Title:
Regular Patterns of Repeated Elements in CAD Assembly Model Retrieval

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Introduction :
The extensive use of CAX tools in industry leads to a mushrooming accumulation of CAD models that are stored in databases. While designing new products, designers usually reuse existing models to speed up the design process [12]. However, nowadays, databases are so large that designers struggle to retrieve product data in general – i.e. drawings, simulation models, videos, technical reports – and CAD assembly models in particular. An efficient retrieval of assembly models requires also information that is implicitly encoded in the CAD models. This implicit information must be made explicit to become usable. So far, the most common solutions rely on the use of Product Data Management (PDM) systems. PDM systems ease the organization and management of product data by enabling designers to add textual metadata. Although PDM systems efficiently manage text-based queries, they do not always fulfil designers' needs. Indeed, sometimes designers prefer to query the system for models geometrically or structurally similar to an existing CAD model (single part or assembly). Content-based algorithms enhanced by additional geometric characteristics are an alternative to extend text-based search capabilities to retrieve 3D models. Cardone et al. [1] identify several scenarios in which the shape similarity search plays a key role. Deshmunk et al. [4] propose a step forward by providing various assembly searching capabilities assuming that all the information is available – e.g. the relationships and the joint constraints.

We propose a framework for the retrieval of globally and/or partially similar assembly models according to different user-specified search criteria. It is based on an assembly descriptor, called Enriched Assembly Model (EAM), organized in several layers that enable multi-level queries. We plan to automatically extract all the included data through the development of dedicated modules by analyzing the geometry and layout of the CAD assembly model. In particular, this work focuses on the identification of regular patterns formed by repeated elements in an assembly and on the exploitation of this information for the model retrieval. Fig. 1 shows an example of an assembly model with circular patterns of screws, bolts and nuts. To the best of our knowledge, current solutions for assembly model retrieval are not able to fully exploit this kind of information for the identification of similarity.

Related works
An efficient and meaningful retrieval of CAD assembly models requires a suitable assembly description involving also characteristics that might be not explicitly encoded in the CAD models, and highlighting different features valuable for different search purposes.

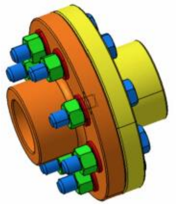

Fig. 1: Assembly of two parts with circular patterns of screws, bolts and nuts.

Jayanti et al. [7] and Tangelder et al. [11] provide a complete overview of 3D shape descriptors. However, these descriptors are focused solely on the shape of a single component and do not consider other relevant information of the assembly such as the relationships between the parts. Hu et al. [6] propose a tool to retrieve assemblies by representing them in a watertight polygon mesh. A vector space descriptor is used to decompose an assembly into different meshes corresponding to the parts of the assembly. Identical parts are merged and a weight based on the number of occurrences is attached to each part in the vector. Nevertheless, the descriptor ignores the relative positions of parts and their constraints. Moreover, the retrieval method is weak in local matching. Miura and Kanai [8] extend their assembly model by including structural information and other useful data – e.g. contact and interference stages and geometric constraints. However, some information must be made explicit by the user. This descriptor has two main limitations. First, it does not consider high-level information, such as kinematic pairs or general assembly shape. Secondly, it lacks various search criteria that might be of interest to the designers. A more complete assembly descriptor is proposed by Chen et al. [2] and relays on the product structure and the relationships between the different parts of the assembly rather than dealing with the shape of the whole assembly. The assembly descriptor takes into account different information levels including the topological structure, the relationships between the components of the assembly, as well as the geometric information. Additionally, the descriptor enables designers to ask rough and incomplete queries that make the search approach more flexible.

The proposed Enriched Assembly Model similarly to the assembly descriptors presented in [2] and [4] is able to support user requests at different level of specification details but differently than [4] does not require the user to add manually some information. Differently than [2] the mapping algorithm is not limited to the identification of assembly models with the same structure in terms of sub-assemblies.

<u>The proposed assembly descriptor:</u>

EAM encodes information at four main layers – statistics, structure, interface and shape – as illustrated in Fig. 2. The various layers help characterizing the assembly at different levels of detail.

The statistics layer contains numerical attributes for allowing a quick search and filtering. It includes three categories: assembly statistics (i.e., number of sub-assemblies, number of principal parts, number of fasteners, number of thin parts, number of patterns of a specific type), part statistics (i.e., percentage of a specific type surface, number of maximal faces of a specific type surface) and interface statistics (i.e., number of a specific joint type, number of elements in contact for a specific contact type).

The structural layer encodes the hierarchical assembly structure as specified by the designer. In this organization, the entire assembly has the same attributes and relationships of a sub-assembly. Moreover, the layer involves high-level information on part arrangement, i.e. regular patterns of repeated parts existing in each sub-assembly.

