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M. Spagnuolo, M. Bronstein, A. Bronstein, and A. Ferreira (Editors)

Automated contextual annotation of B-Rep CAD mechanical components deriving technology and symmetry information to support partial retrieval

K. Li[1]†, A. Shahwan[1,2], M. Trlin[1,2], G. Foucault[1] and J-C. Léon[1,2]

[1]Grenoble University, France
[2]INRIA, France

Abstract

Mechanical components are often related to technological meaning: it is a screw, a ball bearing, . . . Technological meaning relates to the notion of function which, in turn, refers to the environment of a component. Here, it is shown how a digital mock-up contextualizing a set of components is used to annotate its components with technological information. This information is derived from the interfaces between components. Interfaces together with the concept of state of a digital mock-up initiate annotations of components with functional information. Symmetries of components is a complementary information that can contribute to a query. Local rotational symmetry is analyzed and adapted to the context of mechanical components. Then, combining these two categories of information enables the generation of high level queries addressing a subset of a component boundary. Technological as well as symmetry informations are component annotations automatically derived from the digital mock-up analysis and from components analyzed separately.

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1. Introduction

The proposed approach focuses on mechanical components as they are produced by B-Rep CAD modelers during a PDP or available through the STEP format [TS03] described by NURBS and analytic surfaces. This category of models often meets partial matching requirements in industrial applications to search mechanical components for re-use, e.g. *find components featuring a bolted planar flange with six screws forming a circular pattern* (see Fig. 1 where the corresponding configuration is illustrated). However, the notion of circular pattern has to be defined in the model structure to be able to set up an appropriate descriptor. Currently, the structured models [BRS06], [BGT*10] don't contain the appropriate information because they don't incorporate the symmetry properties needed for this query. In addition, the query refers to a bolted flat flange, which conveys some functional meaning that cannot be currently expressed. Regarding these issues, the purpose is to set up the appropriate model annotations, in an automated way.

2. Related work

The introduction has illustrated the missing representation of an appropriate component model to be able to process queries covering symmetry and technological information. Symmetry detection has been studied as part of shape descriptors [MGP06] for mesh models. Approaches differ through the categories of symmetries detected. Here, B-Rep CAD models are under focus. They have been addressed for global as well as partial symmetries [LLM08]. Symmetry of mesh models is subjected to approximations originated by the chordal deviation of the mesh model compared to the real object and is not accurate enough. Identifying local approximate symmetries of B-Rep CAD models is more complicated to extract [LLM08]. Here, symmetry properties ad-

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† Emails: li.ke2002@gmail.com, Ahmad.Shahwan@grenoble-inp.fr, tzmoreno@gmail.com, Gilles.Foucault@ujf-grenoble.fr, Jean-Claude.Leon@grenoble-inp.fr

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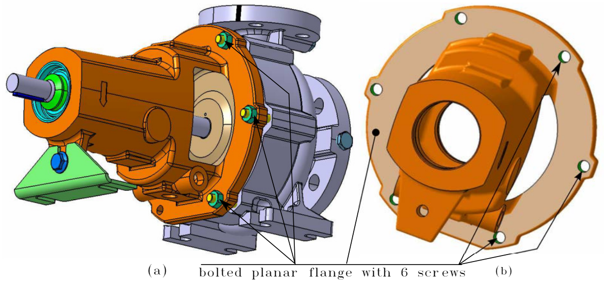

Figure 1: *An example with a bolted planar flange: a) in the context of a product, b) the corresponding local area on a component (planar area in light orange and through holes in green).*

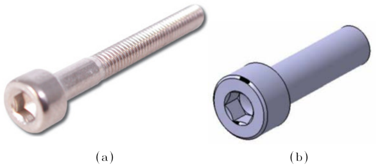

Figure 2: *Examples of components with their real and digital shapes: a) a real screw, b) its digital model.*

dress manufactured objects whose shape assessment must be at least as accurate as the real component, i.e. commonly an order of 10^{-3} unit length for an object of magnitude 10^3 unit length. This level of accuracy requires new developments and a reduction of the algorithmic complexity.

