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A CAD SYSTEM WITH THE ABILITY TO RECORD DESIGNER'S NOTES AND DECISION-MAKING BASES FOR REUSE

Katsumi Inoue, Masashi Yamanaka and Chung-Seong Lee

Abstract

Designers often take marginal notes of the point of design such as decision-making bases, directions for production, etc. during designing hours. The notes are unquestionably valuable as design know-how and the information is worthy of reuse for younger designers. However, not a few are missing unless the designers leave them in the margin of assembly or part drawings, though they may describe some of the important matters in the specifications. Designers who use a CAD system have been faced with the similar problems, because the existing CAD systems do not provide them with a recording function of the notes for good reuse, but just allow users to enter memos in drawings. From this background, a method to manage the designer's notes by relating to drawing information in a CAD system is presented. This will offer the key to the design innovation through acquisition of design know-how during design and reuse them effectively. The frame of the system, which consists of design information database, drawing CAD software and the GUI, is presented to realize the function mentioned above and construct a CAD system with the ability to record the designer's notes and decision-making bases.

Keywords: Design information management, Knowledge management, Computer-aided design, Engineering drawing, Design

1. Introduction

Design support systems have been developed and applied for reducing the time required for designing. Most product design entails modifying design and diverse information related to currently available products is helpful in this process. Studies have been conducted to promote accumulation and reuse of design information; if the information is generalized as design knowledge, it can be extremely effective in designing new products. Wood proposed a method to describe abstract design knowledge in terms of modeling and classifying design information [1]. Shahin presented a database structure to improve the reuse efficiency of design information and described the possibility of realizing design support by reusing design information [2].

In the meantime, the necessity of systems to effectively manage a large quantity of data and information generated by CAD systems has been pointed out. The idea of product data management (PDM), which manages CAD data and documentation data in accordance with the product lineup of, has been introduced. The major functions include the function of automated generation of parts list of products, search functions for products with specific components, and management of data revision history, as well as functions for the progress management of checking, approval and printing processes. Abramovici pointed out the importance of the flexible management of design information in promoting distributed product development and described an expansion of PDM using WEB technology [3]. Using PDM functions, for example, it is possible to search parts drawings through parts which are used in combination with standard parts or those which failed during the production process. However; the currently available PDM does not have the function of obtaining design information such as thinking and intent of designers from drawings, therefore it cannot respond to queries regarding which drawing the designer should refer to in order to obtain the necessary information.

When a designer reads drawings and technical documents but cannot understand the intentions of previous designers who produced the drawings, currently the designer must contact the previous designers or research the related issues by himself. As a method to rectify this drawback, Hatamura proposed the use of context drawings in addition to official parts drawings and assembly drawings [4]. Context drawing is a general term used to describe a drawing not disclosed to the public; it contains idea sketches as well as various levels of planning drawings and memos. He is trying to incorporate context drawings into CAD. Kanou proposed a method to describe design processes in terms of pieces of information and design intention in order to reuse them in the upstream design process [5].

As Hatamura pointed out, designers often make marginal notes of points of design, such as decision-making bases and directions for production, while designing. Notes are unquestionably valuable as design know-how, and the information is worthy of reuse by younger designers. However, much of this information is lost unless designers leave their notes in the margin of assembly drawings or parts drawings, although they may describe some of the important points in the specifications. Designers using a CAD system have been faced with similar problems, because existing CAD systems do not provide designers with a recording function for notes which are suitable for reuse, but allow users only to enter memos in drawings.

Under these circumstances, the authors present a method to make parts drawings and assembly drawings valuable as information sources for design such that

- designers record the bases of their thinking process and decision making as CAD data,
- accumulated design information is compiled into a database and utilized,
- manufacturers or subsequent designers refer to the bases of decision making recorded in the CAD system.

We propose a method for realizing these functions and develop a prototype system based on a 2D-CAD system, then we confirm and discuss the proposed functions.

2. Marginal Notes on Designer's Decision Making

2.1 Design information in drawings

Figure 1 shows design and manufacturing processes. As a result of detailed design, parts drawings and assembly drawings are produced. Before their production, the following documents, sketches and drawings are produced in the design work.

