Title:
Automatic Parts Classification to Enhance the Semantics of the CAD Assembly Models

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Introduction:

Nowadays, to improve efficiency and reduce costs and the human workload, in mechanical industries, the product life cycle and, in particular, the manufacturing process are deeply assisted in all their phases by the use of CAD assembly models. At this purpose, research is very active and several techniques have been defined and implemented, to algorithmically address the most onerous and error prone tasks, from the assembly sequence planning to the subassembly sequence identification, from the assembly or parts retrieval for the model and related knowledge reuse to the production and assembly costs estimation and optimization. In general, all these methods first implement a CAD model processing phase, where the features interesting for the specific process/analysis and their relations are recognized.

However, in most cases, the main weakness that can be observed is that all the data extracted basically rely on geometric information, while the intrinsic engineering meaning of the assembly's components is neglected [8]. For example, the geometric type of the contact surfaces between two parts is taken into account, as well as their distance or their volumetric intersection, whereas the fact that the contact is strengthened by fasteners is overlooked. Even if knowing the type of the parts can be beneficial in selecting the most appropriate operations and sequences thus allowing more robust and efficient process definition, in CAD models all the component categories are treated at the same level. That is to say, there is no clear distinction between a screw or a sheet metal, since they both are geometric objects only described as combination of bounding faces or their constructive elements (e.g. features and dimensional parameters) [2]. This because usually details associated with parts' functionalities and engineering meanings are implicit. This kind of data, in fact, may be included as annotations in the CAD model, but these attributes are not rigorous and unique since they depend on the designer choice, thus it may result difficult and time consuming to interpret them. Moreover, most of the time, especially when the CAD models are in standard exchange formats, such as STEP, the parts' meanings are lost, unless experts manually provide them [1].

We can conclude that the semantic interpretation of the CAD assembly model and its components is a very challenging but interesting topic, which deserves to be deeply investigated, since it can be exploited in several fields. To fill this gap, the paper proposes an automatic part classification methodology for the identification of some standard parts, largely employed in mechanical engineering. Making explicit the

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semantics of the components can be the basis for the understanding of the overall assembly semantics and functioning. The recognition relies on geometric analysis and engineering knowledge, avoiding experts intervention for classifying and labelling parts. The main idea is to assign a part to a specific category (e.g. screw, nut, washer, etc.) when it complies with the engineering and design rules previously defined for that specific class of components.

In the following, after a brief overview of the existing literature in the field of the CAD model classification, the key points of the proposed approach and the algorithm structure are reported. An example of classification applied to an industrial CAD model of a gearbox is finally provided.

State of the Art:

A mechanical assembly is made of many parts of various shapes and sizes and with different purposes. At first glance, a rough distinction can be made between custom designed and standard parts. Custom designed parts generally constitute the body of the assembly (e.g. sheet metal, beams, plates, pipes, etc.) and they can be specifically created for the product under development. The standard components, instead, have a more precise role in the assembly, and thus a more easily recognizable semantic value, moreover they have almost recurrent shape, possibly respecting standardised rules. On the one hand standard parts serve to link the custom designed components (i.e. fasteners), on the other hand they are parts with an intrinsic and well known functionality (i.e. gears). Standard parts are categorised according to their role within the assemblies, consequently the knowledge of standard parts would facilitate the product development process and improve the CAD model processing algorithms, for example reducing the number of parts to deal with, allowing the identification of elements to be ignored or treated in predefined manners.

At this purpose, in literature researches about assembly's parts classification and parts semantic values exploitation can be found. A portion of works, although, provides not totally general solutions, that can not be further exploited in external applications or integrated with other software. This because they exploit CAD systems' tools, that facilitate the managing of the assembly and the reading of parts information or they rely on industrial dataset and specific company catalogues, and it is limiting. More general classification approaches, according to the strategy adopted, can be divided in procedural and artificial intelligence methods. The former exploit geometric and shape information and, when available, parts' arrangement in the assembly and their contacts. Some of them are more targeted at the identification of single specific components, possibly exploiting different shape descriptors [3], others aim to classify parts according to kinematic as well as functional properties [7, 9]. The more recent artificial intelligence methods, instead, allow the identification of a large portion of mechanical parts thanks to machine learning [4, 6] or deep learning [5] techniques. These tools, however, need a high computation time, large training dataset and depending on the approach even complex descriptors of the parts must be calculated.

