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Data format and browser of lightweight CAD files for dimensional verification over the internet[†]

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Abstract

The demand for the use of 3D CAD data over the Internet environment has been increasing. However, CAD data size has deteriorated the communication effectiveness of 3D CAD files. Good design methodology of a lightweight CAD file is required for rapid transmission on the distributed network environment. In this paper, a file translation system is constructed to produce lightweight CAD files from commercial CAD systems by using InterOp and APIs of the ACIS kernel. Using B-rep models and mesh data extracted from the CAD native files, the lightweight CAD files with topological information are constructed as binary files. As the lightweight CAD files retain topological and geometric information, they are applicable to dimensional verification, digital mock-ups, and visualization of CAD files through a CAD viewer. The effectiveness of the proposed lightweight CAD files is confirmed through various case studies on the CAD viewer.

Keywords: CAD visualization; Collaboration; Digital mock-up; Dimensional verification; Geometric simplification; Internet

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1. Introduction

Since its development, the CAD system has been recognized in the industry as an essential tool for designing. 3D CAD systems have enabled engineers to model products on 3D environments and to visualize product images on computers. They have not only reduced design cost, but have also made product modification processes in the product life cycle easier.

With the emergence of the Internet, data sharing between remote locations has become possible. Data shared through the Internet is not only limited to types such as texts or diagrams, but is also expanded to 3D geometric information. One important issue to consider for sharing CAD data on the Internet is the size of the CAD data. In general, 3D geometric data needs large memories. A considerable amount of time is required for sharing and transmission of the data. To reduce such time over the Internet, VRML (virtual reality modeling language) files have been used [1]. Most CAD systems are able to convert 3D geometric information into VRML forms. Currently, VRML is used widely as the file format to realize the VR (virtual reality) on the Internet. Some researches have been done to compress VRML data efficiently [2, 3]. However, VRML on the CAD system is only generated through ACSII format of VRML. File size of the ACSII format is larger than that of the binary type. Therefore, it requires significant time to read and transmit the data [4].

The issue of simplification of CAD model has been studied extensively in relation to the computer graphics field. However, the existing studies have mainly dealt with mesh simplification issues that were problematic in visualization of 3D models. Garland and Heckbert [5] classified the mesh simplification methods into three types: vertex elimination, edge collapse and vertex clustering. The vertex removal method

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proposed by Schroeder et al. [6] was performed by three-phases of classification including vertex identification, vertex elimination, and reconfiguration of meshes for the eliminated hole. The edge collapse was studied by Hoppe [7] based on LOD (level of details) for the mesh simplification method. The mesh simplification in the vertex clustering was studied by Rossignac and Borrel [8].

The above methods are useful in the mesh simplification process. The mesh data is applicable to visualization of the CAD data, but it is not in dimensional verification. The reason is that the mesh data do not include the information regarding edge types, such as circles, lines, and curves that are required in the dimensional verification. Recently, Qiu et al. [9] studied the simplification of a CAD model including the edge information. They included details on edge information such as simplification of trimmed curves. However, the classification of edges is not suitable for dimensional inspection. It is impossible to apply for the dimensional verification.

There are two commercialized light weight CAD files such as the JT file [10, 11] by UGS-PLM and the HSF file [12] by Techsoft3d. They provide several APIs and other convenient features, but they consist of most entities of CAD files. They are not simplified files. In addition, 3D files made by Actify [13] share 3D drawings on the Internet. They are similar to PDF files applicable for sharing of document files on the Internet. Lattice's Technology [14] developed XVL (eXtensible Virtual world Language) which is the mesh optimization file with the concept of expanding VRML [15]. These two files, 3D and XVL, are smaller in size than other lightweight CAD files such as JT and HSF, but the file generation time takes long. In addition, as they do not include feature information of edges, they are not applicable to the dimensional verification over the Internet. It is necessary to develop a new design methodology for lightweight CAD files applicable to the dimensional inspection on the Internet.

Table 1 shows characteristics of several lightweight files according to file compression, B-rep, NURBS and measurement functions. In case of the measurement function, "△"means vertex-based measurement, and "○" is accurate measurement supported by recognition of circle, line and curve attributes. In Table 1, U3D is universal 3D format regarding to ECMA-363 specification [16], X3D is the next version of VRML [17]. 3D-XML [18] is the lightweight format supported by Dassault Systemes. Sony corporation developed COLLADA [19]. 3D PDF [20] is the enhanced version of lightweight document format. Some formats support accurate measurements, but they include most CAD information. They are bigger than the proposed format, and detail comparisons of the performance are to be given in section 4.2.

