Title:
Watermarking Scheme for Geometric Data Protection and Detection on 3D CAD Assembly Model

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Keywords:
Assembly model, Watermarking, CAD, Hash value, Product development

DOI: 10.14733/cadconfP.2015.245-249

Introduction:
Nowadays, different contemporary products are modeled in a CAD environment. These involved a number of components and assembled together to form an assembly model. Such related components of a product are assembled by different mating conditions in a product design and development stage. Normally, the assembly model would be distributed to different personnel involved in the process. To ensure that the assembly model received is an original one and is not modified by any unauthorized persons, watermarks should be embedded into the model.

Different watermarking schemes have been proposed for watermarking 3D geometrical models. A public watermarking scheme was proposed by Fornaro et al. [5] for authenticating CSG models. Sun et al. [6] developed a scheme for non-uniform B-spline surface and the watermark is embedded into the sample points. Ohbuchi et al. [7-8] discussed the problem of watermarking non-uniform rational B-spline (NURBS) surfaces. Other schemes for watermarking parametric surfaces can also be found in [9-13]. Chou et al [14] focused on the issue of watermarking 3D polygonal models. Wang et al. [15] proposed a watermarking scheme for authenticating 3D polygonal model based on integral invariants. In [16], the vertices are clustered to a number of patches and the watermarks are then embedded into selected normal vectors. For instances, Kanai et al. [17] proposed a transformed-domain watermarking approach on 3D polygonal model. In [18], an informed-detection, robust mesh-watermarking algorithm that works in a transformed domain was introduced. Other robust mesh-watermarking algorithms or schemes can be found in [19-23]. A multi-resolution system was proposed by Kim et al. [24] and applied in similarity comparisons for geometry-based or feature-based modes to determine the comparison result in the overall shape and to solve security problems in collaborative design conceptually. However, the watermarking issue about assembly models is ignored or rarely discussed.

Main Idea:
In this paper, a watermarking scheme is proposed specifically for watermarking the assembly model structure via the positions and orientations of the components. An assembly model structure is represented by a tree and an assembly model tree structure consists of N node (Fig. 1). A unique component ID number is assigned to each component. For each component, a hash value is calculated according to the ID numbers of the components related to it in the assembly model tree structure. By detecting the hash value, any minor modification in the tree structure can be detected and verified.

To watermark a component's position and orientation, some points on the surface of a component are primarily noted and selected. All the watermarked points would fulfil the following two criteria: (i) Watermark and the corresponding hash value are embedded to the two coordinates of the watermarked points, and (ii) The watermarked point is on the corresponding component. Consequently, watermarks and hash values are embedded into the coordinates of the selected points using specified keys by changing the values of the coordinates slightly. The coordinates of the selected points are then stored in the attribute properties of the corresponding component. To detect whether a component's position or orientation are altered, the selected points must be checked whether they are still on the component. The coordinates of these points are altered in order to add some watermarks onto them while the points are still kept on the corresponding component. For an arbitrary point P, its containment property related to a component – inside, outside or on a component, can be determined. When the component is transformed, the containment property of a point relative to this component may change in some cases. If more than three points on a component are properly sampled (e.g. the points are not collinear), the possibility for the containment properties of all the sampled points remaining unchanged after the corresponding component is transformed would be low, i.e. at least one of these points will be inside or outside the component after the transformation is performed in most of the cases (See Fig. 2). These containment properties of the watermarked points (i.e. on the component) are then used as one of the hash functions for checking whether the component's position and orientation are altered.

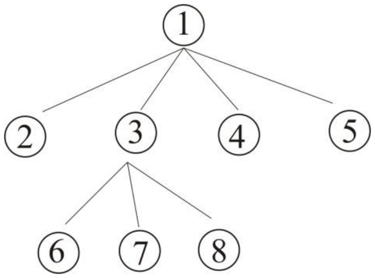

Fig. 1: An assembly model tree structure. Node 1 is the root node, node 3 is an interior node and other nodes are the leaf nodes.

The watermark information may be embedded into the original geometrical data of the model or added into the attributes of the components. Normally, a tree structure is employed for representing an assembly hierarchy so that the structure of the assembly model and the relationship between the sub-assemblies and the components can be illustrated. To anchor the positions and orientations of the components, proper mating conditions between components should be set.

To protect geometric data for a component, the coordinates of these sampled points should be watermarked while the containment properties of these points are unchanged after watermark is embedded. In the proposed scheme, a hash function $h(w_j)$ and a point containment function $g_i(P_j)$ are established (See Eqn. (1.1))

$$h_j = h(w_j) \tag{1.1}$$

where w_j is a watermark and h_j is the hash value for P_j.