Indeed, this query refers to functional aspects of the component through the *bolted planar flange*. Functional description of a component/product refers to the description of what it is for, which relates to the context of a component, i.e. its environment. Current approaches mentioned in the introduction rely all on databases where objects are standalone and isolated of their context. Among shape repositories, the AIM@SHAPE (http://www.aim-at-shape.net) and the Design (http://www.designrepository.org) repositories contain assemblies described through the STEP standard, which is a common neutral representation of Digital Mock-Ups (DMUs). DMUs reduce to a set of components properly located in 3D space, which does not describe precisely the environment of each component.

Form and function have been recognized as tightly related [GK04] because the designer keeps on constructing connections between a function, a behavior and a shape of a component throughout a design process. Though design methodologies are top-down approaches, recent approaches show also that bottom-up ones can be helpful in analyzing product [MYY*10], [APH*03] either from mesh models or B-Rep CAD ones. All these top-down and bottom-up approaches require an environment of a component to progress in the identification of component functions.

3. Component shapes and conventional interfaces

Prior to the presentation of the annotation process enriching component information, it is important to study the content of DMUs and some principles used to define the shape of components in a design context. To be generic, DMU models are acquired through STEP files whose content reduces to the geometric description of each component as well as its location in 3D space, i.e. there is no geometric constraint expressing the relative position of components and there is no modeling history available for each component as commonly available in industrial CAD software. It is now important to observe that the shape of components taking part to a DMU may differ (even significantly) from that of the real object (see Fig. 2). This fact refers to the following definitions.

Real shape of a component C (or real component): it refers to the real physical shape of C.

Digital shape of C: it refers to one possible volume or surface or line model or any combination of these models representing C in a DMU. Here, it is simply designated as a *shape*. Compared to the Real shape of C, its shape can incorporate a simplification process also designated as idealization.

The selection of a shape for C may be originated by either company standardization or the use of component libraries, e.g. Traceparts (www.traceparts.com), or designer's choices to speed up a modeling process or a combination of some of these reasons. Consequently, if real products contain components that interact with each other through interfaces that can only fall into the categories of: contact (when two component boundaries ∂C_1 and ∂C_2 touch each other) or clearance ε (when subsets of ∂C_1 and ∂C_2 are located at a distance $d \geq \varepsilon$), this is no longer sufficient to analyze DMUs. Indeed, the shapes of components can generate interferences in a DMU even though their locations are correct.

As a result, a consistent DMU, i.e. a DMU where all its components coincide with the locations of their associated real components, contains components that can be related to each other through interfaces. An interface between two components C_1 and C_2 of a DMU fall into one of the three following categories: contact, interference, clearance, which clearly extends the configurations addressed in [MYY*10]. Interfaces between components C_1 and C_2 are indeed *conventional interfaces* (CIs). CIs are a subset of the result of a design process of a product, hence they contribute to functions, at a low level. Indeed, CIs contain functional surfaces.

4. Annotating components with functional information

CIs of mechanical components are strongly related to analytic surfaces of type plane, cylinder, cone, sphere. A first

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step of DMU analysis has consisted in identifying CIs in a DMU and form the CI graph whose nodes are the components of the DMU and each arc is a CI between two components. For conciseness purposes, this is not detailed here. CIs form shape features that can be precisely inserted in the boundary of each component to define a first level of annotation. To process high level queries, we refer to the concept of **functional interface** (FI). As an example, a CI of cylindrical contact, CI_{cc}, can be assigned the technological definition of loose fit, i.e. the manufactured diameter of the shaft is always smaller than the one of the housing and the corresponding FI is cylindrical loose fit. The mapping between CIs and FIs is a one-to-many mapping in general, e.g. CI_{cc} can be assigned the technological definition of a snug fit (the manufactured diameter of the shaft is always greater than the one of the housing). FIs form also a taxonomy set up on the basis of the CIs. The CI graph and the FIs addressed here don't place restrictions into specific categories of components as in [APH*03]. Considering the query of the introduction, the *planar flange* refers to a CI of type planar contact, CI_{pc}, and there is only one FI associated to CI_{pc}.