Table 1. Comparisons of lightweight file formats.

Name of format	Compression	B-rep	NURBS	Measurement
VRML(1)	X	X	X	△
U3D(16)	△	X	X	△
X3D(17)	△	X	O	△
3D-XML(18)	△	X	O	△
JT Open(10)	O	O	O	O
COLLADA(19)	X	X	△	△
Lattice 3D XVL(14)	O	△	O	O
HSF(12)	O	△	O	O
PDF(20)	O	O	O	O
Proposed format	O	△	X	O

O: supported	△: partially supported	X: not supported

By the way, Song and Chung have developed several collaborative viewers on the Internet [21-24]. A Web-based dimensional verification system was studied to reduce the lead-time and improve flexibility of the reverse engineering process [21]. In this system, point data measured on a layout machine is directly used to verify design specifications. In 2007, they developed a STEP translation server supporting most CAD native formats to devise a CAD viewer on the Web [22]. To develop the Web-based interference verification system applicable to the single-level assembly of injection mold design processes, a lightweight CAD file converted from a CAD data was used as a native file of the CAD viewer [23]. Song and Chung [24] also proposed a multi-CAD assembly method through an XML and the lightweight CAD file. The lightweight CAD file produced from various CAD files through ACIS kernel and InterOp includes not only mesh and B-Rep data, but also topological data [25]. It was used to visualize CAD data and to verify dimensions of the parts.

Contrary to the previous application papers of the lightweight CAD files [23, 24], design methodology of the lightweight CAD file is described in detail in this paper. To increase the interface performance of the developed system under various types of commercial CAD files, a lightweight CAD file generating algorithm is proposed. Contrary to existing methods [26], the B-rep (boundary representation) model and mesh information are used to design lightweight files. Triangle meshes display all geometric shapes with small triangles. As the geometry is composed of simple triangles connected with adjacent triangles, the topological information is simple as well. On the other hand, the B-rep covers linear lines, B-splines, NURBSs and other various types of geometries. The B-rep model represents complex geometries accurately by using the various geometric elements and complex topological information. However, simplification of the B-rep model is more complex than the case of triangle meshes. In this paper, as the simplification of the CAD file is applied for dimensional verification processes, the simplification of the B-rep model is conducted after restructuring CAD entities. The restructuring process is conducted through the recognition of geometric features according to the measured items of the dimensional verification module.

The structure of this paper is as follows: Part 2 describes configuration of the translation system for interfacing of various CAD data. Part 3 proposes the structure and generation process of the developed lightweight CAD file. Part 4 verifies performance of the lightweight CAD file. Several case studies confirm effectiveness of the design methodology of lightweight CAD files**.**

2. Configuration of translation system

CAD models are expressed with parametric surfaces. A general method for visualization of CAD models on a screen is to visualize the surface by dividing it into triangular meshes. The distributed CAD system stores the meshes using the general method to interpret the parametric surface and to reduce the time spent on generating meshes. The mesh generation method chosen for this research is the mesh generation function of the ACIS kernel. Fig. 1 shows the structure of the system that translates various commercial CAD files into the proposed lightweight files. Fig. 1(a) shows neutral files and commercial CAD files that this system supports. Interpretation and translation of the commercial CAD files is done by InterOp, and Fig. 1(b) shows that the files are translated into the ACIS data structure. Fig. 1(c) is the module that generates the lightweight CAD file from the ACIS kernel data. In this ACIS kernel, information extraction required for the proposed lightweight file is classified into two processes. First, MESH_MANAGER, a mesh generating function of the ACIS kernel, generates meshes using the method of section 3.3 and extracts information of the meshes. Secondly, edge information required for dimensional verification is extracted through the method of section 3.4. Entity characteristics of the ACIS kernel are considered in this procedure. The proposed lightweight file is generated by converting the meshes and edge information into their binary forms, and then by the compression process by using the compression library.