The interface layer provides the specification of the interfaces among the parts in the assembly. It is specified hierarchically. The highest level indicates the mechanism defined in the assembly and collects the joints between parts embedded in the entire assembly model, thus it considers all the possible part interactions. The joint level contains the relationships between two components while the contact level is the lower one and it encodes the degree of freedom between the faces of the parts involved in joints.

The shape layer includes various shape descriptors of both the sub-assemblies and their elements to provide shape information at different levels of detail and is exploited for the retrieval with exact and rough queries with unprecise shapes.

The proposed EAM is a very rich model including, apparently some redundant information, but it has the advantage of allowing scalable queries. A complete EAM is computed only for the stored models, whereas for the query model only the data at the detail level required by the query are computed and exploited for the matching, thus reducing the complexity of the system.

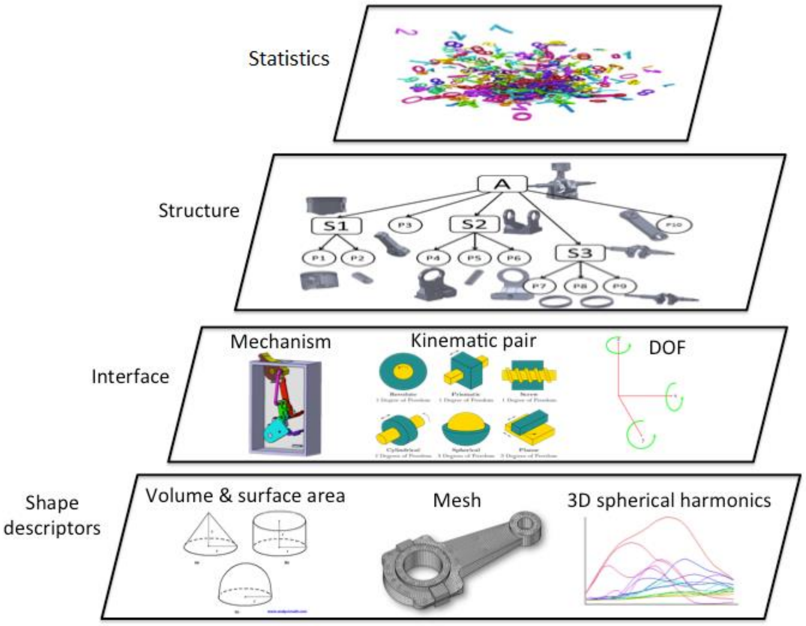

Fig. 2: The Enriched Assembly Model.

The identification of regular patterns of repeated parts:

Among the tools that analyze a CAD assembly model to extract the information to be stored in the EAM, here we focus on the method for the identification of regular configurations in a set of repeated parts (RP) in an assembly.

Repeated parts are identified in the model as multiple instances of the same object or by considering parts having identical values of the part statistics data layer and same volume and surface area in the shape descriptors layer. The method applies a series of grouping and filtering processes to reduce the complexity and the number of elements on which to perform the symmetry rule detection [3]. The computation is simplified by the consideration that if a set of congruent sub-parts is characterized by a regular arrangement, then also the respective centroids do. Vertices of the model and other characteristic points are used to compute the centroid for every RP. First of all, the RPs groups of RPs are computed whose centroids are at a constant distance d. We define a *d*-adjacency matrix as follows. Let $\{C_0,......C_{n-1}\}$ be a set of points in R^3 and *d*>0 a real number, we call *d*-adjacency matrix the n x n symmetric matrix M_d such that:

$$M_d(i,j)=\begin{cases}1 & if \quad |dist(C_i,C_j)-d|<\varepsilon \\ 0 & if \quad |dist(C_i,C_j)-d|\geq\varepsilon\end{cases} \qquad \forall\ i,j=0,..,n-1 \qquad (1)$$

Where ε is a tolerance value and *dist* is the Euclidean distance between points. A *d*-adjacency matrix can be viewed as a network of points in R^3 each of them connected to one or more points of the network by a straight arc of length *d*. A list of adjacency matrices at constant distance *d* is then created, one for each distance *d* found between the centroids of the RPs. Among the various adjacency matrices only those corresponding to coplanar barycenters are considered. The adjacency matrices are used to quickly identify the sequences of equidistant centroids and then the possible patterns involving as many as possible RPs. At first, the path detection algorithm aims at identifying all the possible paths in the centroid network represented by a given *d*-adjacency matrix. These paths correspond to sequences of at least three centroids satisfying specific geometric conditions. The developed method is focused on regular arrangements of RPs whose centroids lie all on a line or on a circumference. A path is built step by step, by first choosing an initial seed path of three centroids (seed1, seed2, seed3) and, once the type of the path that is going to be built has been established, by adding every time a new centroid to the current path if possible. If the three initial points are aligned, it will be a seed path of type linear; otherwise, it will be a seed path of type circular. In both cases, at first the attempt of expansion is done in the “seed1 to seed2” direction; when the expansion in this direction is no longer possible then a second expansion attempt is done in the “seed2 to seed1” direction. The expansion from a seed set ends when the maximum expansion is reached in both the directions.

