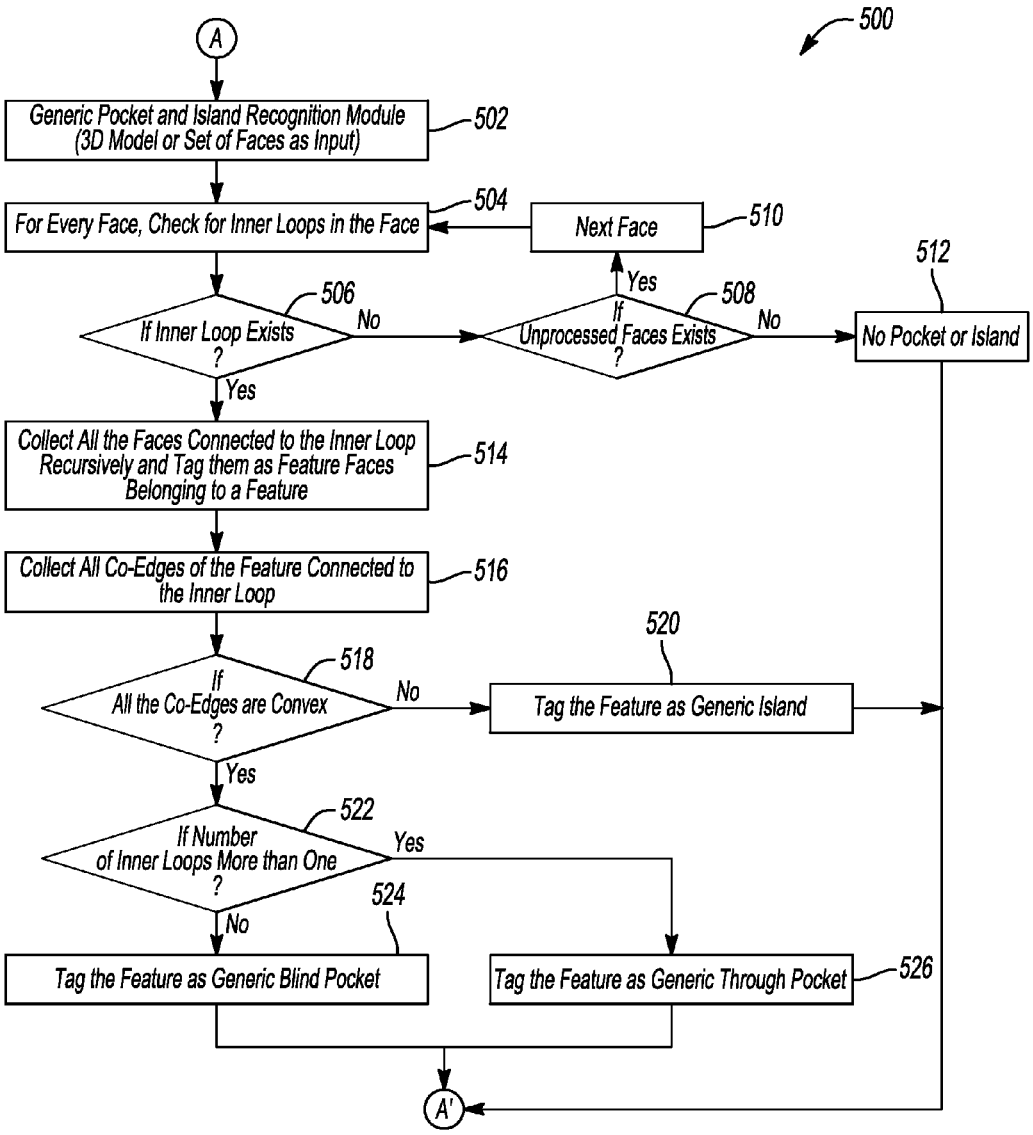
500
A
Generic Pocket and Island Recognition Module (3D Model or Set of Faces as Input)
502
For Every Face, Check for Inner Loops in the Face
504
Next Face
510
512
If Inner Loop Exists ?
506
No
Yes
If Unprocessed Faces Exists ?
508
Yes
No
No Pocket or Island
Collect All the Faces Connected to the Inner Loop Recursively and Tag them as Feature Faces Belonging to a Feature
514
Collect All Co-Edges of the Feature Connected to the Inner Loop
516
520
If All the Co-Edges are Convex ?
518
No
Tag the Feature as Generic Island
Yes
If Number of Inner Loops More than One ?
522
Yes
524
No
Tag the Feature as Generic Blind Pocket
Tag the Feature as Generic Through Pocket
526
A'

Fig-5

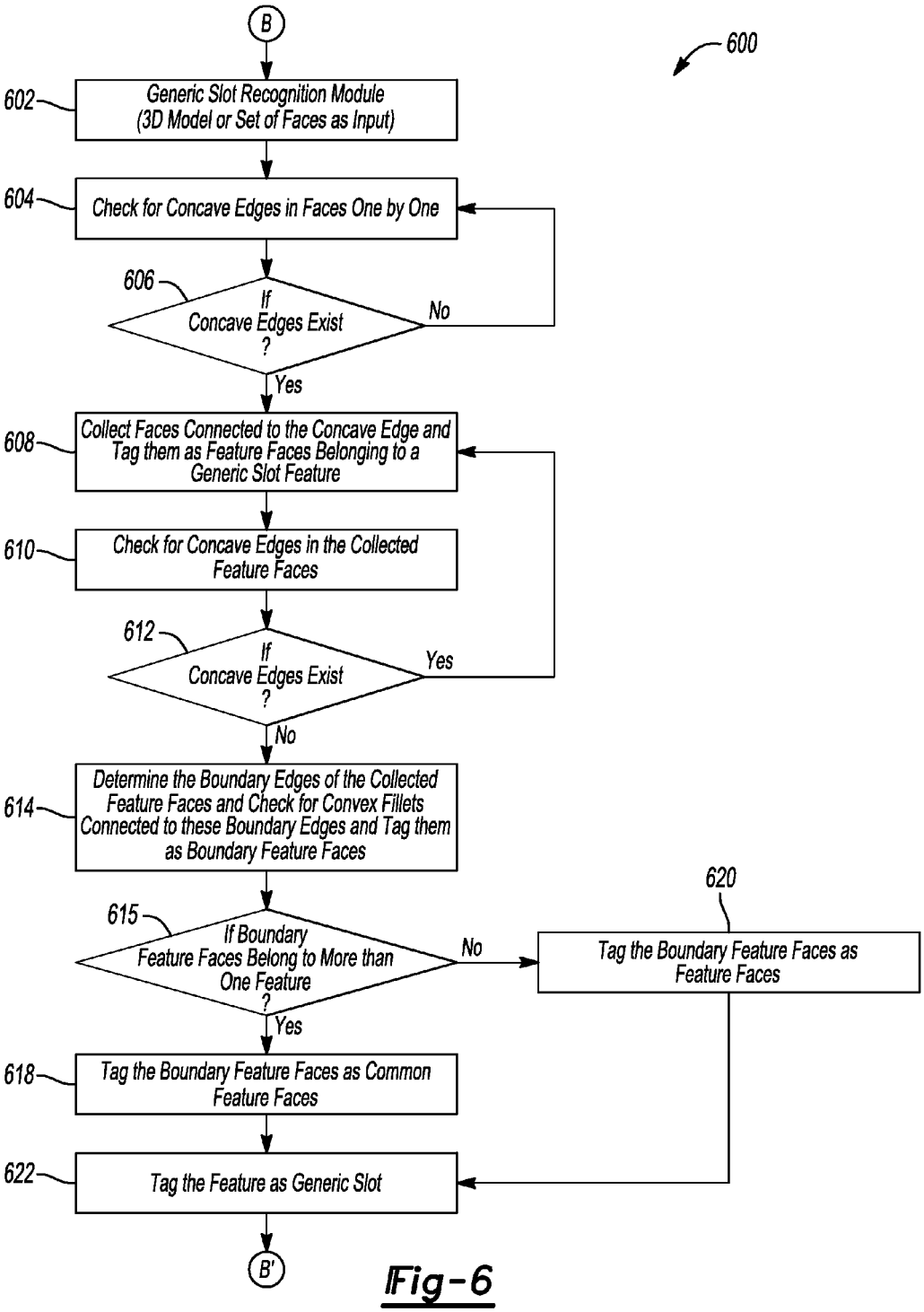
B
600
602
Generic Slot Recognition Module (3D Model or Set of Faces as Input)
604
Check for Concave Edges in Faces One by One
606
If Concave Edges Exist ?
No
Yes
608
Collect Faces Connected to the Concave Edge and Tag them as Feature Faces Belonging to a Generic Slot Feature
610
Check for Concave Edges in the Collected Feature Faces
612
If Concave Edges Exist ?
Yes
No
614
Determine the Boundary Edges of the Collected Feature Faces and Check for Convex Fillets Connected to these Boundary Edges and Tag them as Boundary Feature Faces
615
If Boundary Feature Faces Belong to More than One Feature ?
No
620
Tag the Boundary Feature Faces as Feature Faces
Yes
618
Tag the Boundary Feature Faces as Common Feature Faces
622
Tag the Feature as Generic Slot
B'