For example, Table 2 shows entities that are mapped between CATIA V5 and translators in the translation process indicated above. During the translation process, the entity mapping converts the CATIA entity into the ACIS kernel entity, and then it is mapped and translated into an entity of the proposed lightweight file structure. Here, cylinders, cones, tori and other geometric features are processed as Faces. The reason why feature information becomes integrated into the Face is because reduction of geometric attributes is required for simplification of data processing. In addition, the method of expression differs depending on the types of commercial CADs. Therefore, in this paper, the above feature information is used for dimensional verification after mapping it into a Face entity [27].

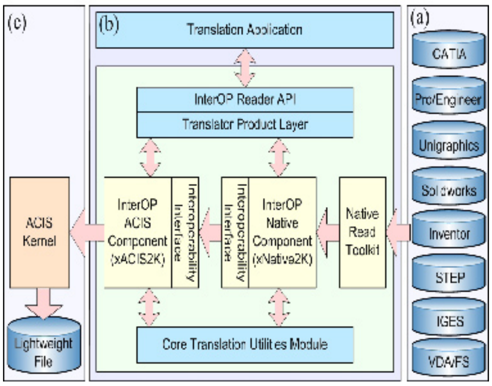

Fig. 1. Proposed translator converting commercial CAD and neutral files to the proposed lightweight file.

Table 2. Entity mapping : CATIA, ACIS and proopsed.

Native CAD entities	ACIS entities	Proposed entities
CATLine	STRAIGHT	Line
CATCircle	ELLIPSE	Conic
CATEllipse	ELLIPSE	Conic
CATNurbsCurve	INTCURVE	Curve
CATPlane	PLANE	Face
CATCylinder	CONE	Face
CATNurbsSurface	SURFACE	Face
CATTorus	TORUS	Face
CATSphere	SPHERE	Face
CATBody	BODY	Solid

2.1 ACIS geometric modeling toolkit

A non-manifold model is used in order to enhance the geometry and topology data, and to generate data required by downstream CAD systems. Every life-cycle product information, ranging from wireframe models of the initial design stage to complete 3D solid models of the production stage, is stored in one data structure of non-manifold models. A non-manifold modeler ACIS, an object-oriented geometric modeling toolkit, was developed for CAD system developers and has been accepted as modeling kernels of many CAD systems. To create and manage a CAD data set, ACIS offers C++ classes, API (application procedural interface) functions, and DI (direct interface) functions. Fig. 2 shows the ACIS data structure representing a non-manifold model [28].

2.2 InterOp translator

Spatial's InterOp [29] translators let you access 3D data without extensive code modification or expensive CAD software and APIs. InterOp translates commercial CAD and neutral CAD data into the ACIS kernel data transparently. It allows direct and indirect exchanges of solid, surface, and wireframe data between a variety of neutral and commercial CAD 3D formats, such as CATIA V5, CATIA V4, IGES, STEP, VDA-FS, Pro/ENGINEER (Pro/E), Parasolid, Unigraphics (UG), SolidWorks, Inventor, and ACIS. Each translator is fine-tuned and updated regularly to ensure accurate 3D data interoperability.

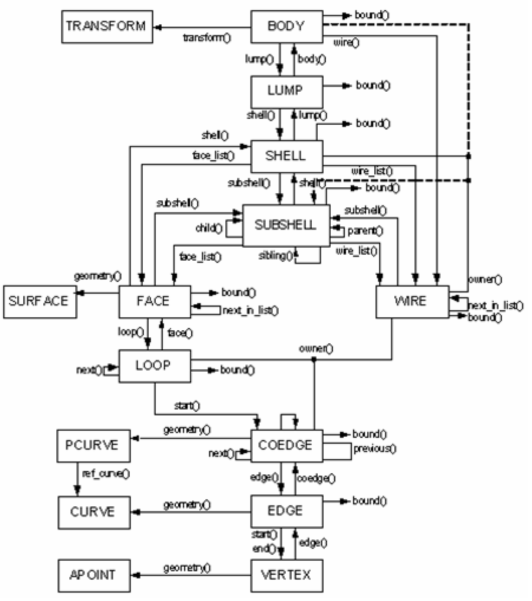

Fig. 2. Structure of the ACIS kernel data.