Now, the FIs need to be processed to filter them out and retain the appropriate interpretation of each of them. To this end, the concept of state of a DMU is introduced. If the concepts of behavior and function as addressed in [GK04] refer more or less explicitly to state variables, the concept of product or DMU state is not explicitly used as part of a design process. Here, its definition is as follows:

State of a DMU: Given an FI for each CI of the CI graph, a behavior law is applied to each component of the DMU. This behavior law helps characterizing the physical objective of the state and this physical objective is qualitative. Applying the behavior law successively to each component until a consistent result is obtained, validates the FI used in this DMU state. Otherwise, unsuccessful applications of the behavior law reject the candidate FIs of components.

As an example, the first state currently implemented, $\mathcal{S}_{se}$, is based on the objective expressing that a DMU, considered in a configuration at 'rest', is such that each of its component must satisfy qualitatively the static equilibrium law, i.e. no component must fall apart in the DMU.

The DMU analysis is part of a module connected to a database to enrich the components with technological data (see Fig. 3). Based on this principle, the database can contain standalone components annotated with technological information as well as sets of components forming assemblies. This architecture incorporates a *simulator*, e.g. a Finite Element analysis, that can take advantage of the technologically enriched component and assemblies to generate more efficiently FE models.

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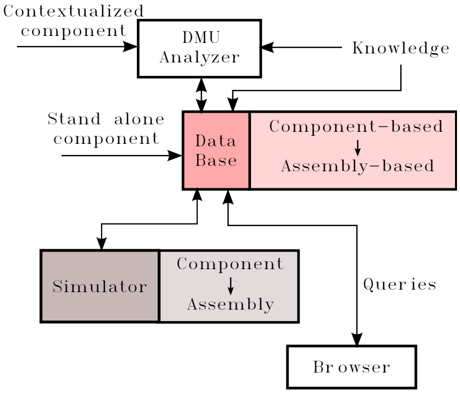


Figure 3: *Overall architecture of the database environment supporting the annotation process.*

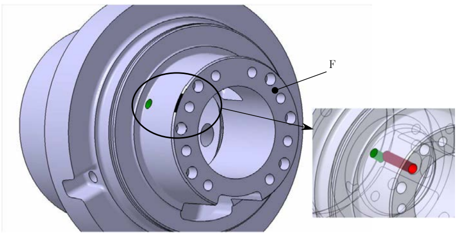


Figure 4: *Mechanical component featuring a local, not exact, rotational symmetry of holes. The detail image shows that the rotational symmetry is influenced by an orthogonal hole (in green) crossing an element of this symmetry (in red).*

5. Local symmetry properties contributing to a query

To complete the example query of the introduction, we need component symmetry information, which is intrinsic to each component and partially valid since the flange relates to a subset only of the component boundary.

Global and local reflective symmetries of objects have already been addressed [Li11] and can be obtained accurately and rapidly, i.e. at the accuracy of a modeling kernel (10^{-3} unit length) and a time scale of 0.2s for a CAD model having 400 boundary patches.

Fig. 4 is an example of local rotational symmetry based on a distribution of blind holes. Only one exact congruence is valid inside the planar face labeled F on Fig. 4 since the cylindrical surface of one of its holes (in red) is perturbed by an orthogonal hole (in green).

Reducing the extent of the rotational symmetry property to F only is not meaningful because the circular contours in F are neither defining a function nor a manufacturing operation. It is mandatory to include hole faces adjacent to F to obtain areas contributing effectively to an assembly, hence functional, feature or a drilling operation. It is therefore nec-

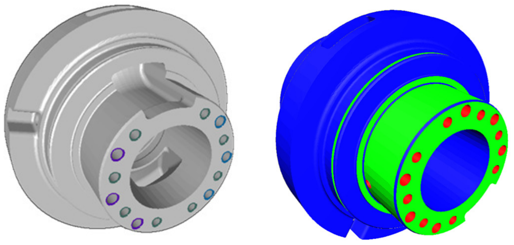
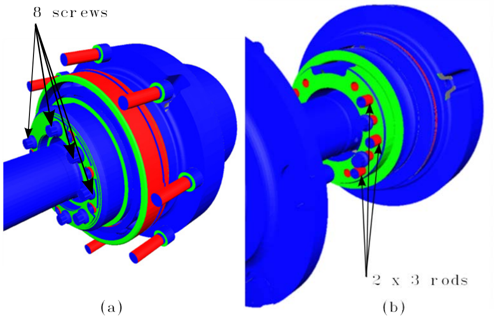