Fig-6

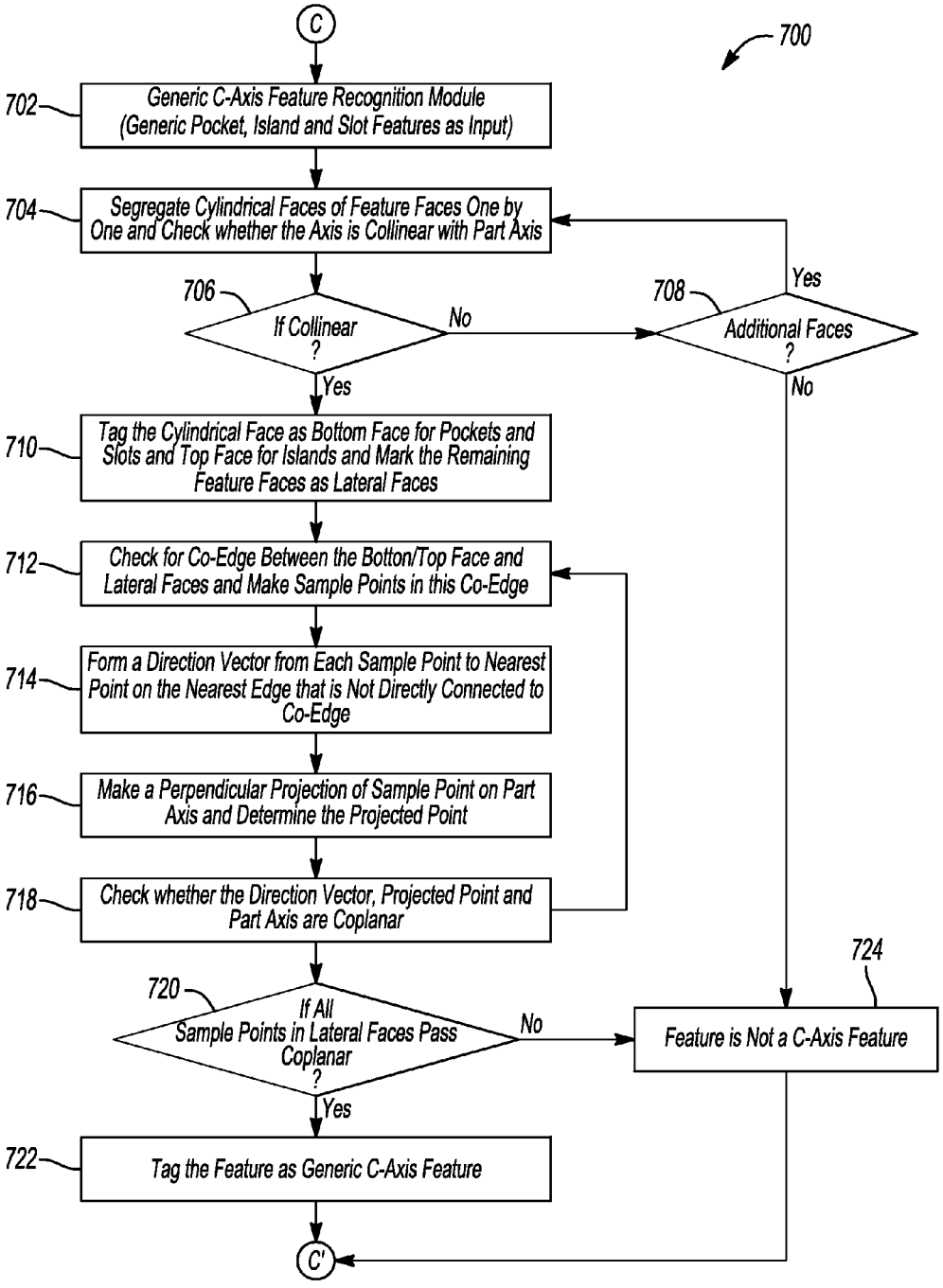
C
700
702
Generic C-Axis Feature Recognition Module (Generic Pocket, Island and Slot Features as Input)
704
Segregate Cylindrical Faces of Feature Faces One by One and Check whether the Axis is Collinear with Part Axis
706
If Collinear ?
No
Yes
708
Additional Faces ?
Yes
No
710
Tag the Cylindrical Face as Bottom Face for Pockets and Slots and Top Face for Islands and Mark the Remaining Feature Faces as Lateral Faces
712
Check for Co-Edge Between the Botton/Top Face and Lateral Faces and Make Sample Points in this Co-Edge
714
Form a Direction Vector from Each Sample Point to Nearest Point on the Nearest Edge that is Not Directly Connected to Co-Edge
716
Make a Perpendicular Projection of Sample Point on Part Axis and Determine the Projected Point
718
Check whether the Direction Vector, Projected Point and Part Axis are Coplanar
720
If All Sample Points in Lateral Faces Pass Coplanar ?
No
Yes
724
Feature is Not a C-Axis Feature
722
Tag the Feature as Generic C-Axis Feature
C'

Fig-7

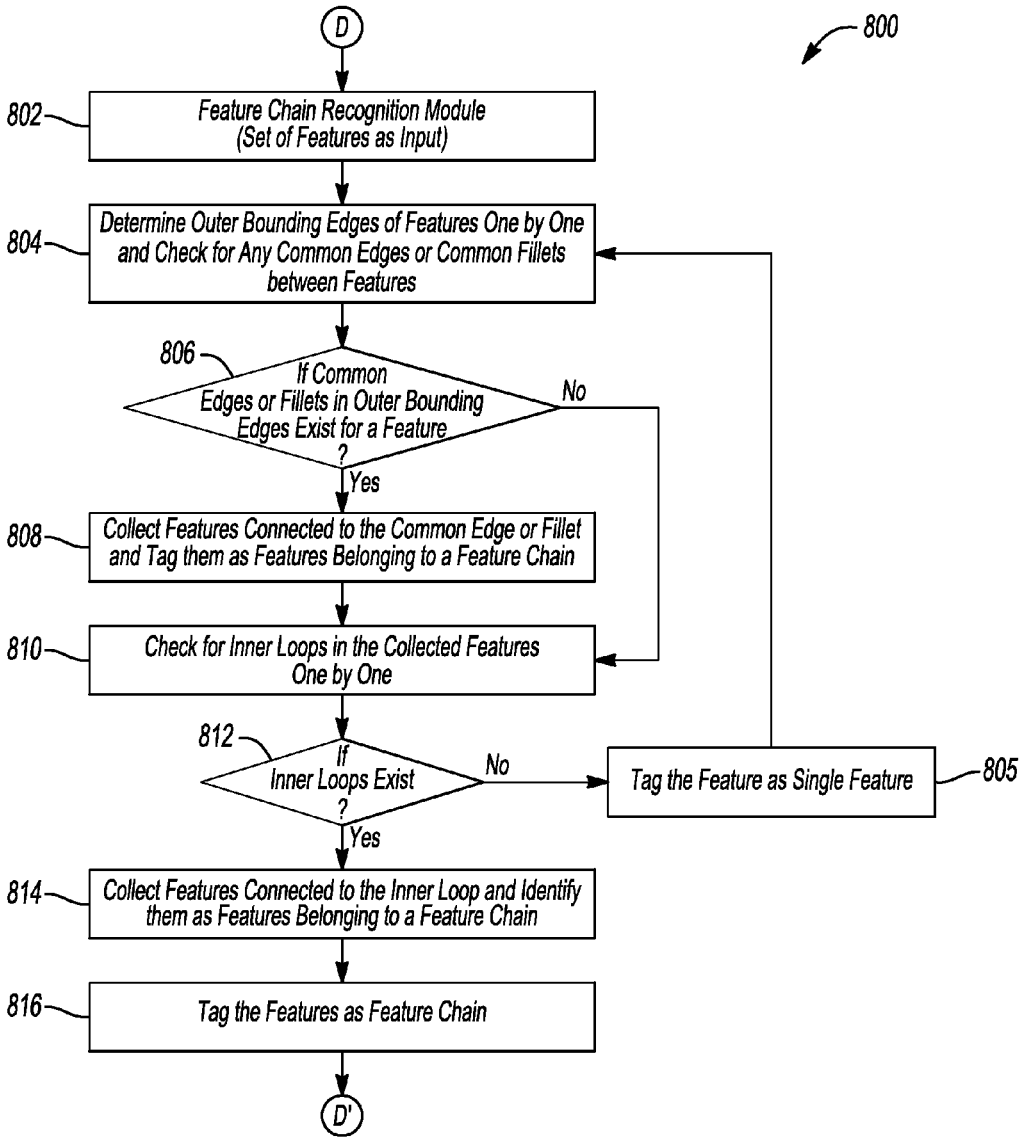
D
800
802
Feature Chain Recognition Module (Set of Features as Input)
804
Determine Outer Bounding Edges of Features One by One and Check for Any Common Edges or Common Fillets between Features
806
If Common Edges or Fillets in Outer Bounding Edges Exist for a Feature ?
No
Yes
808
Collect Features Connected to the Common Edge or Fillet and Tag them as Features Belonging to a Feature Chain
810
Check for Inner Loops in the Collected Features One by One
812
If Inner Loops Exist ?
No
Tag the Feature as Single Feature
805
Yes
814
Collect Features Connected to the Inner Loop and Identify them as Features Belonging to a Feature Chain
816
Tag the Features as Feature Chain
D'