3. Design methodology of the lightweight CAD file

3.1 Necessary information for dimensional verification

Dimensional verification on a CAD viewer is enabled if all geometric data composed of the parametric surface and curve information of a CAD model are available. To save them as a file for a future application, a large amount of file size is required. As the CAD viewer file with the VRML format is constructed only with mesh information extracted from a CAD file, current collaborative CAD systems do not contain geometric information [1]. The VRML mesh data are inappropriate for the dimensional verification. To resolve this limitation of current CAD viewers, this paper proposes a construction method of dimensional inspection items prior to constructing a lightweight CAD file. According to the items, required entities are extracted from the commercial CAD file first. Using this information and the mesh data, a lightweight CAD data applicable to the dimensional inspection on the CAD viewer is constructed. Table 3 shows the necessary information for the dimensional verification. Defined items for the dimensional verification are shown on the first column. Required entities for carrying out the defined items of the dimensional verification are listed in the second column as

Table 3. Necessary information for the dimensional verification.

Measuring items	Necessary information	Resultant values
Point coordinate	Point	Coordinate value
Line length	Start point, End point	Length
Point to point distance	Point	Distance
Line to line minimum distance	Line	Distance
Edge to edge minimum distance	Edge	Distance
Surface to surface minimum distance	Tessellated triangle	Distance
Arc radius	Radius	Radius
3 points curvature radius	Points	Radius
3 points angle	Points	Angle
Surface area	Tessellated triangle	Area
Volume, Weight	Tessellated triangle	Volume
Size of bounding box	Bounding box	Size
Center to center distance	Conic center	Distance

point, line, conic, edge, and tessellated triangle. The third column shows calculated values as results of the dimensional verification.

3.2 Data structure of the lightweight CAD file

The lightweight CAD file structure being discussed in this paper is designed in two parts depending on the application as shown in Fig. 3. One is the edge data part (Fig. 3(a)) and the other is the triangle mesh data part (Fig. 3(b)) for dimensional inspection. Detailed structure of the proposed lightweight file is described below.

"Group" is the top entity for managing the combined structure of several solids. "TRANSFORM" is the matrix for translation and rotation of each "Group". "Solid" is applicable to the solid of the CAD entity. In addition, a solid consists of faces. "Face" is located under the "Solid". "Face" consists of tessellated triangle data for visualization of the CAD model and edge information for the dimensional verification. "Edge" is saved with a separator to be classified into "Line", "Conic" and "Curve". They are composed of linear lines, conic curves and spline curves, respectively. The separator identifies edges and enables dimensional verification.

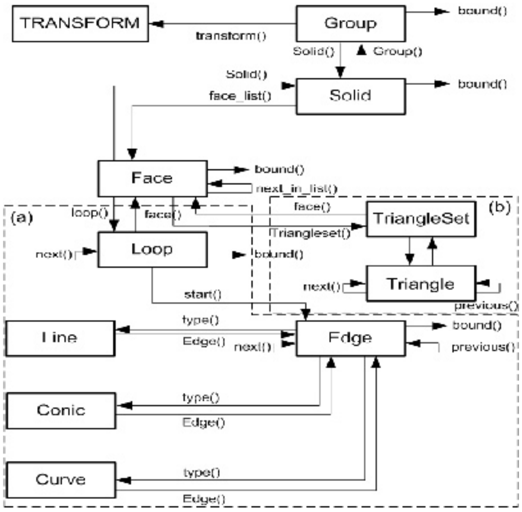

Fig. 3. Structure of the proposed lightweight file.

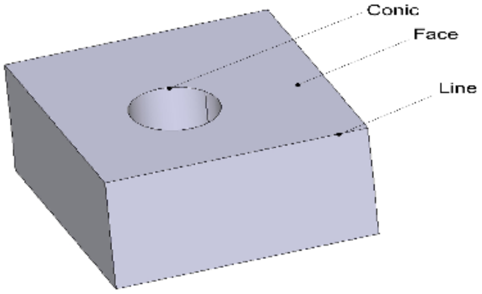

Fig. 4. Sample model.

Fig. 4 shows a straightforward example part model to describe the proposed lightweight file structure. It consists of a single solid. Under the solid, there are eight faces with six faces of the hexahedron and two conical type faces. In Fig. 5, the proposed lightweight file structure of the upper face is described for the sample part model. It consists of the loop to show external edges and other edges constructing the face. The external edges consist of four-line entities, and the internal edges consist of two conic entities to represent the circle.