(a) (b)

Figure 5: *C_F annotated with the rotational symmetry analysis and FI analysis. (a) one group (3 holes) is violet, one group (3 holes) is blue, one group (8 holes) is dark green. (b) FI: contact surfaces are in green, interferences are in red, blue surfaces are not interfaces.*



(a) (b)

Figure 6: *(a) A subset of the DMU and CIs and components near C_F. (b) show CIs and components nearby C_F.*

essary to contextualize the definition of a rotational symmetry, hence the concept of **Approximate rotational symmetry** that cannot be detailed here.

6. Results

Fig. 5 illustrates an example of a component C_F structured with rotational symmetry and FI information. C_F satisfies a query for a flat flange with 8 screws. FI information (see Fig. 5b) is external to C_F and has been obtained through the DMU analysis represented in Fig. 6 where the CIs of components are automatically identified. The two major categories of CIs, i.e. contacts and interferences, currently used, are illustrated with green and red faces, respectively. Fig. 6a is a cutout of the DMU containing 112 components to highlight the layout of the components in the sub-assembly of an even more complex product. The component in red is C_F. Fig. 6b gives a partial view of the same DMU after the CIs identification, showing the components around C_F.

$\mathcal{S}_{se}$ produces a unique FI for the cylinders of C_F, which is a thread and adjacent components can be identified as screws. Other CIs of C_F subjected to $\mathcal{S}_{se}$ retain their FI and can be identified as rods. Among the 14 cylinders forming rotational symmetric patterns on the contact interface of C_F, the previous annotations produce only 8 threads related to screws with a rotational symmetric layout, which is the desired information to answer the query.

7. Conclusion. Acknowledgments

The proposed approach shows how annotations can be automatically attached to components through the analysis of their environment in a module forming a database front-end to load components and assemblies. Because functionally related information is external to a component, it has been demonstrated how geometric information can be related to technological information through a bottom-up process. Symmetry properties, though they are intrinsic to an object are generally not part of an object representation have been combined with technological information to enable high level queries as needed for design re-use purposes. The careful structure of technological information enables a robust annotation process using FIs and states with various ontology-structured information. Object query for partial matching is no longer reduced to sub-graph matching but evolves in rule-based expression as needed to use ontologies.

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References

[APH*03] AGRAWALA M., PHAN D., HEISER J., HAYMAKER J., KLINGNER J., HANRAHAN P., TVERSKY B.: Designing effective step-by-step assembly instructions. *ACM SIGGRAPH* (2003), 828–837. 2, 3

[BGT*10] BAI J., GAO S., TANGA W., LIU Y., GUO S.: Design reuse oriented partial retrieval of cad models. *CAD 42* (2010), 1069–1084. 1

[BRS06] BESPALOV D., REGLI W. C., SHOKOUFANDEHA A.: Local feature extraction and matching partial objects. *CAD 38* (2006), 1020–1037. 1

[GK04] GERO J. S., KANNENGIESSER U.: The situated functionŬbehaviour. *Design Studies 25* (2004), 373–391. 2, 3

[Li11] LI K.: *Shape Analysis of B-Rep CAD Models to Extract Partial and Global Symmetries*. PhD thesis, Grenoble University, Nov. 10th, 2011. 3

[LLM08] LI M., LANGBEIN F., MARTIN R.: Detecting approximate symmetries of discrete point subsets. *CAD 40*, 1 (2008), 76–93. 1

[MGP06] MITRA N., GUIBAS L., PAULY M.: Partial and approximate symmetry detection for 3d geometry. *ACM Transaction on Graphics 25*, 3 (2006), 560–8. 1

[MYY*10] MITRA N. J., YANG Y.-L., YAN D.-M., LI W., AGRAWALA M.: Illustrating how mechanical assemblies work. In *ACM SIGGRAPH* (2010). 2

[TS03] TC184-SC4 I.: *ISO-10303 Part 42 - Geometric and topological representation*. ISO, 2003. 1

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