Fig-8

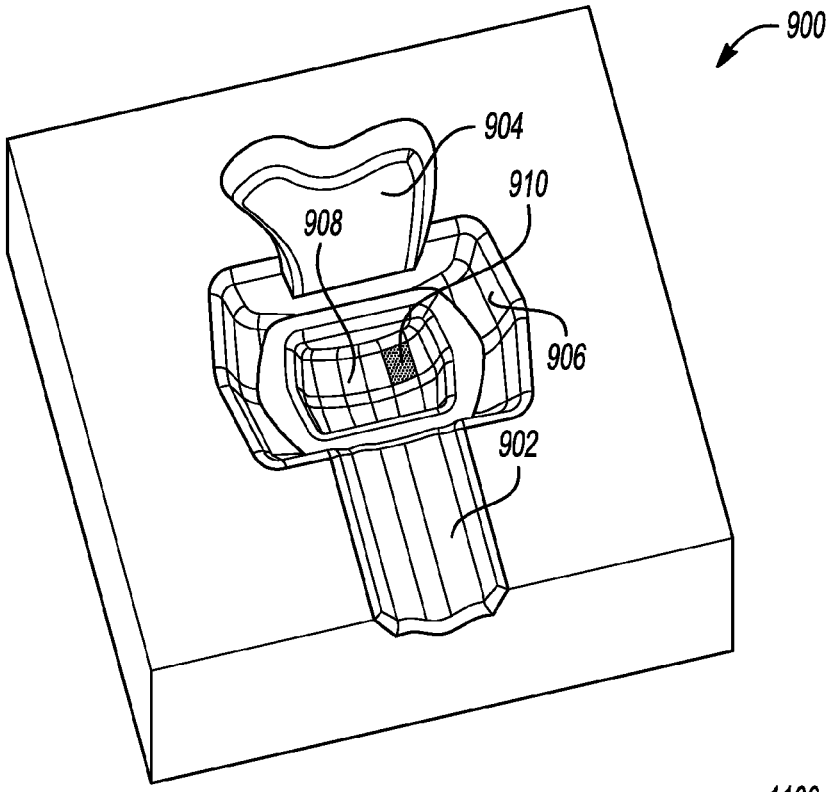

Fig-9

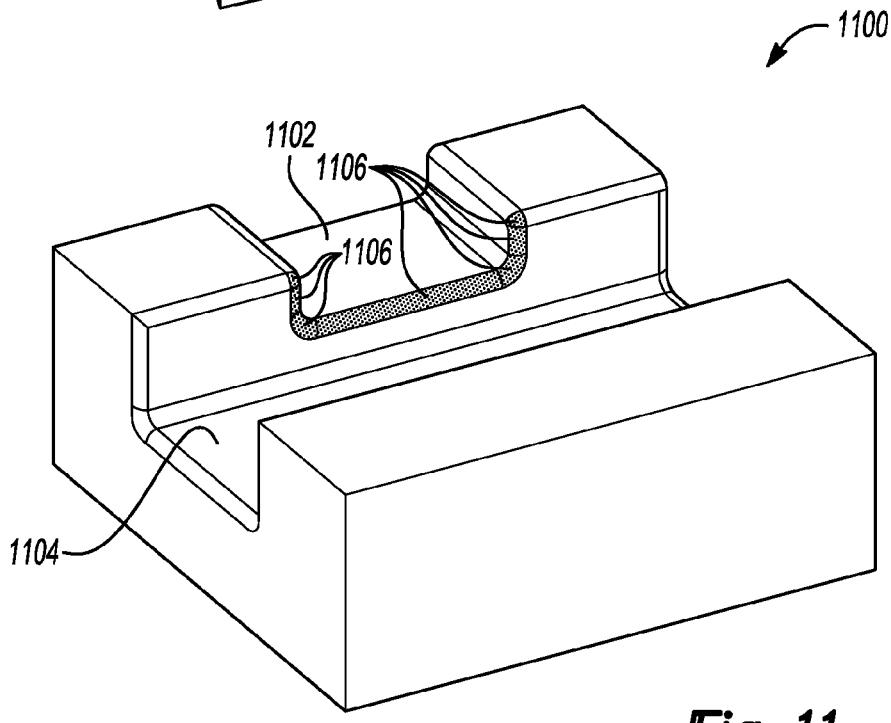

Fig-11

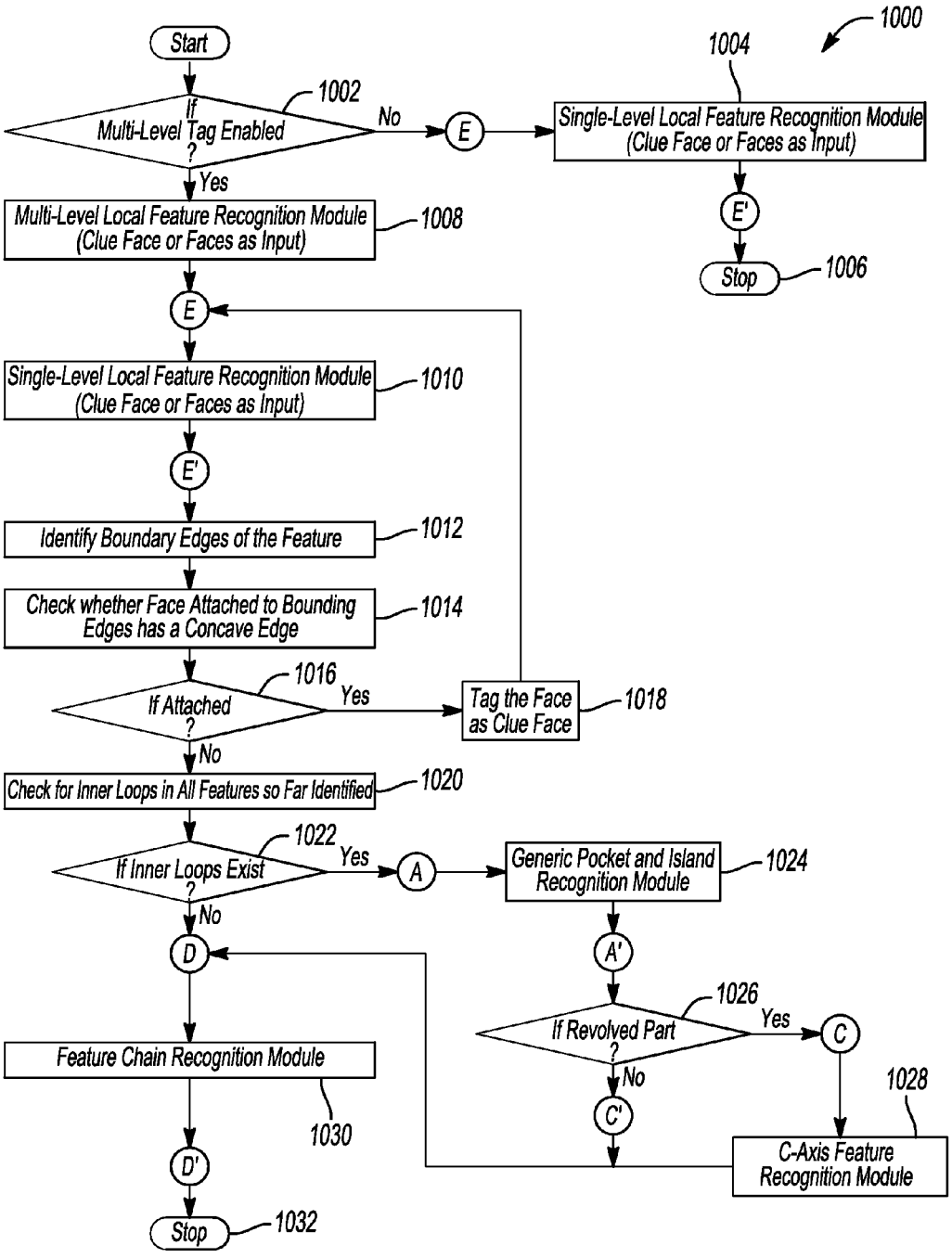
1000
Start
1002
If Multi-Level Tag Enabled ?
No
E
1004
Single-Level Local Feature Recognition Module (Clue Face or Faces as Input)
E'
Stop
1006
Yes
Multi-Level Local Feature Recognition Module (Clue Face or Faces as Input)
1008
E
Single-Level Local Feature Recognition Module (Clue Face or Faces as Input)
1010
E'
Identify Boundary Edges of the Feature
1012
Check whether Face Attached to Bounding Edges has a Concave Edge
1014
1016
If Attached ?
Yes
Tag the Face as Clue Face
1018
No
Check for Inner Loops in All Features so Far Identified
1020
1022
If Inner Loops Exist ?
Yes
A
Generic Pocket and Island Recognition Module
1024
No
D
A'
1026
If Revolved Part ?
Yes
C
No
C'
1028
Feature Chain Recognition Module
1030
C-Axis Feature Recognition Module
D'
Stop
1032

Fig-10A

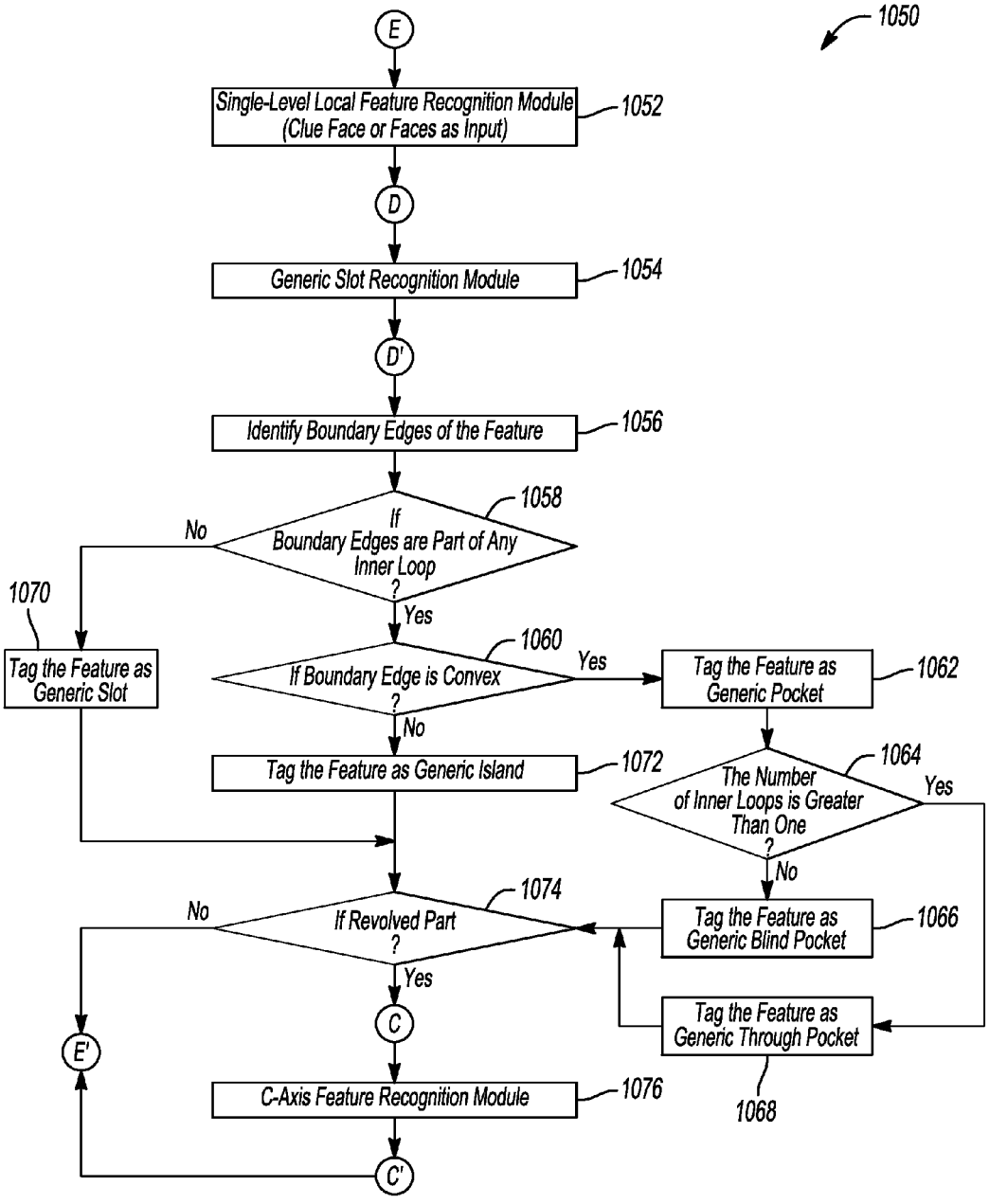
1050
E
Single-Level Local Feature Recognition Module (Clue Face or Faces as Input)
1052
D
Generic Slot Recognition Module
1054
D'
Identify Boundary Edges of the Feature
1056
1058
If Boundary Edges are Part of Any Inner Loop ?
No
Yes
1070
Tag the Feature as Generic Slot
1060
If Boundary Edge is Convex ?
Yes
Tag the Feature as Generic Pocket
1062
No
Tag the Feature as Generic Island
1072
1064
The Number of Inner Loops is Greater Than One ?
Yes
No
1074
If Revolved Part ?
No
Tag the Feature as Generic Blind Pocket
1066
Yes
C
Tag the Feature as Generic Through Pocket
E'
C-Axis Feature Recognition Module
1076
1068
C'