Next is another example composed of several solids. Fig. 6 shows an assembly file composed of six solids. Fig. 7 describes the lightweight file structure of the assembly model shown in Fig. 6. Each solid part is defined as a solid of the proposed lightweight file. In addition, the solids are bound together by a group for easier management. When it is necessary to read other assembly data or part files, additional groups are created to accommodate new solids. The substructure of the faces is similar to the structure shown in Fig. 5.

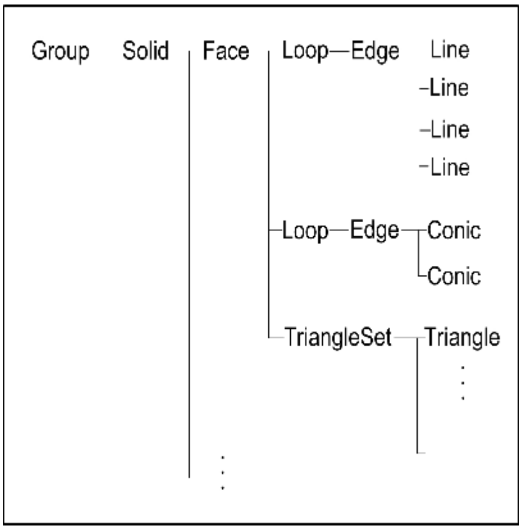

Fig. 5. File structure of the sample model.

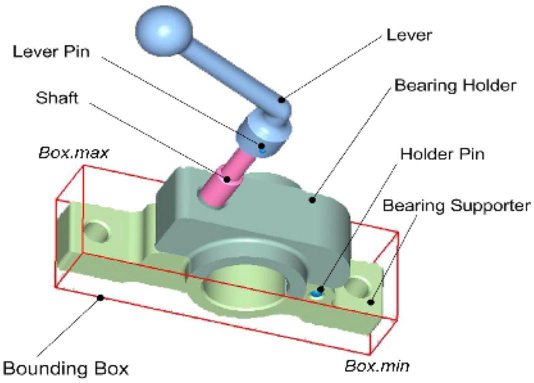

Fig. 6. Bounding box of the assembly part.

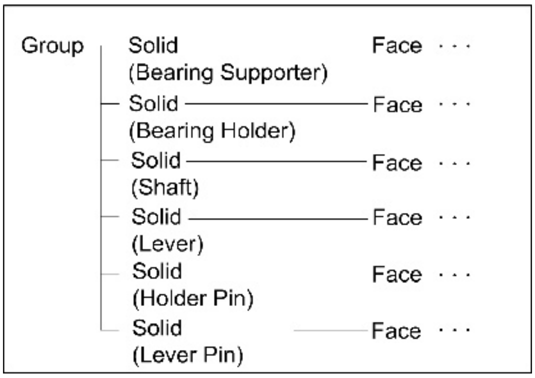

Fig. 7. File structure of the assembly part.

3.3 Mesh generation with multiple accuracies

The mesh generation function of the ACIS Kernel generates meshes according to the input tolerance level as a parameter. When generating meshes, it would not be efficient if the tolerance value of a single accuracy were applied to entire CAD models. To relieve this problem, the tolerance level is calculated by considering a bounding box of each body entity of the ACIS Kernel. In other words, for each solid, the bounding box size is selected according to the appropriate tolerance level of meshes. Fig. 6 shows a bound-ing box of the bearing supporter part. Mesh generation accuracy is calculated according to the following equation:

$$Dist = \sqrt{(\mathrm{Box.max.x\text{-}Box.min.x})^2 + (\mathrm{Box.max.y\text{-}Box.min.y})^2 + (\mathrm{Box.max.z\text{-}Box.min.z})^2}$$
$$T_{mesh\ \ tolerance} = Dist/\mathrm{Value} \qquad (1)$$

where $\mathrm{Box.max}$ is the maximum value of the bounding box and $\mathrm{Box.min}$ is the minimum value of the bounding box. The distance between $\mathrm{Box.max}$ and $\mathrm{Box.min}$ is divided by the user-specified tolerance value. Multiple tolerance levels are to be selected according to shapes of solids.

3.4 Extraction of the ACIS Kernel information

To construct the proposed lightweight CAD file applicable to the dimensional inspection, necessary information described in Table 2 should be extracted from the CAD data. To carry out this procedure, InterOp is used for translation from commercial CAD files into ACIS kernels. Using APIs of the ACIS kernel, CAD data on the ACIS kernel is extracted [30]. Extraction procedure of the ACIS kernel information corresponding to the CAD data is performed by the following procedure shown in the flowchart of Fig. 8.