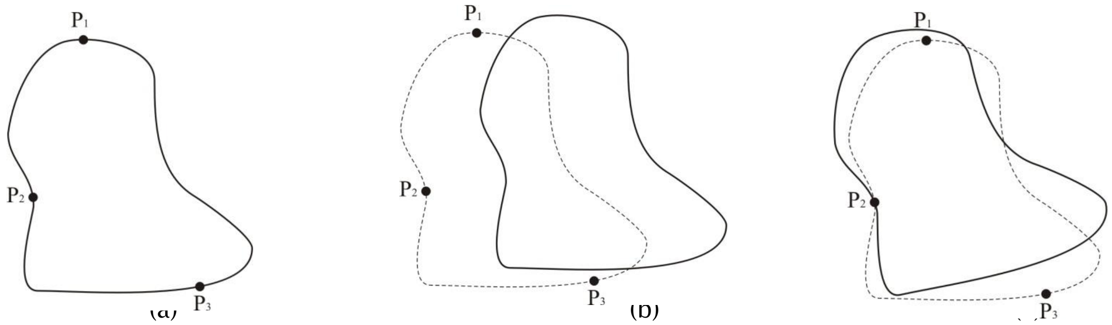

Fig. 2: (a) Three points are sampled on the boundary of a component. (b) P1, P2 and P3 are outside after the component is translated. (c) P2 is still on the component but P1 and P3 are inside and outside after the component is rotated about P2.

For a component, n_i points on it are sampled and each point P_j is denoted as (x_{j1}, x_{j2}, x_{j3}) (the coordinates are relative to the working coordinate system of the assembly model). A watermark w_j would first be embedded into x_{jk} (k = 1, 2 or 3) so that x_{jk} is modified as x_{jk}'. The hash value h_j is then embedded into another coordinate (x_{jl}) of P_j such that l is not equal to k. A new point P_j' is then resulted. As a result, any unauthorized changes on the components' positions and orientations on the assembly model can be detected by extracting the watermarks of the assembly model. To verify the proposed scheme, an assembly model is tested as an example (Fig. 3). In this assembly model, there are 11 components. For each component, 3 points are selected for anchoring the position of the component. In Fig. 3(b), selected points for one of the components are shown and their coordinates are listed in Tab. 1. The parameters, the watermark and the hash function of the watermarking process are shown in Tab. 2.

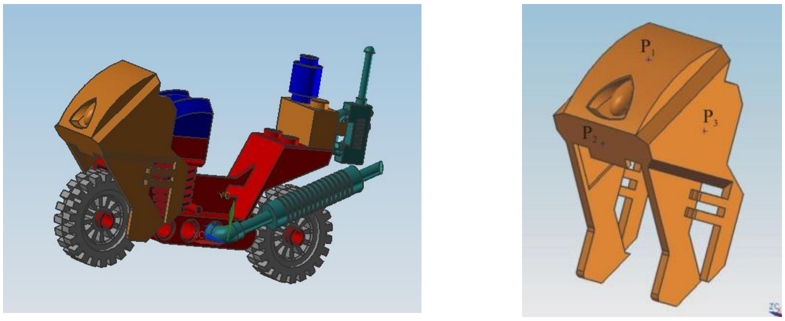

Fig. 3: (a) An example assembly model. (b) The points on the surfaces of one of the components for embedding the watermark.

Point	x_{j1}	x_{j2}	x_{j3}
P_1	31.4943	33.8035	21.4936
P_2	36.9442	18.7554	22.3712
P_3	24.2010	25.3267	11.5729

Tab. 1: Coordinates of the points for watermarking.

Point	x_{j1}	x_{j2}	x_{j3}
P_1	31.5008	33.7978	21.4941
P_2	36.9508	18.7619	22.3712
P_3	24.2108	25.4100	11.5729

Tab. 2: The coordinates of the example points in Table 1 after the watermark is embedded.

Discussions:

In this paper, a watermarking scheme specifically for watermarking an assembly model is proposed. In this methodology, some points on each component of the assembly model are extracted. The coordinates of these points are altered in order to add some watermarks onto them while the points are still kept on the corresponding component. These containment properties of the watermarked points (i.e. on the component) are then used as one of the hash functions for checking whether the component's position and orientation are altered. As a result, any unauthorized changes on the components' positions and orientations on the assembly model can be detected by extracting the watermarks of the assembly model.

Conclusions:

In the proposed method, the watermarks do not alter the geometries of the components and can be applied in an assembly model. The watermark information can be embedded into a selected vertex with flexibility. Besides, the original assembly model with watermark information can be accurately and quickly detected and verified when compared with other existing CSG models. The memory sizes of these watermarks are negligible when compared with the file sizes of the assembly model so that the resultant file size of the assembly model would not be largely altered by the proposed method. As a result, an assembly model would now possibly be watermarked by the proposed method without violating the geometric data. It is convenient and efficient for authorized personnel in the development process to detect any unauthorized modifications of the 3D assembly model via file exchanges on the internet. Geometric data of the assembled models can be protected.

Acknowledgements:
The work presented in this paper was supported by a grant from the Hong Kong Polytechnic University (Project No.: G-YH61). Their financial supports have made this research to complete successfully.

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