Fig-10B

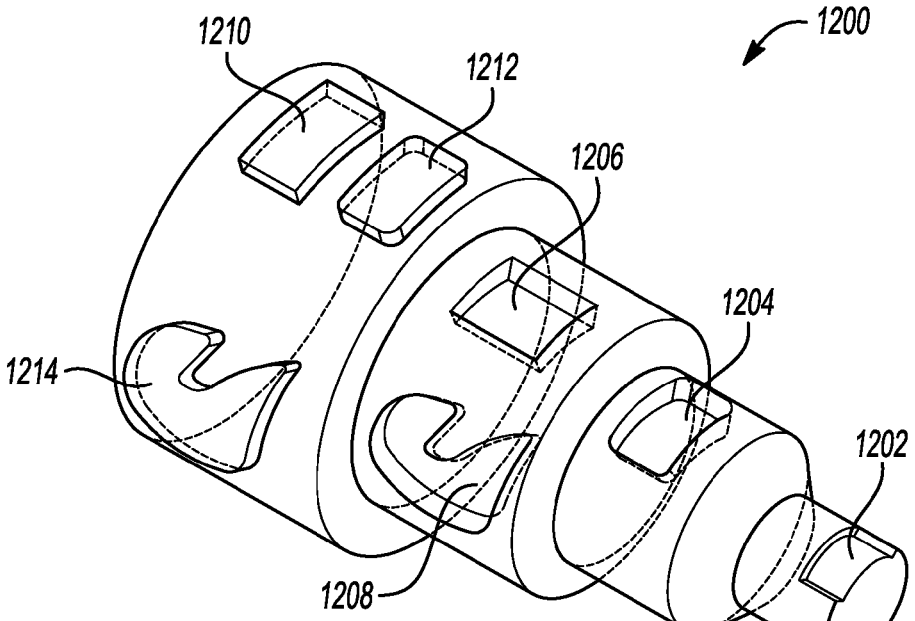
1200
1210
1212
1206
1204
1214
1202
1208

Fig-12

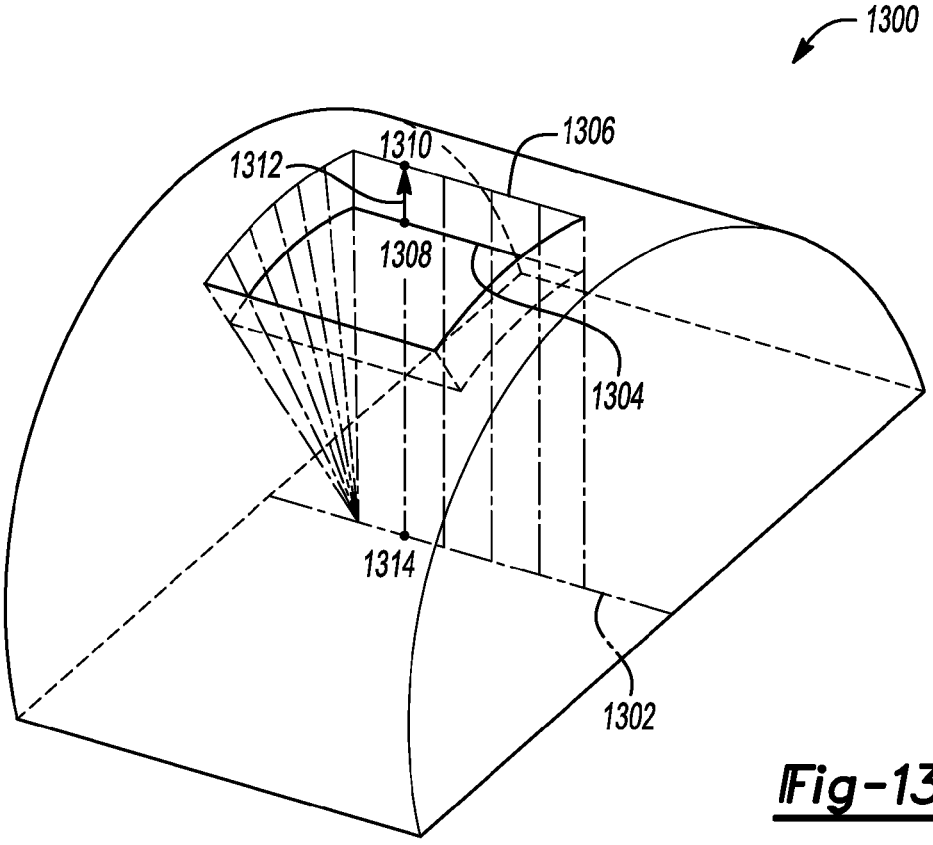
1300
1306
1310
1312
1308
1304
1314
1302

Fig-13

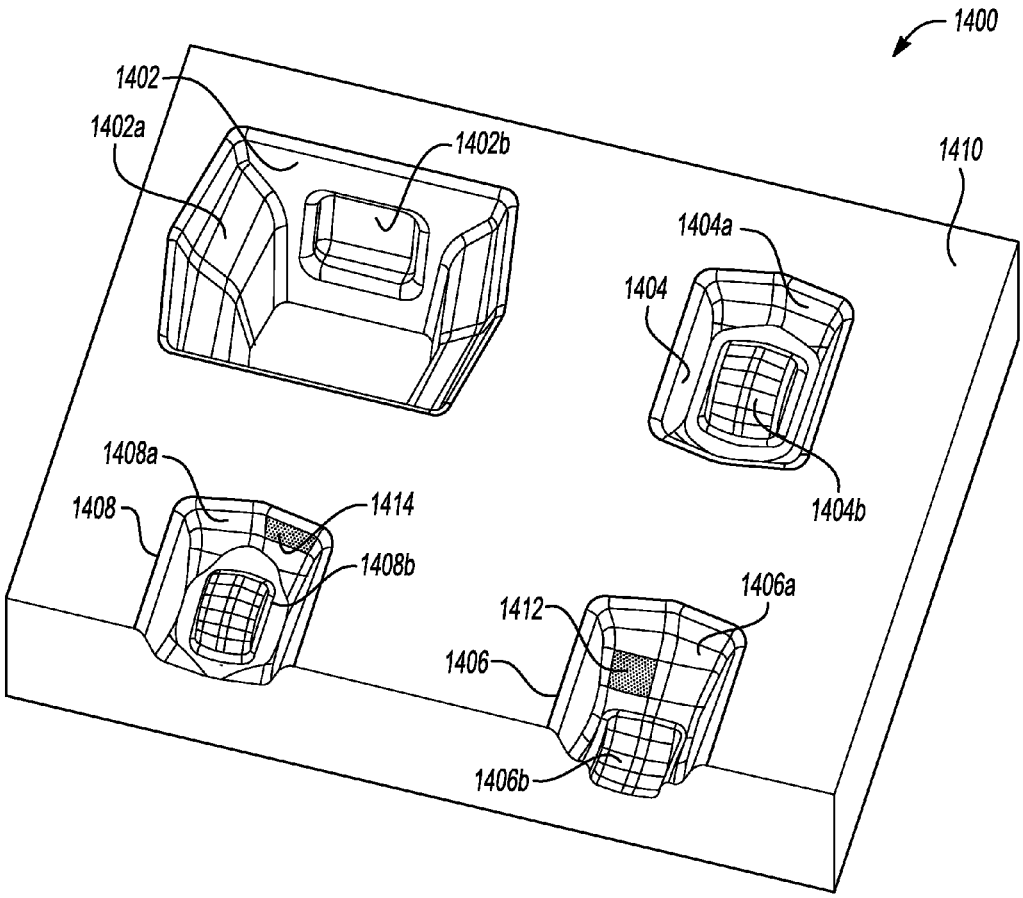
1400
1402
1402a
1402b
1410
1404a
1404
1404b
1408a
1408
1414
1408b
1406a
1412
1406
1406b

Fig-14

METHODS AND SYSTEMS FOR FEATURE RECOGNITION

TECHNICAL FIELD

The present disclosure relates generally to methods for recognizing features from three-dimensional models for application in various domains, such as design, analysis, manufacturing, prototyping, manufacturability analysis, assembly, costing, sustainability, etc., in which such features may be of use.

BACKGROUND

Solid modeling is a term that refers to a set of techniques that may be used to create and store computer based representations of physical objects. A number of techniques have evolved over the years for providing computer-based representations of three-dimensional parts. One of these techniques is Boundary Representation (B-rep).

A B-rep model of a mechanical part consists of a set of "faces," "edges," and "vertices," which are connected together to form a topological structure of the part. By using such a representation, it is possible to evaluate many properties of the part from its computer model. These include the mass, the volume, the moments of inertia and products of inertia and other geometric information like face adjacencies, outer loop and inner loop of faces, face data, edge data, and vertex data. Additionally, such models enable computer-based analysis of stress and strains in the part under different loading conditions, manufacturability analysis, tool path generation, etc. B-rep modeling is a popular method of representing solid models. Other representations of solid models are also known in the art.

Software based on solid modeling is widely used by engineers to create models of parts that may eventually be manufactured. Software such as SolidWorks (Solidworks Corporation), Pro/Engineer (Parametric Technology), CATIA (Dassault systems), NX (Siemens), Inventor (AutoDesk) are examples of solid modeling software.

Traditionally, work in feature technology has mainly focused in two areas: feature based design and feature recognition. In feature-based design, the basic unit is a feature that is defined as a region of design or manufacturing interest in a part. Most CAD systems provide a suite of standard features such as holes, ribs, extruded/revolved depressions, and protrusions for designing parts. The parts are designed as sequences of these features, and are represented as a design tree (or feature tree). However for many applications, the design tree may not provide the required information directly. For example in manufacturing, protrusions in a feature tree need to be mapped as slots with islands while generating the tool path for machining. Further, the actual feature in the part may not correspond exactly to the feature in the design history due to feature interactions. For example, a blind hole could become a through hole due to the imposition of other features. In such situations, the only approach is to use feature recognition from the part model. In a few situations, one encounters models that do not have any feature information. This could result from modeling in non-feature based systems or from translation of data from one CAD system to another. In such cases, feature recognition is essential to extract the necessary information.

In the area of feature recognition, many techniques have been proposed and implemented. For a comprehensive review of feature recognition techniques, reference is made to Qiang Ji and Michael M. Marefat (Ji et al); "Machine

Interpretation of CAD Data for Manufacturing Applications," ACM Computing Surveys, Vol. 24, No. 3, September 1997.

Several of the techniques described in Ji et al reference the use of graph-based approaches for recognizing features. In the graph-based approach, features are represented using an attributed face-adjacency graph. The graph is constructed by using faces as nodes and edges as arcs. In addition, attributes are added to nodes and arcs representing the topological and geometric characteristics of the corresponding faces and edges.

Feature recognition proceeds by matching the feature graph to an appropriate subgraph of the graph representation of the part. However, a graph-based approach tends to be computationally expensive, especially in the presence of feature interactions, since it involves sub-graph matching problems. The efficiency is hence dependent on the attributes used in the graph that aid in pruning down the search during recognition. Further, many of the approaches proposed so far use feature hints that depend on specific feature types that may not be generally applicable.

SUMMARY

A computer-implemented product includes instructions embodied in a non-transitory computer read-able medium that, when executed by a processor, cause the processor to receive input selecting one of a plurality of faces of a boundary representation model of an object. The computer-implemented product further includes instructions that cause the processor to identify boundary edges of the model outside the one of the faces not separated from the one of the faces by an intervening concave or convex edge. The boundary edges may define a perimeter of a topological feature containing the one of the faces. The computer-implemented product further includes instructions that cause the processor to identify a set of the faces including the one of the faces contained by the perimeter, and to generate output highlighting the boundary edges and set of the faces of the topological feature.

A computer-aided design tool comprises at least one processor configured to receive a boundary representation model of an object, to receive input selecting one of a plurality of faces of the boundary representation model of the object, and to identify boundary edges of the model outside the one of the faces not separated from the one of the faces by an intervening concave or convex edge. The boundary edges define a perimeter of a topological feature containing the one of the faces. The at least one processor is further configured to identify a set of the faces, including the one of the faces, contained by the perimeter, and to generate output highlighting the boundary edges and set of the faces of the topological feature.

A computer-implemented product includes instructions embodied in a non-transitory computer read-able medium that, when executed by a processor, cause the processor to generate a list of faces comprising a solid model, to identify boundary edges for a plurality of topological features of the solid model from the list of faces, and to identify at least one of the boundary edges as being shared among the topological features. The computer implemented product further includes instructions that cause the processor to, in response to identifying at least one of the boundary edges as being shared, identify the topological features as being common, and in response to user input selecting one of the topological

features tagged as being common, to generate output highlighting the other of the topological features tagged as being common.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an exemplary block topology of a feature recognition system;

FIG. **2** is an exemplary three-dimensional view of a solid model that contains a feature chain comprising multiple features;

FIG. **3** is a block diagram illustrating a parent child relationship of a feature chain containing multiple features as shown in FIG. **2**;

FIG. **4** is a flow chart of a feature recognition method;

FIG. **5** is a flow chart of a pocket and island recognition method;

FIG. **6** is a flow chart of a slot recognition method according to an embodiment;

FIG. **7** is a flow chart of a c-axis feature recognition method;

FIG. **8** is a flow chart of a feature chain recognition method;

FIG. **9** is a three-dimensional view of a solid model that contains a feature chain;

FIGS. **10**A-**10**B are flow charts illustrating a local feature recognition method;

FIG. **11** is a solid model comprising features sharing a common convex fillet;

FIG. **12** is a three-dimensional view of a solid model that contains a revolved part with a revolved feature with pockets, islands, and a slot;

FIG. **13** is an example of a solid model comprising a c-axis pocket; and

FIG. **14** is a three-dimensional view of a solid model that contains various cases of feature chains.