(1) Project book: While calculating the cost and development period, desired functions are realized as design specifications.

(2) Idea sketch: Ideas to satisfy requirements are vaguely conceptualized and compiled as

sketches and memos. At this stage, generally, several ideas are examined.

(3) Drawing for refinement: In order to realize ideas, concrete ideas of mechanisms and structures are formulated by referring to past related drawings, parts catalogues and standards. Here, materials, heat treatment and processing methods are also examined. Several drawings for refinement are produced to evaluate their ideas.

(4) Final planning drawings: A final plan to satisfy the requested functions and restricting conditions is decided. All information to be included is determined at this stage.

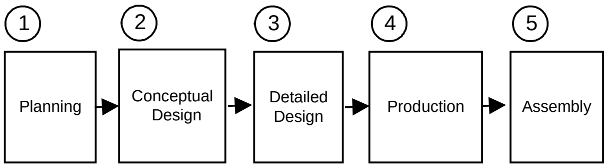

Figure 1 Design and manufacturing process

The information included in a design book is limited; often the designer's thinking process is not recorded at all but only kept by the designer. The bases of thinking process and decision making process in (2)-(4) above are recorded as memos in the margin of the final planning drawings and in the designers' personal notes; however, they are not included in parts drawings and assembly drawings. However, it is not easy for inexperienced designers to speculate how various matters other than values determined by formulas are selected and determined to produce drawings. Designers often refer to drawings of past and related products for current design work. Thus, a support system, which records the bases for decision making by relating them to design information such as shapes and dimensions, and conveys them to designers, is required to improve design efficiency by enabling the reuse of design information.

As above, bases of the designer's thinking process and the decision making process cannot be shown on drawings. Useful design information is stored in the form of memos for drawings for refinement, designer's notes, technical documents such as design books. In terms of recording media, it is possible to present information by directly writing comments on the sheet of drawings, and by gluing pieces of paper on which memos are written. In cases of CAD drawings, it is ideal to treat information generated by using word processors and spreadsheet software as CAD data. It is also possible to store design information and ordinal CAD data independently after determining a relationship between them. As described below, we adopt this method in this study.

2.2 Designer's ideas hidden in the directions written on drawings

Design information is used during the stages of planning, manufacturing and assembling shown in Figure 1; however, it should be recorded at the stage when a design has been finalized. Therefore, assuming that design information is recorded mostly in the detailed design stage, we analyze the functions required for the prototype of a support system.

Designers may record the base of decision making, design know-how, specific items related to design objects and remarks related to manufacturing and assembling as information. In order to analyze and locate specific features of the contents of design information and objects to be recorded, the use of practical design examples makes such tasks easy. Therefore, we select a prototype traction drive continuously variable transmission (CVT) as a practical example. Designer writes comments deemed important on 38 parts drawings; the total number of comments is 105. Table 1 shows an example. Drawing 32-2002-1 is for a shaft. The material is carburized to increase strength; however, the screw section should not be carburized, and chamfer for the groove of O rings is indicated. These comments are useful for designing other types of equipment; it may be possible to generalize this kind of information as design knowledge after its accumulation. We analyze the contents of design information and features after this preparation.

Table 1 Example of comments indicated in drawings

Drawing No.	ID	Comments
32-2002-1	1	Carburization preventing treatment is needed to the screw section
32-2002-1	2	Note of “Phase free” is needed for a widths across flats on shafts
32-2002-1	3	A corner at groove of O ring are chamfered
32-2002-1	4	Corner rounding should be as large as possible to improve strength
32-2002-1	5	The standard tolerance is 25js6, but a little large clearance would be better
32-2003-0	1	Use a finished plate for cost down
32-2003-0	2	Plating to prevent rusting
32-2003-0	3	A hole for drain should be as large as possible

First, the objects for which design information is provided are classified; Table 2 shows the results of this classification, together with the number of comments. In this example, the designer considers to include much information for dimensions and shapes. In other words, these are mainly comments on the required shape and dimensions to insure basic performance as a traction drive CVT. In the 2D-CAD used in the support system described later, the object of this information is related to the graphic data on the drawings. Accordingly, the design information can be related to relevant graphic data, and highlighting the relevant objects and describing them using a leader and balloon in the drawings can indicate the presence of recorded information. Figure 2 shows the objects for which information is recorded. The dimensions and tolerance classified in Table 2 are typical examples of the objects. Drawings also include management information such as designers’ names and drawing numbers; most of this is standardized information entered in the title block; thus, it is different from design information of which positive application is being studied.