This paper wants to overcome this issue, implementing a more practical standard parts classification. In particular, it is proposed not only to assign the parts to a category, but also to characterise them by the main engineering dimensions (e.g. length, width, thread, etc.) and deduce their semantic meaning. Aiming to provide an automatic parts classification, avoiding a great computational effort, but at the same time ensuring reliable results, the approach is based on geometric analysis and engineering knowledge on the class characteristics and usage. It is in fact evident that, from an engineering point of view, standard parts' shapes are ruled by regulations and catalogues. That is to say, excluding additional customization, each element belonging to a class is characterized by common class-specific features and its design follows international standards. Just think to the class of screws: although several types of screws exist, all of them always have a head and a stem, and the relationship between their lengths has to be in a given range. For each part category, catalogues exist detailing the general rules they have to follow and the admissible sizes.

Thus, exploiting engineering knowledge on the class characteristics, CAD model geometric analysis and features recognition algorithms, the proposed method analyses each assembly's part and assesses if its geometry respects a specific class distinguishing characteristics both in shape and sizes.

In the following section, the algorithm is outlined: the main assumption and the structure implemented are described, as well as the properties of the resulting classification.

Standard Parts Classification Approach:

As previously said, having available the information related to standard parts in a product model is very helpful for the specification of the various processes involved in the whole product life cycle. Hence, the work here described is focused on the identification within a CAD assembly of these meaningful parts, which satisfy some recurrent or even standard rules. Currently, the part categories considered are: screws, nuts, O-ring, washers, circlips, keyways and studs (see Fig. 1).

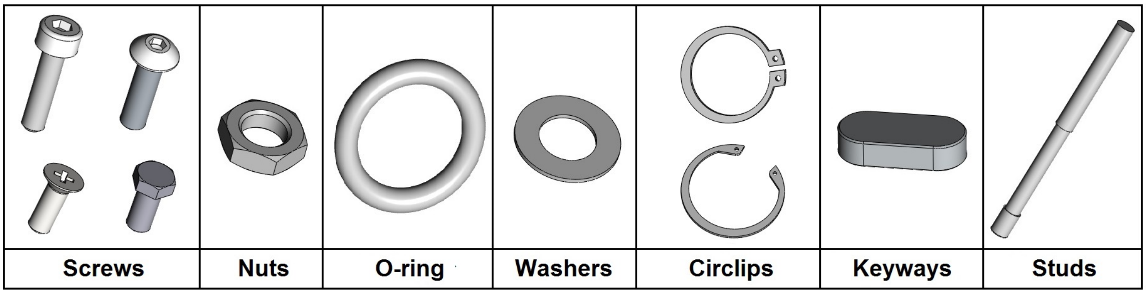

Fig. 1: Classes of parts recognized by the classification process.

The proposed algorithm applies a rule based approach which mainly exploits geometric and topological information present in the B-rep model representation as filters for discarding/accepting the class membership. As a consequence, it is very fast in providing the resulting classification. Moreover, no specific CAD systems are required, thus it can be integrated in several contexts as preliminary phase to assist the CAD model processing.

In particular, it takes in input a CAD assembly model in STEP format and evaluates some basic and easily accessible geometric properties of its parts. Gathering up engineering knowledge of mechanical components, catalogues on norms and design rules, for each considered class, the most typifying aspects have been singled out. That is to say, we have identified those characteristics, both relative to shape and sizes, that a component must necessarily have to belong to one of the classes. The properties are then translated in geometric requirements, such as the presence of specific types of faces (e.g. planar, cylindrical, toroidal, etc.), their particular arrangements, ranges for some the dimensions. Iteratively, each CAD assembly model part is analyzed singularly with a schema that proceeds by steps, in a selection process where if the current part does not satisfy a requirement it is skipped, without evaluating the other features. More specifically, for each assembly's component, first, the faces are counted: if the number of faces is in a given range, the algorithm proceeds to verify the type of surfaces of the faces and to evaluate their relative positions (e.g. parallel, perpendicular, etc.), the symmetry of the part and the existence of specific sequences of faces. If one of the possible combinations specified for the considered categories is satisfied, the component is supposed to belong to the corresponding class. To confirm this assumption, the dimensions and their ratio are checked.