DETAILED DESCRIPTION

Embodiments of the present disclosure are described herein. It is to be understood, however, that the disclosed embodiments are merely examples and other embodiments can take various and alternative forms. The figures are not necessarily to scale; some features could be exaggerated or minimized to show details of particular components. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a representative basis for teaching one skilled in the art to variously employ the embodiments. As those of ordinary skill in the art will understand, various features illustrated and described with reference to any one of the figures can be combined with features illustrated in one or more other figures to produce embodiments that are not explicitly illustrated or described. The combinations of features illustrated provide representative embodiments for typical applications. Various combinations and modifications of the features consistent with the teachings of this disclosure, however, could be desired for particular applications or implementations.

The embodiments of the present disclosure generally provide for a plurality of circuits or other electrical devices. All references to the circuits and other electrical devices and the functionality provided by each, are not intended to be limited to encompassing only what is illustrated and described herein. While particular labels may be assigned to the various circuits or other electrical devices disclosed, such labels are not intended to limit the scope of operation for the circuits and the other electrical devices. Such circuits and other electrical devices may be combined with each other and/or separated in any manner based on the particular type of electrical implementation that is desired. It is recognized that any circuit or other electrical device disclosed herein may include any number of microprocessors, integrated circuits, memory devices (e.g., FLASH, random access memory (RAM), read only memory (ROM), electrically programmable read only memory (EPROM), electrically erasable programmable read only memory (EEPROM), or other suitable variants thereof) and software which co-act with one another to perform operation(s) disclosed herein. In addition, any one or more of the electric devices may be configured to execute a computer-program that is embodied in a non-transitory computer readable medium that is programmed to perform any number of the functions as disclosed.

This disclosure proposes a system and method to provide a frame work for defining and recognizing features, in particular, generic features, in Boundary Representation (B-rep) models. The B-Rep model represents three-dimensional (3D) model data by bounding surfaces. It contains model information in the form of solids, faces, edges, and vertices. A solid is a bounded volume of multiple faces. The face data may contain surfaces like planar, cylindrical, spherical, toroidal, conical or spline surfaces, etc. The faces may contain bounding loops formed by edges like lines, circles, arcs, splines, etc. The faces may have several bounding loops, an outer loop that represents an outer boundary of a surface and inner loops that represent holes in the face. The inner loop may be a clue used for the feature recognition method explained in this disclosure.

The disclosure may include software modules (i.e., algorithms) which operate on B-rep solid models and which are executed on a local computer, a computer communicating in a network, a computer communicating with a server, and/or a combination thereof. The modules may be implemented in any programming language including, but not limited to, C or C++, and may use local operators from known geometric modeling kernels.

FIG. **1** is an exemplary block topology of a feature recognition system. The feature recognition system **100** may have hardware architecture for executing a feature recognition analysis software used for product development and manufacturing. The software system **100** may be web-based and/or executed on hardware of a local computer. The software system **100** may include product development methods that integrate one or more computer-aided designs (CAD) and/or computer-aided manufacturing (CAM) models. The system may include, but is not limited to, a computer **102**, initial processing algorithms **104**, feature recognition algorithms **106**, and a database **108**. The one or more algorithms may be executed on hardware at the computer **102** and/or at a remote server in communication with the computer **102**. The system **100** may be a tool operated for analysis of one or more models.

For example, the system **100** architecture may be a web-based software working over an internet and/or intranet allowing worldwide access to one or more facilities across the globe. The primary requirement of the computer **102** is that it has access to the feature recognition software (library executable file). The software may reside at a host location which is located on a customer server with access to a server manager and any computer **102** that has a browser with access to the internet and/or intranet. The system **100** architecture may allow a user to create an enterprise specific knowledge database bank **108** allowing for feature recogni-

tion analysis to cross reference a technical specification, a specific customer requirement, and/or other product manufacturing requirements.

The database bank **108** may include several databases to store data input, technical requirements and specifications, and feature recognition algorithms. For example, the database bank **108** may include, but is not limited to, a revolved feature database **108***a*, a pocket and island database **108***b*, a slot database **108***c*, and a feature chain database **108***d*. The database bank **108** may store the feature recognition algorithms so that the system **100** may update the feature recognition software based on software updates, user input, and/or historical data generated during execution of the one or more algorithms.

The system **100** architecture network may include, but is not limited to, a server (not shown), one or more processors (not shown), one or more computer systems (e.g., computer **102**), and software executed on the computer **102** hardware. The system **100** may be designed as a standalone system. The one or more computer systems **102** may be located at an individual user site having a single office, or several offices globally located.

In one embodiment, the system **100** architecture may include, but is not limited to, a webserver (not shown), a database **108**, initial processing algorithms **104**, and one or more computer systems **102**. The webserver may comprise a processor, RAM, a hard disk drive, and the necessary server software. The database **108** may include, but is not limited to, a relational database management system (e.g. Microsoft SQL server) having a processor, RAM, a hard disk, and an operating system software. The one or more computer systems **102** comprise at least one processor, RAM, browser, and internet/intranet software requirements.

The initial processing algorithms may be located at the computer **102** and comprise an input module **110**, a three dimensional geometric kernel module **112**, and/or a knowledge management module (not shown). The input module **110** may receive one or more B-rep models. The three dimensional geometric kernel module **112** may process the input data format and provide application programming interfaces for geometry inquiry at the computer **102**. The knowledge management module may manage the one or more modules and software algorithms in communication with each other to execute the feature recognition system.

The feature recognition software **106** may be a standalone design using only a database system as the backend database manager. The feature recognition algorithms may include, but are not limited to, a revolved feature module **116**, a generic pocket and island module **118**, a generic slot module **120**, a c-axis module **122** and/or a feature chain module **124**. The revolved feature module **116** may identify a revolved feature of the part. The generic pocket and island module may identify a pocket and/or island of the part. The generic slot module may identify a slot on the part. The feature chain module may identify one or more connected features of the part.

The feature recognition software **106** may include application programming interfaces allowing software components to interact with other product development, design, and manufacturing applications. The system **100** executing the feature recognition software **106** may communicate with other software via a set of rules for encoding models in a format that is both human-readable and machine-readable. The software may include, but is not limited to, using and/or creating product and manufacturing models based on product and process requirements, manufacturing requirements, detective controls, control (test and detection activities) implementation design details, product details related to FMEAs, problem details related to global 8D method, and final solution and validation design requirements.

For example, the recognition software-based system **100** and method of this disclosure may have the input module **104** receive the B-rep from, for example, one of a solid modeling program (e.g., SolidWorks) or any other source capable of providing a standardized data structure for describing solids. The system **100** and methods disclosed below may identify feature recognition of interacting features of the part.

Feature interactions may result in a parent child relationship between features. Parent child information may provide information such as the order of features to be machined. The parent child information of features that are connected to each other in such a way may influence a machining strategy of each feature while providing an enhanced manufacturing process of the part.

A product development cycle may depend on computer aided design and manufacturing such that the product data is represented as three-dimensional models and/or in two-dimensional orthographic representations. Automation of downstream activities may require relevant information to be retrieved from the three-dimensional model. Generally, such information is manually retrieved and fed for processing. Manual methods may affect productivity and largely rely on individual's capability and judgment, which may not be consistent. The system **100** may provide an automated way of extracting such information and assist in automation and improve productivity. Hence, an automatic method for extraction of such information from a three-dimensional model through features is disclosed and discussed in more detail below.

For example, the three-dimensional model may be generally stored as the B-rep model that serves as a data model. The data model may provide the three-dimensional model data as a whole. The shapes of local regions within the three-dimensional model may contain information relevant to design, manufacturing, costing, etc. The system **100** may identify these local regions using the feature recognition algorithms **106**. Depending on the type of information content in the one or more features, they may be classified into various feature types like functional features, form features, design features, manufacturing features, assembly features, tolerance features, inspection features, etc. Many definitions for the term "feature" have been proposed in the literature. A feature represents the engineering meaning or significance of the geometry of a part or assembly as disclosed in Shah, J. J., *Features in Design and Manufacturing, in: Intelligent Design and Manufacturing*, A. Kusiak (ed.), John Wiley & Sons, 1992, and in Shah, J. J. and M. Mantyla, *Parametric and Feature-based CAD/CAM*, John Wiley & Sons: New York, N.Y. 1995. It is generally agreed that features may have attributes that have to do with geometry of the part and attributes that deal with the function they serve in the part as disclosed in Kannan, T. R., *An Integrated Planner For Manufacture of Sheet Metal Components Using STEP AP*-203, Ph.D. Thesis, India Institute of Technology Madras, Chennai, 2007.

The three-dimensional modelers like SolidWorks, Inventor, Pro/E, CATIA, NX, etc. may use some sort of feature based modeling techniques, in which the three-dimensional model may be created by means of features, which adds or subtracts volumes. A feature tree may be listed for a three-dimensional model which stores the historical feature data of a model and is generally accessible through suitable application programming interfaces. Though these models may

be feature based, the feature information in these models may not be useful for downstream automation as the features are more of design features and may not provide sufficient information for manufacturing, processing, or costing, etc.

For example, a hole in a part may be manufactured only when the feature information is listed as a hole and includes hole parameters like a hole axis, diameter, height, through or blind hole, bottom angle, etc. The hole may be created in these three-dimensional modelers using multiple methods like hole wizard or extruded cut of a circular sketch or revolved cut of a rectangular sketch, in which the respective features in the feature tree may be listed as a hole or extruded-cut or revolved-cut. For manufacturing, the feature should be identified as a hole irrespective of the design method used. With design feature tree information, it may not be possible to identify extruded-cut or revolved-cut as a hole. Similarly for any model, irrespective of design features used to create the three-dimensional model, features have to be reinterpreted in the form of manufacturing features to facilitate various downstream automation processes. The systems and methods of feature recognition herein may identify feature chains comprising features such as pockets, slots and islands disclosed and discussed in further detail below.

It may also be possible that a three-dimensional model created in any CAD modeler may need to be processed in another CAM system where the CAD and CAM systems are not from the same vendor. To address such cases, most of the CAD/CAM systems may provide options for importing three-dimensional model(s) made from third party software. After importing, however, the three-dimensional model may list only as an imported solid in the feature tree without any feature information. The systems and methods for feature recognition may provide feature information as disclosed and discussed in further detail below.

FIG. **2** is an exemplary three-dimensional view of a solid model that contains a feature chain comprising multiple features. The solid model may have one or more features for a specifically designed part and/or component. The one or more features may include, but are not limited to, slots, pockets, islands, other relevant features (e.g., fillets and chamfers that are part of the slots, pockets, and islands), and/or a combination thereof.

A design and manufacturing process may be driven by the solid model. The solid model may be received by the feature recognition software. The feature recognition software may process the solid model to generate a list of recognized features. The list may be provided to one or more application programs for interpretation of these features. The list may be communicated to other application programs with the use of application program interface functions and class-based interfaces.

For example, one or more solid models may be developed to include feature information. If the solid models are converted across CAD systems and/or if the models were created using older generation CAD systems, the feature information may be lost during conversion and/or not available based on the older generation tools. The feature recognition software may receive the one or more solid models and generate feature information. The feature information may include the list of recognized features, information about machinable features, and/or a combination thereof.