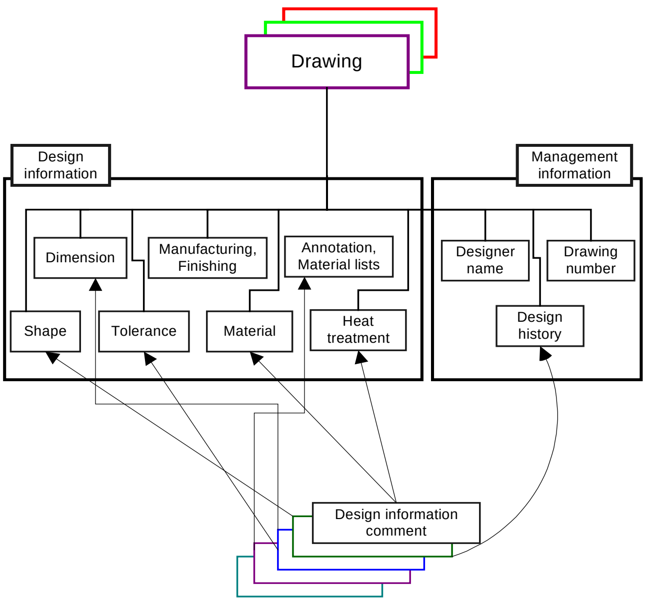

Figure 2 Design information of drawing to be recorded

Table 2 Classification of designer's comments given to CAD graphic objects of traction drive CVT

CAD graphic object	Number of commnets
Shape	15
Dimension	48
Tolerance	4
Manufacturing, Finishing	10
Material	4
Heat treatment	1
Annotation, Material lists	18

Next, we focus on the engineering and industrial meaning of design information. The information is generally related to functions, strength, assembling/disassembling, manufacturing costs, etc. Most design information is recorded in the detailed design stage, but the recorded design information is utilized in all design stages. Table 3 summarizes indexes showing contents of information and the design stages during which the information is utilized. Classification here may vary depending on the product type and the viewpoint of designer; however, this type of classification should make the analysis and practical use of design information easy. Furthermore, the indexes in the table correspond to X in "Design for X"; this is expected to contribute to the accumulation and analysis of design information which is independent of the design object.

Table 3 Index of design information utilized in each design process

Design process	Index
① Planning	Durability, Handiness, Cost, Function
② Conceptual design	Safety, Function
③ Detailed design	Structure, Shape, Dimension, Strength, Lubrication, Assembly/Disassembly
④ Production	Structure, Shape, Dimension, Strength, Lubrication, Assembly/Disassembly
⑤ Assembly	Layout, Fits, Lubrication, Assembly/Disassembly, Safety

3. Prototype Based on Two-Dimensional Drawing System

3.1 Design of prototype system

Based on the analysis in section 2, we develop a prototype design support system which enables us to record and reuse design information. Figure 3 shows the system structure. It operates on a personal computer and consists of a database of accumulated design information, 2D-CAD, and graphical user interface (GUI). The AutoCAD is for 2D-CAD, and a commercially available relational database, MS-Access, is used. The GUI is developed by the authors; it handles the input of design information into the database, relating the database and CAD data, and data management. As discussed in section 2.1, it is desirable to treat design information as CAD data, however, from the viewpoint of simplicity of constructing the system, we use a standard database. In the system, all design information is recorded in the database; the database is accessed through the GUI. The design information as well as other information required for relating to CAD data is also recorded in the database.