1. From the ACIS kernel data, the top entity called “BODY” is searched. (Here, the “BODY” is an entity applicable to a part of the CAD entity.)
2. Once the search is completed, various types of attribute information of the part are extracted from the searched “BODY”.
3. A “LUMP” is searched from the “BODY” and then a “SHELL” is searched from the “LUMP”.
4. A “FACE” is searched from the “SHELL”, and attribute information, such as color, is extracted from the “FACE”.

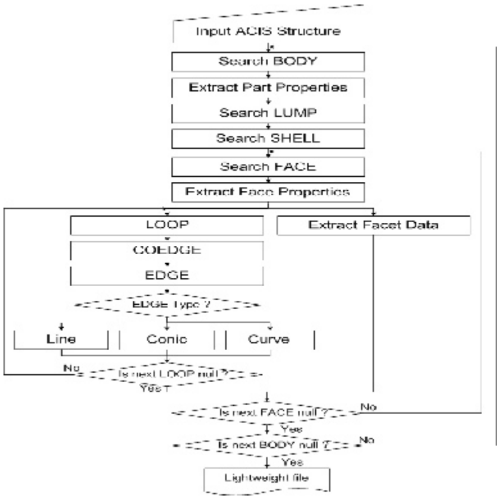

Fig. 8. Flowchart to extract the ACIS Kernel data.

5. The information extraction process of the "FACE" consists of extraction of facet data required for visualization and a "LOOP" composed of external lines.

6. The extraction process of a contour searches for the "LOOP" from the "FACE".

7. A "COEDGE" is searched from the "LOOP" and then an "EDGE" is searched from the "COEDGE".

8. Once the "EDGE" is searched, the edge type is determined to classify it as a line, conic, or a curve to enable the dimensional verification. Depending on the classification type, the information required for the dimensional verification is extracted and stored.

9. A value of null occurs when a loop does not exist anymore. Steps from 6 to 8 are repeated until a null is reached.

10. The triangle mesh information is generated and extracted by using the ACIS function from the "FACE" and is saved to be used for visualization.

11. If other faces exist, steps from 4 to 10 are repeated. If not, number 12 is performed.

12. If other bodies exist, steps from 1 to 11 are repeated. If not, number 13 is performed.

13. All details extracted from the above procedure are saved as a proposed lightweight file and the process is completed.

3.5 Store of markup and dimensional verification data

The markup function enables distributed clients to collaborate with each other through expressing and sharing their opinions on visualized geometric features. As shown in Fig. 9, clients are able to select markup types, such as lines, arrows, rectangles, etc. (Fig. 9(a)). Then, they leave a mark on a visualized feature and express their thoughts in writing. Moreover, the viewpoint of a present client, which can be represented by viewing scales, viewing centers, and rotational vectors mathematically (Fig. 10(a)), is stored together with dimensional verification and markup results by using the user viewpoint function (Fig. 9(b)). Verification results, composed of label position coordinates, select points, resultant values and user viewpoint names, have different information according to verification functions, such as coordinates, line length, point to point distance, etc. Therefore, verification results are classified and saved according to the verification function argument that identifies verification functions. A label, including a resultant value, is generated when the verification process is finished. Coordinate values called label position coordinates are shown on the monitor (Fig. 10(b)).

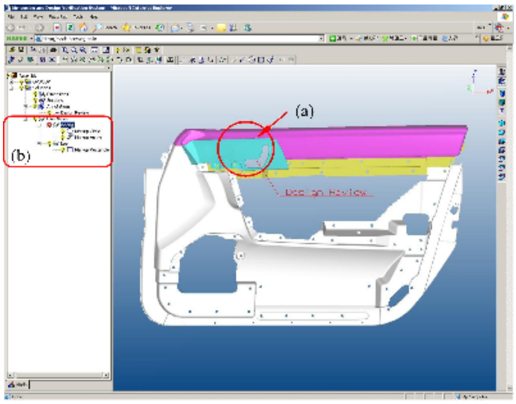

Fig. 9. Example of the user viewpoint and markup.

Markup results are classified according to the markup function argument identifying markup types. Each result consists of a selected point, color, text and user viewpoint name (Fig. 10(c)).