The solid model **200** may comprise various types of features including, but not limited to, pockets, slots (steps), and islands. The feature recognition software may generate feature information that includes designs in which more than one pocket is lying inside another pocket as shown in FIG. **2**. A pocket may have child pockets in more than one feature faces, two or more pockets in a single feature face, and pockets inside child pockets.

For example, the solid model **200** includes a pocket **202** which contains pockets in three feature faces. One of the feature faces has an obround shaped pocket **206**. Another feature face contains two pockets **208** and **210**. The third feature face contains a pocket **204** in which one of the feature faces has another rectangular child pocket **212**, which further contains a circular child pocket **214**. All of these features **202**, **204**, **206**, **208**, **210**, **212**, **214** form a feature chain and the parent child relationship is shown in the form of a graph in FIG. **3** below.

Based on the feature information, the application software using feature recognition software may automatically generate computer numerical control (CNC) instructions for manufacturing of the part or component. The application software using feature recognition software may also generate information to be used by coordinate measuring machines for automated inspection based on the feature information. The application software using feature recognition software may map the feature information onto the CAD system and/or other manufacturing/processing application's feature tree illustrating feature interaction.

FIG. **3** is a flow chart illustrating a parent child relationship of the feature chain **300** containing multiple features as shown in FIG. **2**. Based on the solid model **200**, the feature recognition software may determine the parent child relationship of features and output the feature chain **300**.

For example, the feature chain **300** for the solid model **200** may be illustrated as a single feature chain having multiple levels. The recognition software may output a first level **302** illustrating the solid model **200** selected for generating the feature chain **300**. The single feature chain **300** illustrates a pocket **202** as a parent feature at a second level **304**. The pocket **202** comprises child features in three feature faces. The child features of the parent pocket **202** are illustrated at a third level **306**. The child features in the third level **306** includes a pocket **204** at one face, an obround shaped pocket **206** at a second face, and two pockets **208** and **210** at a third face.

The pocket **204** at the second face may comprise another rectangular child pocket **212** as illustrated in a fourth level **308** of the single feature chain **300**. The rectangular child pocket **212** may comprise a circular child pocket **214** as illustrated in a fifth level **310** of the single feature chain **300**.

The feature chain **300** may provide information for generating a processing strategy comprising a particular sequence for machining the features based on the parent child relationship. The feature chain **300** may provide the feature information of individual features such as the set of faces that form a feature. The feature chain **300** comprising the parent child information may provide the order of features to be machined and information of features that are connected to each other in such a way that they influence machining strategy of each other. For example, the machining strategy for the pocket **204** may now be influenced in response to the rectangular pocket **212** and the circular child pocket **214** in the solid model **200** based on the feature information of the feature chain **300**.

FIG. **4** is a flow chart of a feature recognition method **400** according to an embodiment. The method **400** may be implemented using software code contained within the feature recognition executable. In other embodiments, the method **400** may be implemented on a controller (processor), implemented at a server in communication with the controller, and/or a combination thereof.

Referring again to FIG. **4**, the feature recognition method and its components illustrated in FIG. **1** are referenced throughout the discussion of the methods to facilitate an understanding of various aspects of the present disclosure. The method **400** of recognizing features of a solid model while communicating with one or more development and manufacturing computer-aided tools may be implemented through a computer algorithm, machine executable code, or software instructions programmed into a suitable programmable logic device(s) of the controller, such as the controller of a computer, the one or more controllers at a server, or a combination thereof. Although the various operations shown in the flowchart diagram **400** appear to occur in a chronological sequence, at least some of the operations may occur in a different order, and some operations may be performed concurrently or not at all.

In operation **402**, the one or more processors may be initialized to begin execution of the recognition method. For example, a CAD and/or CAM application may initialize the feature recognition method by calling a library containing the feature recognition tool. In other embodiments the feature recognition method may be embedded in several formats including, but not limited to, software executable, a library, a dynamic link library, and/or may be a part of an application as direct source code.

In operation **404**, the feature recognition software may receive three-dimensional model data in a B-rep format as input. The feature recognition software may receive and process the geometry and topology data generated by any three-dimensional geometry kernel based on the three-dimensional model.

In operation **406**, the feature recognition software may determine if the model is a revolved part based on a cylindrical surface. For example, the software may recognize the revolved feature based on several features including, but not limited to, a reference cylindrical surface and a turn axis. If the model is a revolved part, then it is processed by a revolved feature recognition algorithm in operation **408**.

The revolved feature recognition module may identify the axis of the cylindrical surface and tag the axis as a part axis. The revolved feature recognition model may segregate and tag faces belonging to the revolved feature based on cylindrical faces in the model comprising the same axis as the part axis. These faces are cylindrical feature faces. The adjacent faces on both sides of these cylindrical surfaces may be identified. The adjacent face may be a conical face (frustum) or planar face, which may be connected to another cylindrical feature face with either smaller or larger diameter. This cylindrical feature face may further be connected to a conical face or planar face, which may be connected to another cylindrical feature face. There may be a chance that such an adjacent face may be a full cone or a planar face without an inner loop, or that the adjacent face specifies the end face on one side. All of these faces may also be tagged as revolved feature faces by the revolved feature recognition module.

In operation **410**, the feature recognition software may determine if the model has additional faces. If the software does not recognize additional faces, the software may stop processing the model in operation **412**. The remaining faces are further processed by consecutive algorithms for recognition of other features.

In operation **414**, if the three-dimensional model is not a revolved feature, then the model data is directly sent to a generic pocket and island recognition algorithm. The software may determine generic pocket and island based on inner loops, and concavity and convexity of inner loop co-edges. The software may tag the feature faces of the generic pocket and island inner loops. The generic pocket and island recognition module may generate an output. The generic pocket and island recognition module is discussed in further detail in FIG. **5**.

In operation **416**, the feature recognition software may determine if the pocket(s) and/or island(s) are in a revolved part. If the pocket(s) and/or island(s) are in a revolved part, the software may further process the recognized features using a C-axis feature recognition algorithm in operation **418**.

For example, the C-axis feature recognition module may classify the recognized features into C-axis pockets and C-axis islands based on a cylindrical bottom face or a cylindrical top face comprising the same axis as the part axis for the pockets and islands respectively. The lateral feature faces are further checked whether they converge to meet the part axis, which may be verified by co-planarity of the part axis, projected vertex of multiple sample points of a bottom co-edge on the part axis, and a direction vector of sample points of the bottom co-edge with respect to nearest points in a top edge of the lateral feature faces. The C-axis feature recognition module may generate an output. The C-axis recognition module is discussed in further detail in FIG. **7**.

In operation **420**, the remaining faces, if any, are further processed by a generic slot recognition algorithm. The generic slot recognition module determines where a slot is recognized based on concavity and convexity of edges, adjacency of faces and convex fillets. The module implements the fillet recognition method to recognize fillets as disclosed in U.S. Pat. No. 6,597,355, the contents of which are hereby incorporated by reference. The generic slot recognition module may generate an output. The generic slot recognition module is discussed in further detail in FIG. **6**.

In operation **422**, the feature recognition software may determine if the slot is in a revolved part. If the slot(s) are in a revolved part, the software may further process the recognized parts using a C-axis feature recognition module in operation **424**.

For example, the C-axis feature recognition module may classify the slots in the revolved part as a C-axis slot based on a cylindrical bottom face or a cylindrical top face having a same axis as the part axis for the slot. The lateral feature faces are further checked whether they converge to meet the part axis, which is verified by co-planarity of part axis, projected vertex of multiple sample points of a bottom co-edge on the part axis and a direction vector of sample points of the bottom co-edge with respect to nearest points in a top edge of the lateral feature faces. The C-axis feature recognition module may generate an output. The C-axis recognition module is discussed in further detail in FIG. **7**.

In operation **426**, the recognized features such as pockets, islands, slots and C-axis features are further processed by a feature chain recognition algorithm. The feature chain recognition module determines where features are integrated as feature chains based on feature adjacency, inner loops in feature faces, shared fillets, and/or a combination thereof. The feature chain recognition module may generate a parent child relationship based on the integrated features. The feature chain recognition algorithm may generate an output to one or more computer-aided design and manufacturing applications. The feature chain recognition algorithm is discussed in further detail in FIG. **8**.

The feature recognition software may transmit the output results from the one or more module to a product and/or manufacturing analysis tool (e.g., CAD, CAM, etc.). The

feature recognition software may be disabled based on a completed analysis, a request received by an analysis tool, and/or a request received by user input in operation **428**.

FIG. **5** is a flow chart of a pocket and island recognition method **500**. The pocket and island recognition method may receive a request from the feature recognition software to perform analysis on the solid model. The pocket and island recognition method comprises a process that receives the three-dimensional model data to check whether one or more faces have any inner loops in operation **502**.

In operation **504**, the method checks for inner loops in the one or more faces of the solid model. The method may check to see if an inner loop exists in the three-dimensional model in operation **506**.

In operation **508**, if an inner loop does not exist, the method may determine whether the one or more faces exists and are unprocessed. If there are other faces that exist and are waiting for processing, the method may continue to check for inner loops in the next face in operation **510**. If no faces are unprocessed, and no inner loops exist, the method may determine that no pocket or island is present on the solid model in operation **512**.

In operation **514**, the method may encounter an inner loop and collect all the faces (first level faces) connected to the inner loop recursively. The method may tag all the faces connected to the inner loop as feature faces belonging to a feature. Then the faces that are attached to the first level faces are also collected and added to the feature faces. This process is continued recursively until no more adjacent faces are left to collect and this cluster of faces forms a feature. Once a face is collected, it is tagged as belonging to a feature. While checking adjacency, only faces that do not belong to any feature is collected further to avoid indefinite looping due to cyclic adjacency of faces.

In operation **516**, the method may collect all co-edges of the feature connected to the inner loop. The method may determine if the co-edges attached to the inner loop are concave in operation **518**. If the inner loop is concave then the feature is classified as a generic island feature in operation **520**.

The method may determine if the co-edges attached to the inner loop are convex, then the feature is classified as a generic pocket feature. The methods may recognize various types of 2.5D pockets effectively including various hole types, as well as three-dimensional pockets. All these features are identified as generic pockets. The methods may determine 2.5D islands and 3D islands as generic islands. Generic pockets may be blind pockets or through pockets.

In operation **522**, the method may determine a blind and through pocket classification with the fact that blind pockets have one inner loop and through pockets have two or more inner loops. While collecting the connected faces recursively by starting from an inner loop, if the feature faces are connected to another inner loop, then the face containing the inner loop is not collected as a feature face. Only faces connected to outer loops of other faces are collected recursively. This check is mainly to avoid a whole model getting recognized as a through pocket as all the faces are connected through these two inner loops and may get collected as a single feature, which is not desired. Limiting the recursive collection to only outer loop connectivity effectively avoids this issue.

In operation **526**, when the cluster of feature faces are connected to two or more inner loops, then the feature is classified as a generic through pocket. If the feature has only one inner loop, then it is classified as a generic blind pocket in operation **524**. Though this method covers a large number of through pockets, there are cases where a through pocket has only one inner loop due to feature interactions. Such features are recognized as a feature chain. The output of the pocket and island recognition method may be transmitted to the feature recognition method **400**.

FIG. **6** is a flow chart of a slot recognition method **600** according to an embodiment. The slot recognition method may receive a request from the feature recognition software to perform analysis on the solid model. The slot recognition method comprises a process that receives the three-dimensional model data and/or the set of faces as input in operation **602**.