A path of centroids gives an outline of the RPs placement but it is necessary to verify the correct orientation of the corresponding RPs to assess that the identified path really indicates a regular pattern of repeated parts. Currently, this phase of the algorithm has been developed for RPs containing exclusively planar and cylindrical faces and for the following types of pattern: linear translational, circular translational, circular rotational and reflectional. It is based on the verification that the entities of the RPs satisfy the same transformation rule of the related centroids. Specifically, for centroids lying on a linear path the candidate pattern is the linear translational, whilst for centroids lying on a circular path, the candidate patterns are the circular translational or rotational. Reflectional patterns are verified only in case of only two RPs. Therefore, when a path of centroids is identified, for any pair of RPs corresponding to two consecutive centroids in the path, two levels of check are performed. The first check considers the real vertices in the RPs, the second exploits the surface information of the faces. First, the method verifies if for any vertex in one RP, there is a vertex in the successive RP that is obtained applying to the first vertex the transformation under verification. If the test on the vertices is positive, then a second level of verification is performed on the face orientation. In case of linear translational pattern, for each planar face in the first RP it is verified if there exist a planar face in the successive RP with the same normal. For each cylindrical face, the method checks if there exists a corresponding translated cylindrical face in the second RP by exploiting axis and edge information [3].

Results:

The retrieval tool based on the EAM is developed as plugin of the commercial CAD system SolidWorks [10], by exploiting its application programming interface (API). Assembly models encoded in STEP format represent the input for the assembly retrieval framework. To validate the developed method, we collected models from public datasets as GrabCAD [5], Tracepart [9] and Visionair [13].

The achieved results confirm that regular patterns can be exploited to further characterize assembly models for improving the model searching. Fig. 3 shows a subset of the obtained results. The query model in the first example has two repeated wheels that form a reflective pattern; the retrieval tool correctly identifies models with the same pattern. The second example shows the retrieval of elements presenting the same type of patterns of the query model – i.e., circular patterns of bolts and screws. The models retrieved in the first row have the same type of pattern with the same number of repeated elements. The second row contains models with patterns involving a greater number of elements being the query not posing conditions on the cardinality of patterns and pattern elements to consider.

Conclusions:

In this paper, we propose a model, called Enriched Assembly Model (EAM) suitable for the hierarchical matching of CAD assembly models. To be generally applicable, the EAM is built from CAD assembly models encoded in ISO 10303-21 STEP format (AP203 or AP214). Various tools are being developed to extract the required EAM information from the CAD assembly models. Among them, the method to detect and exploit regular patterns of repeated parts within the assembly is presented as well as some results of its use for the retrieval of similar assembly models.

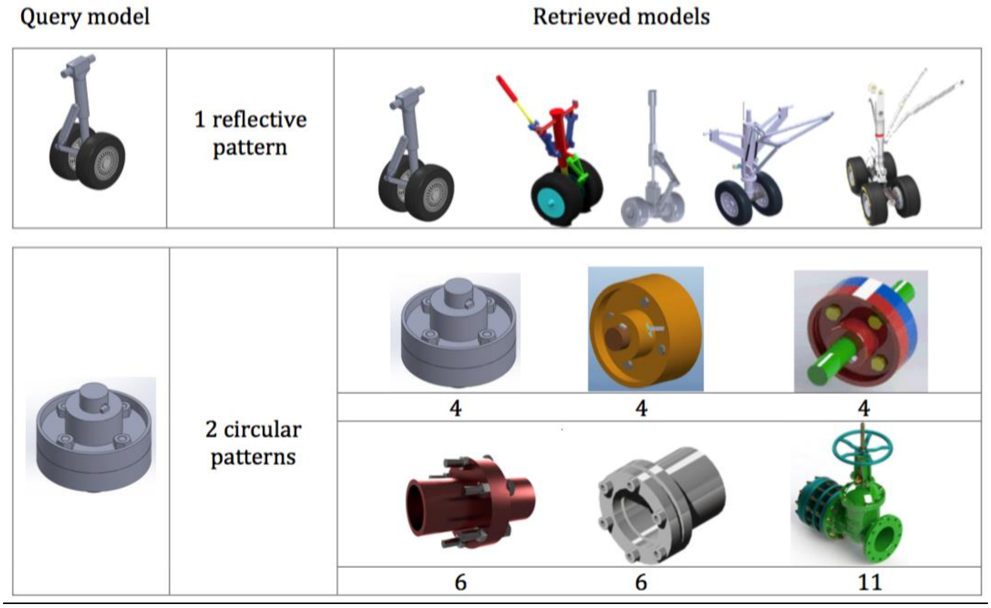

Fig. 3: Results of two different query models.

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