If new dimensional verification or markup functions are required, the developed system can be updated by assigning verification and markup function arguments and implementing the added functions. Fig. 10 shows the data structure [21].

3.6 Data store and compression

The lightweight CAD data are classified and saved as follows:

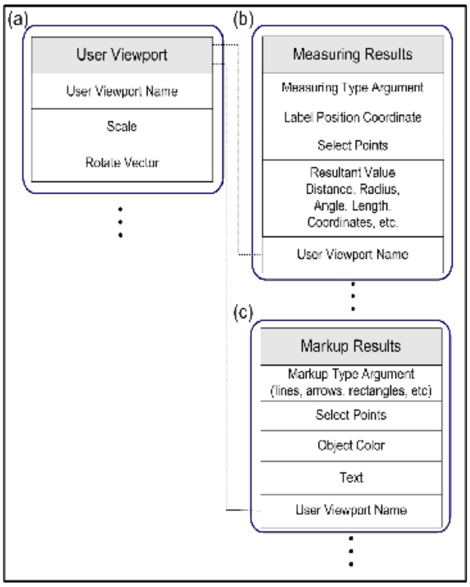

Fig. 10. Structure of the measurement and markup data.

1) Coordinate encoding: There is a research result that shows that saving of coordinate values as 8 to 12 bits is sufficient [4]. Coordinate encoding, however, is related to the accuracy of the measurement, and therefore, saves the information as 32-bit floating types.

2) Normal vector encoding: The normal vector is used for floating types within the viewing system. However, this is not the value used in the dimensional verification, and it is not saved as floating type information. Significant digits are secured by multiplying 10,000 to the floating type information. Then it is encoded into a 16-bit integer type and the normal vector information is saved.

3) Entity separator encoding: The factor classifying each entity is saved as a 1-byte integer type and determines the entity type.

4) Color encoding: Color information of the entity is divided into three colors (R, G, and B), each of which functions as a 1-byte integer type.

The above data saved in binary-type are compressed through the *zlib* library [31] to minimize the file size of the data.

4. Case study

4.1 Application of the proposed lightweight file

Various applications are described to verify the usefulness of the light weight CAD file developed in this paper.

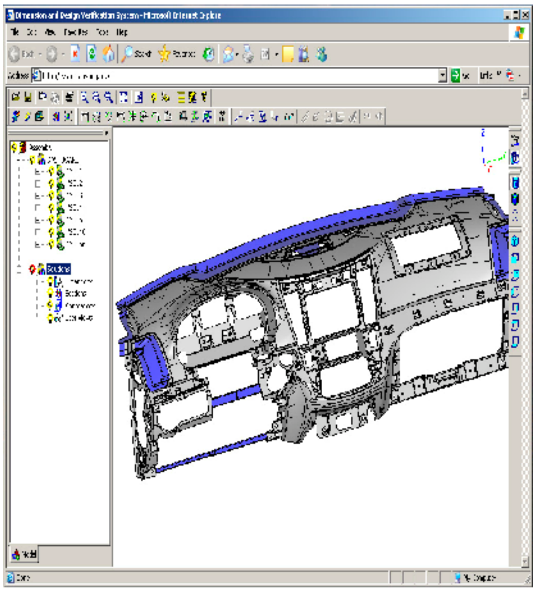

Fig. 11. Case study: CAD assembly file of a dashboard.

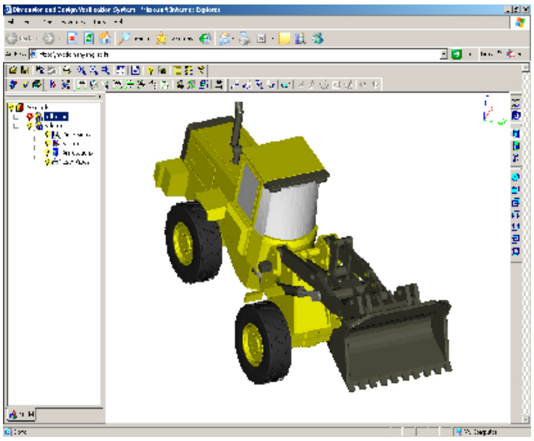

Fig. 12. Case study: CAD assembly file of a bulldozer.