In operation **604**, after identifying all the pockets and islands, the remaining faces in the three-dimensional model are processed to check whether there are any concave edges. The method may check each face one by one to determine if a concave edge exists in operation **606**.

In operation **608**, upon encountering a concave edge, the faces that are directly attached to the concave edge are collected and tagged as faces that belong to a feature. The method verifies whether any of the collected feature faces comprise any other concave edges in operation **610**. If the method detects that concave edges exist in the collected feature faces, it may request that the concave edges be added to the feature faces in operation **612**. This process is continued recursively until no more adjacent concave edges are left to collect.

For example while checking adjacency, only faces that do not belong to a feature are collected further to avoid indefinite looping due to cyclic adjacency of faces. For a slot feature, the above method would collect the faces without convex fillets around the feature boundary that are expected to be a part of the slot. So, an additional operation may be added to the method to collect these fillets.

In operation **614**, the method may identify the boundary edges of the collected feature faces and check for convex fillets connected to these boundary edges and tag them as boundary feature faces. While the method **600** is checking for convex fillets connected to bounding edges of feature faces, all convex fillets are checked even if they are already tagged as boundary feature faces of other features.

In operation **616**, the method **600** checks whether the boundary feature faces belong to more than one feature. If the boundary faces belong to more than one feature, the boundary feature faces are tagged as common feature faces in operation **618**.

In operation **620**, if the boundary faces belong to only one feature, the boundary feature faces are tagged as feature faces of corresponding features. Common feature faces are tagged as feature faces of all the features sharing these fillets. All the feature faces and common feature faces are tagged as belonging to the slot feature in operation **622**. The output of the slot recognition method may be transmitted to the feature recognition method.

This method effectively collects all the feature faces as a slot feature as shown in FIG. **11** below. There may be more than one slot feature in the three-dimensional model and hence the remaining faces are checked further for any concave edge or concave fillet and the same process may be repeated.

FIG. **11** is a solid model **1100** having features sharing a common convex fillet. The solid model has a first slot **1102** and a second slot **1104** sharing few convex fillets **1106**. The convex fillets **1106** are common to both slot features **1102**, **1104** and appear as feature faces for both features. This information is given so that during downstream operations a user may handle these faces accordingly, for example, to

machine common fillets either with the first slot feature **1102** or with the second slot feature **1104** depending on the machining strategy adopted. This may avoid common fillets getting machined two times, which is redundant.

FIG. **7** is a flow chart of a C-axis feature recognition method **700** according to an embodiment. A revolved part is another group of parts that requires a different type of design, manufacturing, and other downstream applications. Such parts mostly consist of at least one of a revolved feature and a revolved feature with pockets, islands and slots as shown in FIG. **12**. The pockets, islands, and a slot in a revolved feature may be slightly different in the sense that bottom faces of pockets and slots and a top face of islands are cylindrical and have the same axis as a part axis, and lateral feature faces converge to the part axis. Such features may be referred to as wrap features or C-axis features. The term C-axis feature comes from the fact that such features may be machined in a mill-turn machine with a Z-axis, X-axis, and C-axis control.

For revolved parts or mill-turn parts, the revolved feature and the part axis is initially identified. The revolved feature is identified by taking a cylindrical surface as an input, which is manually selected by the user. The axis of this cylindrical surface is identified as a part axis. All the faces that are recognized as part of revolved feature are tagged as revolved feature faces.

The feature recognition method discloses the process for recognition of generic C-axis features. After recognition of a revolved feature, the remaining faces are processed by generic pocket, generic island, and generic slot methods disclosed above and respective features are identified.

In operation **702**, the C-axis feature recognition method comprises a process that receives the generic pocket, island, and/or slot features as input to check whether the one or more features are C-axis features. The method may segregate cylindrical faces of a feature face one by one to check whether the cylindrical axis is collinear with the part axis in operation **704**.

In operation **706**, the method may check each cylindrical face one by one to determine whether the cylindrical axis is collinear with the part axis. If the axis is not collinear with the part axis, the method may proceed to the next unprocessed cylindrical feature face in operation **708**.

In operation **710**, if the cylindrical face has an axis that is collinear with the part axis, the method may tag the cylindrical face as a bottom face for pockets and slots or a top face for islands. The method may mark the remaining feature faces as lateral faces. The method may check for co-edges between the bottom/top face and lateral faces, and make one or more sample points in this co-edge in operation **712**.

For example, FIG. **13** depicts a solid model comprising a c-axis pocket. In FIG. **13**, the generic pockets are further processed to identify the bottom face and the lateral faces. The bottom face is identified from the feature faces, and only cylindrical faces are segregated first. Among the cylindrical faces are the faces that comprise the same axis as the part axis **1302** and are considered as bottom faces. All the remaining faces are marked as lateral faces. The lateral faces are checked by the method of identifying the co-edge **1304** that is shared between the bottom face and the lateral face.

In operation **714**, the method may form a direction vector from all sample points to a nearest point on the nearest edge that is not directly connected to the co-edge. The methods may make a perpendicular projection of the sample points on the part axis and determine the projected point in operation **716**.

Continuing from the generic pocket example in FIG. **13**, the nearest edges that are not directly connected to co-edge **1304** are determined and tagged as reference edge **1306**. The co-edge **1304** may be divided into a number of segments depending on the edge length such that each segment is an identified length. Vertices of these segments are taken as sample points and from each sample point the closest point on the reference edge **1306** may be determined. The closest point may be directly obtained by a geometric kernel application programming interface. A direction vector **1312** may be formed between sample point **1308** and closest point **1310**. A perpendicular projection of a sample point **1308** on the part axis may be made and the projected vertex **1314** may be determined.

In operation **718**, the methods may check whether the direction vector **1312**, the projected vertex **1314** and the part axis **1302** are coplanar. Operations **714**, **716** and **718** are performed for all sample points. If all sample points in the lateral faces pass the co-planarity check, then it passes C-axis check, otherwise it fails C-axis check in operation **720**. For example, for a pocket to qualify as a C-axis pocket, all the sample points in all the lateral faces should pass the C-axis check. For C-axis islands and slots also, the same procedure as explained above is adopted for determining top face in case of islands and bottom face in case of slots. The C-axis check for lateral faces is the same method **700** for pockets, islands and slots.

In operation **722**, the method may tag the feature as a generic C-axis feature if it passes the C-axis check. The method may tag the feature as a non-c-axis feature if it fails the C-axis check in operation **724**. The output of the C-axis feature recognition module may be transmitted to the feature recognition method.

For example, FIG. **12** depicts a three-dimensional view of a solid model **1200** that contains a revolved part with a revolved feature comprising pockets, islands, and a slot. The feature recognition method identifies the revolved part comprising generic C-axis pockets **1204**, **1206**, **1208**, a generic C-axis slot **1202**, and generic C-axis islands **1210**, **1212**, **1214**.

FIG. **8** is a flow chart of a feature chain recognition method **800**. The features may be adjacent to and/or implanted in one or more features as shown in FIG. **2**. Such features are recognized as feature chains. The features such as generic pockets, generic islands, generic slots, and C-axis features are given as input to this method in operation **802**.

In operation **804**, the method may check the features one by one, determine outer bounding edges, and identify feature adjacency. The method to identify feature adjacency between features is determined by checking whether there is any common edge (e.g., fillet) shared by two or more features. In prior systems, a common edge between two or more features may not be identified because once an edge is identified as belonging to a particular feature, that edge or fillet can not be found to be associated with other features. It, for example, may be removed from a list of available edges free to identify as belonging to subsequently identified features, which may cause incomplete data being transmitted to other product development tools and/or additional machining steps to be taken for manufacturing the features.

The method may identify if common edges or fillets exist between outer bounding edges of features in operation **806**. The method may check each feature one by one to determine outer bounding edges. If none of the outer bounding edges of a feature in a model have common edges or fillets with other features, or none of the feature faces have inner loops

shared with other features, the method may tag the feature as a single feature in operation **805**.

In operation **808**, if the common edges or fillets exist in the outer bounding edges, the method may collect features connected to the common edge or fillet and tag them as features belonging to a feature chain.

In operation **810**, the features that share inner loops with other features are also checked and considered as adjacent features. In all such cases, the features are collected as a single feature chain and the individual features are listed as child features. The method may check each feature one by one to determine if an inner loop exists in operation **812**.

In operation **814**, the method may collect features connected to the inner loop and identify them as features belonging to a feature chain. The method may generate a tag for the identified features as the feature chain in operation **816**.

For example, the features that lie inside other features can be of different types such as pockets inside a pocket, islands inside a pocket, islands inside an island, pockets inside an island, pockets inside a slot and islands inside a slot. These pockets and islands are initially identified separately by the inner loop method and slots are identified by an edge-concavity method and listed as feature chains as these features contain an inner loop connected to another pocket or island feature. There are cases in which a slot is adjacent to another slot and listed as feature chains as these features share common edges or fillets in the feature boundary.

FIG. **9** is a three-dimensional view of a solid model **900** that contains a three-dimensional feature chain. The feature recognition method may receive the solid model **900** and determine that the solid model **900** comprises a feature chain consisting of four features including a first slot **902**, a second slot **904**, a third slot **906**, and a first blind pocket **908** inside the third slot **906**. The feature recognition method may identify that the model comprises three features **902**, **904**, **906** that are adjacent to each other. The feature recognition method may recognize that another feature, the first bind pocket **908**, is connected to an inner loop of one of the feature faces of the third slot **906**. The feature recognition model may output a parent child relationship that includes a label for the first blind pocket **908** as a child designation of the third slot **906** in the feature chain. The feature recognition method identifies few convex fillets as a part of the first slot **902** and the third slot **906**. The method may recognize convex fillets as part of one more features.

FIG. **14** is a three-dimensional view of a solid model **1400** that comprises common fillet feature chains. The solid model **1400** includes feature chains **1402**, **1404**, **1406** and **1408** comprising two or more features.

The feature recognition method may identify a first feature chain **1402** including a generic through pocket **1402***a* and a generic blind pocket **1402***b*. The two generic pockets **1402***a*, **1402***b* are adjacent to each other through an inner loop, and both are clubbed as a single feature chain.

The feature recognition method may identify a second feature chain **1404** including a generic blind pocket **1404***a* and a generic island **1404***b*. The feature recognition method may identify a third feature chain **1406** consisting of two generic slots **1406***a* and **1406***b*. The feature recognition method may identify a fourth feature chain **1408** consisting of a generic slot **1408***a* and a generic island **1408***b*.

FIGS. **10**A-**10**B are flow charts illustrating a local feature recognition method. The feature recognition method may include a local feature recognition method that may take a set of faces or a single face from three-dimensional model data in a B-rep format to recognize features. Automatic feature recognition works by taking the whole model as input and recognizes all the features.

Automatic feature recognition requires models to be accurate as recognition of most of the features depends on face adjacency information. Though face adjacency is disrupted in few regions of the part (e.g., model), there could be features in other areas which could be recognized. This would require a semi-interactive way to recognize features in unaffected regions of the three-dimensional model. Also, there is a need from industry to recognize certain features in a semi-interactive way. This kind of approach is helpful for parts that require multiple machining strategies involving different machines and processes, such as a part that requires a few features to be machined via milling and a few other features to be machined via electro discharge machining (EDM). To cater to these requirements, a local feature recognition approach has been described in this disclosure.