It is to underline that the proposed approach is not restrictive. The evaluation criteria are conceived to include the minimum needed characteristics, in order to allow the recognition of both parts modeled in different ways and varieties of parts. For example, whether the chamfers are modeled or not is not discriminatory, as well as the absolute sizes of the parts are not considered due to their variability, but rather the ratio of the sizes is taken into account.

To be more accurate, for some classes, subcategories are distinguished. For instance, the class of screws includes hex head screws (socket or not) and cross recess head screws (countersunk raised, raised cheese, countersunk flat). Circlips, instead, are divided in internal, external or snap ring.

Thanks to its structure the classification algorithm associates additional information with the components, beyond the type. In particular, the dimensions generally used in mechanics, and reported in engineering catalogues, are automatically extracted, such as length, width, height, diameter, nominal diameter, socket depth, key size or chord. In this way, parts of the same class can be then grouped by dimensions, as it is relevant in several tasks such as assembly planning or costs estimation. Practical information is thus supplied with no human intervention, and it enhances our classification, since dimensions are rarely returned by existing methods.

Example of Classification:

In this section an example of parts classification by means of the proposed algorithm is reported, in particular an industrial CAD model of a gearbox is considered (Fig. 2).

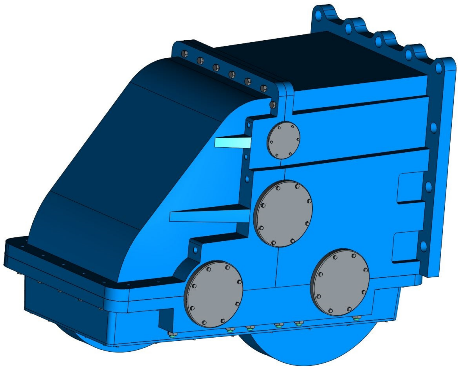

Fig. 2: CAD model of a gearbox.

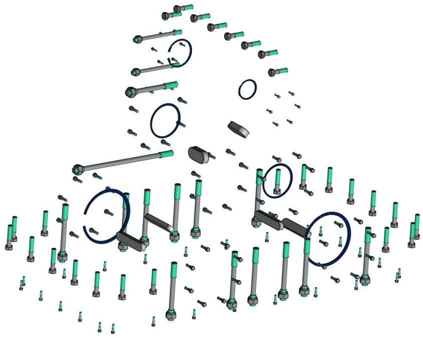

Fig. 3: Parts recognized by the classification.

The assembly is made of 426 parts, a reasonably high number, that consequently involves computational effort during the processing phase. At this purpose, the classification can significantly improve the assembly's details available and reduce the number of parts to analyse, by recognizing and labelling most of the standard parts included in the model, and thus enhancing the semantic and engineering knowledge of the assembly.

The parts classified are in fact 282, the 66% of the total, and more specifically: 112 screws (divided in 5 subcategories by thread pitch and length), 86 washers (divided in 3 subcategories by diameter and thickness), 46 circlips (divided in 5 subcategories by shape, diameter and thickness), 16 nuts (divided in 2 subcategories by thread pitch and height), 16 studs (divided in 3 subcategories by thread pitch and length) and 6 keyways (divided in 3 subcategories by length, width and height) (Fig. 3).

From these results it is evident that more than half of the assembly's components are actually fasteners or, however, parts with a precise engineering meaning. The method presented allows to automatically classify them in few seconds, only starting from the CAD assembly model. Once identified, these parts can be treated in a predefined way, for example simplifying the graph of the assembly's parts contacts, by excluding standard parts from the nodes of the graph, but rather leveraging the knowledge of their functionality as contact attributes, reducing the computational cost.

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Conclusions:

In this paper an automatic CAD assembly component classification is presented. Differently from existing methods, our approach is focused on the recognition of those mechanical components having a defined function in the assembly, and thus a specific engineering meaning, in order to enhance the semantics of the CAD model.

The algorithm is based on the specification of standard engineering and design rules in terms of shape and geometric features of the parts. It results promising and allows to recognize most of the standard parts included in the assembly, along with knowing their dimensions. Future works will enrich the classification with additional classes of parts and will improve the recognition, by considering further standard properties and engineering rules, to overcome misleading situations.

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