Fig. 11 shows a dashboard CAD file with large capacity. It is designed by CATIA V5 and converted into the proposed lightweight file. The visualization result shown in Fig. 10 is produced by the developed Web-viewer [26]. Active X control is applied to develop the Web-viewer that is able to plug-in on the Web browser by using Visual C++ and the OpenGL library.

Fig. 12 shows the visualization screen of a bulldozer model. It is the proposed lightweight file and is generated from the CATIA V4 model composed of several part drawings. This process enables it to be applied for visualization and verification.

Table 4. Performance of the proposed lightweight file.

Name	CATIA	VRML	PDF*	Developed Lightweight File	
				Size	Data Generation Time (sec) on Pentium IV with 3.0 GHz CPU
Dashboard	59.8MB	29.5MB	1.62/8.48/29.4MB	4.0MB	3.5
Bulldozer	9.1MB	3.7MB	0.96/ 2.64/5.32MB	1.1MB	1.2
Clutch	36.9MB	12.2MB	1.96/6.39/14.8MB	2.9MB	2.6

* File sizes of PDF are categorized into the Tessellation with compression / Tessellation without compression / Tessellation with B-rep.

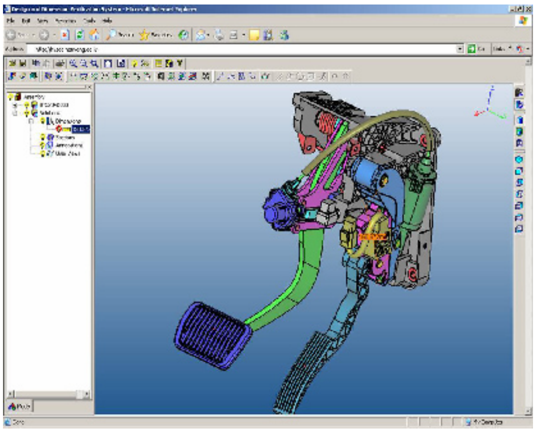

Fig. 13. Case study: CAD assembly file of a clutch.

Next is the application of the proposed lightweight file for dimensional verification. It is designed by considering the information required for dimensional verification. As shown in Fig. 13, it is useful for measurements, such as a distance between the center of a circle to that of another found in an automobile clutch part.

4.2 Comparisons of data size

In general, VRML is used as a visualization tool of CAD/CAM data over the Internet, but VRML files generated from most CAD systems have their capacity reach to several tens of megabytes. On the other hand, the file format developed in this research is relatively smaller in size than VRML. Table 4 shows comparisons of file sizes of the original CAD data, VRML, PDF (tessellation with compression / tessellation without compression / tessellation with B-rep) and the proposed lightweight files. The tessellation with compression of PDF shows the smallest file size, but this format is not applicable to accurate measurement. Comparing the proposed file format with the tessellation with B-rep of PDF applicable to the measurement, the developed lightweight file is the smallest format supporting accurate measurement. The sixth column shows the required time to generate the proposed lightweight files on the PC of Pentium IV with 3.0 GHz CPU speed. The time required for data storage does not increase rapidly even when the file size is enlarged. The reason is that even small-sized files take approximately 1 second to undergo an initialization process of the compression library.

5. Conclusions

Design methodology of lightweight CAD files for web-based collaboration has been proposed to obtain the following conclusions:

(1) The lightweight CAD file for web-based collaboration has been developed, and the prototype system utilizing it is materialized for verification.

(2) By developing the batch translation system from a CAD file to the proposed lightweight file through InterOp and the ACIS Kernel, the issue of interface and connectivity for various commercial CAD systems has resolved.

(3) The lightweight CAD file possesses triangle data and edge information to support dimensional verification. They are applied for not only the CAD file visualization but also actual work sites requiring fast visualization and dimensional verification for CAD data.

(4) As the developed file has smaller file size than the original CAD file as well as the VRML file of it, it has an outstanding reconfiguration speed in file visualization. It is confirmed to be appropriate for the distributed environment.

(5) The proposed lightweight file is designed to save CAD geometry information, dimensional verification data, mark up data, and user defined view ports to allow the delivery of all work content enabling data sharing for multiple collaboration.

(6) The effectiveness of the developed file system

has been verified through visualization and dimensional verification of large-capacity CAD data for dashboard, bulldozer, clutch, etc. over the Internet environment.

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