Local feature recognition works by taking a set of faces or a single face as input. These input faces are clue faces for local feature recognition and are used for recognizing features that contain clue faces as feature faces. In local feature recognition, there are two options: single-level recognition and multi-level recognition. In single-level local feature recognition, features containing only the clue faces are recognized, whereas in multi-level local feature recognition, a feature chain containing the clue faces is recognized. It may be a requirement for local feature recognition, in certain circumstances, that the clue face or clue faces contain at least one concave edge for effective local feature recognition.

In operation **1002**, the local feature recognition method **1000** may determine if the multi-level tag or single level tag is being requested. In single-level local feature recognition, the clue faces are initially sent to the generic slot recognition module in operation **1004**.

As illustrated in FIG. **10**B, the single-level feature recognition method **1050** may receive a clue face(s) as input in operation **1052**. The generic slot is recognized by checking whether any concave edges are attached to the clue face and collecting feature faces as explained in the generic slot recognition module method in operation **1054**. Irrespective of whether a feature is a slot or pocket or island, this method initially recognizes all types of features as generic slots. Then these generic slots are further analyzed to recognize generic pockets and islands as follows. The single-level feature recognition method may identify boundary edges of the feature in operation **1056**. If the bounding edges are part of any inner loop in the model, then the feature could be either a pocket or an island in operation **1058**. If the boundary edges are not part of any inner loop, the method may tag the feature as a generic slot in operation **1070**.

In operation **1060**, the method may determine if the boundary edge is convex or concave. The feature is classified as a generic pocket if bounding edges are convex in operation **1062**. The method may classify the feature as a generic island if the bounding edges are concave in operation **1072**.

In operation **1064**, the method may determine whether the number of inner loops is greater than one. For generic pockets if the feature faces are connected to one inner loop, the feature is classified as a blind pocket in operation **1066**. If the feature faces are connected to one or more inner loops, the feature is classified as a through pocket in operation **1068**.

In operation **1074**, if the revolved part tag is on before recognizing a local feature, then slots, pockets and island features are further processed in the generic C-axis feature

recognition module. The C-axis feature recognition module may further classify these features into C-axis features as explained in the C-axis feature recognition module in operation **1076**.

In operation **1008**, as illustrated in FIG. **10**A, if the multi-level tag is selected the method may enable the multi-level local feature recognition; a feature chain connected to clue faces is recognized as follows. Initially the feature containing the clue faces is identified using single-level local feature recognition in operation **1010**.

In operation **1012**, the bounding edges of the feature are identified by the local feature recognition method **1000**. The identified boundary edges are checked to determine whether any of the faces attached to these bounding edges have any concave edges in operation **1014**.

In operation **1016**, if a concave edge is found, then the method **1000** may tag the face. The tagged face having the concave edge may be assigned by the method **1000** as a clue face in operation **1018**. The method may continue to execute the single-level local feature recognition until all concave edges have been identified. This process may be performed recursively until there are no other adjacent faces having any concave edges in operation **1016**.

In operation **1020**, the method checks for inner loops in the feature faces. The method may determine if inner loops exist in the feature in operation **1022**. If an inner loop exists, the method may **1000** recognize the features connected to these inner loops using the generic pocket and island recognition module in operation **1024**.

In operation **1026**, the method **1000** may determine if the feature is a revolved part. If a revolved part, the pocket and island features are further processed in the generic C-axis feature recognition module in operation **1028**. The C-axis feature recognition module may further classify these features into C-axis features as explained in the C-axis feature recognition module.

In operation **1030**, the method may process all the recognized features in the feature chain recognition module to recognize feature chain and parent child information. The local feature recognition method may output one or more items including feature information and a parent child relationship of the feature chain in operation **1032**.

For the solid model **900** shown in FIG. **9**, the local feature recognition method may receive face **910** as a clue face and upon executing single-level local feature recognition, recognize only a blind pocket feature **908**. Upon executing multi-level local feature recognition with the clue face **910**, the method may recognize a feature chain consisting of four features including a first blind pocket **908**, a first slot **906**, a second slot **904**, and a third slot **902**.

For the solid model **1400** as shown in FIG. **14**, the local feature recognition method may receive face **1410** as a clue face and upon executing single-level local feature recognition, the method may recognize none of the features as the face **1410** does not have any concave edges attached to it.

Upon executing the multi-level local feature recognition with the clue face **1410**, the method may recognize two feature chains **1402** and **1404** based on inner loops in the clue face. The multi-level local feature recognition method with clue face **1410** may identify a first feature chain **1402** consisting of a generic through pocket **1402***a* and a generic blind pocket **1402***b*. The multi-level local feature recognition method may further identify a second feature chain **1404** consisting of a blind pocket **1404***a* and a generic island **1404***b*.

For the same solid model **1400** as illustrated in FIG. **14**, the local feature recognition method may receive face **1412** as a clue face. Upon executing the single-level local feature recognition for face **1412** as the clue face, the method may recognize only a generic slot feature **1406***a*. Whereas upon multi-level local feature recognition with clue face **1412**, it may recognize a feature chain **1406** containing two generic slot features **1406***a* and **1406***b*. The model **1400**, however, actually contains four feature chains **1402**, **1404**, **1406** and **1408**. If the user intends to recognize all the feature chains **1402**, **1404**, **1406** and **1408**, then the user may recognize these features in two methods. One method is to execute multi-level local feature recognition once with three clue faces **1410**, **1412** and **1414** selected. Another method is to execute multi-level local feature recognition three times, each time with a single clue face **1410**, **1412** and **1414** respectively.

While exemplary embodiments are described above, it is not intended that these embodiments describe all possible forms encompassed by the claims. The words used in the specification are words of description rather than limitation, and it is understood that various changes can be made without departing from the spirit and scope of the disclosure. As previously described, the features of various embodiments can be combined to form further embodiments of the invention that may not be explicitly described or illustrated. While various embodiments could have been described as providing advantages or being preferred over other embodiments or prior art implementations with respect to one or more desired characteristics, those of ordinary skill in the art recognize that one or more features or characteristics can be compromised to achieve desired overall system attributes, which depend on the specific application and implementation. These attributes can include, but are not limited to cost, strength, durability, life cycle cost, marketability, appearance, packaging, size, serviceability, weight, manufacturability, ease of assembly, etc. As such, embodiments described as less desirable than other embodiments or prior art implementations with respect to one or more characteristics are not outside the scope of the disclosure and can be desirable for particular applications.

What is claimed is:

1. A computer-implemented product including instructions embodied in a non-transitory computer read-able medium that, when executed by a processor, cause the processor to:

in response to input defining a boundary representation model of an object,

identify boundary edges of the model outside one of the faces not separated from the one of the faces by an intervening concave or convex edge, the boundary edges defining a perimeter of a topological feature containing the one of the faces,

identify a set of the faces, including the one of the faces, contained by the perimeter, and

generate output highlighting the boundary edges and set of the faces of the topological feature.

2. The computer-implemented product of claim **1** further including instructions embodied in the non-transitory computer read-able medium that, when executed by the processor, cause the processor to, in response to any of the boundary edges being convex and forming an inner loop, tag the boundary edges and set of the faces as belonging to a pocket.

3. The computer-implemented product of claim **1** further including instructions embodied in the non-transitory computer read-able medium that, when executed by the processor, cause the processor to, in response to any of the

boundary edges being concave and forming and inner loop, tag the boundary edges and set of the faces as belonging to an island.

4. The computer-implemented product of claim **1** further including instructions embodied in the non-transitory computer read-able medium that, when executed by the processor, cause the processor to, in response to the boundary edges not forming an inner loop, tag the boundary edges and set of the faces as belonging to a slot.

5. The computer-implemented product of claim **1**, wherein the boundary edges are fillets or chamfers.

6. The computer-implemented product of claim **1** further including instructions embodied in the non-transitory computer read-able medium that, when executed by the processor, cause the processor to, in response to the boundary edges and set of the faces of the topological feature comprising at least one face that is cylindrical and that has a same axis as the topological feature, tag the topological feature as a cylindrical feature.

7. The computer-implemented product of claim **1** further including instructions embodied in the non-transitory computer read-able medium that, when executed by the processor, cause the processor to:

identify boundary edges for one or more chained topological features of the model having a shared face among the plurality of faces;

tag the one or more chained topological features as being common; and

in response to tagged as being common faces, highlight both topological features having common faces as feature chain.

8. The computer-implemented product of claim **7**, wherein the one or more chained topological features include a slot, pocket, island, or c-axis.

9. A computer-aided design tool comprising:

at least one processor programmed to

receive input selecting one of a plurality of faces of a boundary representation model of an object; and

in response to the input,

identify boundary edges of the model outside the one of the faces not separated from the one of the faces by an intervening concave or convex edge, the boundary edges defining a perimeter of a topological feature containing the one of the faces,

identify a set of the faces, including the one of the faces, contained by the perimeter, and

generate output highlighting the boundary edges and set of the faces of the topological feature.

10. The computer-aided design tool of claim **9**, wherein the processor is further programmed to, in response to any of the boundary edges being convex and forming an inner loop, tag the boundary edges and set of the faces as belonging to a pocket.

11. The computer-aided design tool of claim **9**, wherein the processor is further programmed to, in response to any of the boundary edges being concave and forming and inner loop, tag the boundary edges and set of the faces as belonging to an island.

12. The computer-aided design tool of claim **9**, wherein the processor is further programmed to, in response to the boundary edges not forming an inner loop, tag the boundary edges and set of the faces as belonging to a slot.

13. The computer-aided design tool of claim **9**, wherein the boundary edges are fillets or chamfers.

14. The computer-aided design tool of claim **9**, wherein the processor is further programmed to, in response to the boundary edges and set of the faces of the topological feature comprising at least one face that is cylindrical and that has a same axis as the topological feature, tag the topological feature as a cylindrical feature.

15. The computer-aided design tool of claim **9**, wherein the processor is further programmed to

identify boundary edges for one or more chained topological features of the model having a shared face among the plurality of faces;

tag the one or more chained topological features as being common; and

in response to user input selecting one of the chained topological features tagged as being common, generate output highlighting the other of the chained topological features tagged as being common.

16. The computer-aided design tool of claim **15**, wherein the one or more chained topological features include a slot, pocket, island, or c-axis.

17. A computer-implemented product including instructions embodied in a non-transitory computer read-able medium that, when executed by a processor, cause the processor to

generate a list of faces comprising a solid model;

identify boundary edges for a plurality of topological features of the solid model from the list of faces;

identify at least one of the boundary edges as being shared among the topological features;

in response to identifying at least one of the boundary edges as being shared, identify the topological features as being common; and

in response to tagged common topological features, highlight both topological features tagged as being common.

18. The computer-implemented product of claim **17**, further including instructions embodied in the non-transitory computer read-able medium that, when executed by the processor, cause the processor to, in response to any of the boundary edges being convex and forming an inner loop, tag the inner loop and corresponding faces from the list of faces as belonging to a pocket.

19. The computer-implemented product of claim **17** further including instructions embodied in the non-transitory computer read-able medium that, when executed by the processor, cause the processor to, in response to any of the boundary edges being concave and forming and inner loop, tag the inner loop and corresponding faces from the list of faces as belonging to an island.

20. The computer-implemented product of claim **17** further including instructions embodied in the non-transitory computer read-able medium that, when executed by the processor, cause the processor to, in response to the boundary edges not forming an inner loop, tag the boundary edges and corresponding faces from the list of faces as belonging to a slot.

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