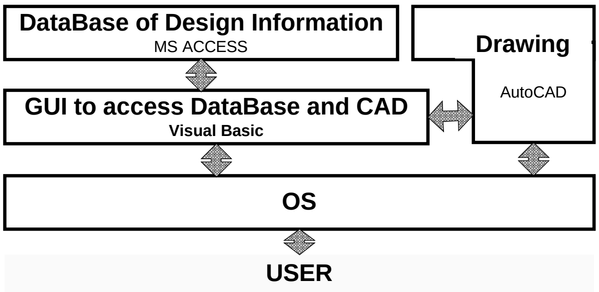

Figure 3 Construction of developed support system

Information regarding comments which provide design information, classification of contents, and connection to CAD graphic data is provided in the database. Design management information shown in Figure 2 such as designers' names and drawing number is recorded as an attribute. In order to define the relationships among accumulated pieces of design information, a model database is constructed using an entity relationship diagram (ERD) [6].

Figure 4 shows the structure of the database based on the ERD. An entity represents a single logical object that exists in the model. It encapsulates all of the attributes related to that object. Following this definition, first, entities to be used for the construction of a design information database are determined. Here, six entities shown in Figure 4 are used. The "design information" shows the entity in which information is actually recorded. Next, relationships between entities are defined. A relationship describes an association or dependency that exists between two entities. For example, when considering the relationship between drawings and design information comments, the relationship is 1: N since there are several design information comments in a drawing. An attribute is defined for each entity. Attributes hold specific information that describes an entity. The "comment number" is the attribute indicating the leader and balloon number shown in a drawing; "comment" is the attribute recording comments of design information.

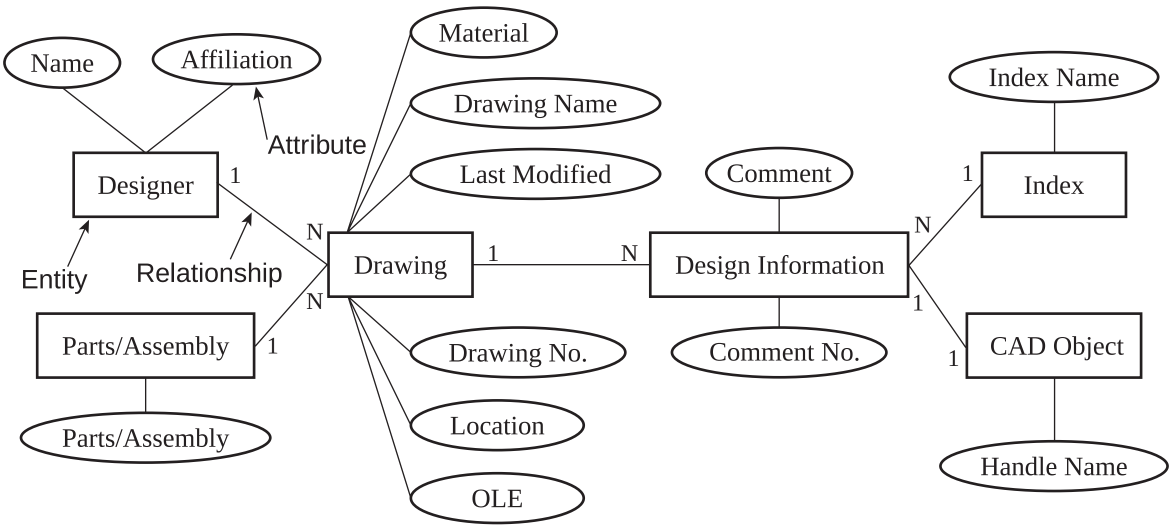

Figure 4 Construction of design information database based on ERD

3.2 Functions of prototype systems

We analyze requests for the system and realized the following three major functions in the system.

(1) Management of design information

This is a function of input of design information, as well as its addition, deletion and renewal, and at the same time it manages the relationship between drawing information and design information. Figure 5 shows a screen image of this GUI. At the time of entering new information, first, a drawing of the object is selected, and the design information is input into the empty text box. After entering the information, the graphic data in the drawing and design information are automatically correlated by clicking the graphic object on the drawing. Figure 5 shows the drawing to which design information is incorporated. When such a drawing is displayed on the CAD screen, graphic data related to design information are highlighted. A leader and balloon with the information number as shown in Figure 6 is also displayed indicating the presence of design information. By repeating this process, the user of this system can record several pieces of information on a drawing.

Figure 5　Example of screen image of developed GUI

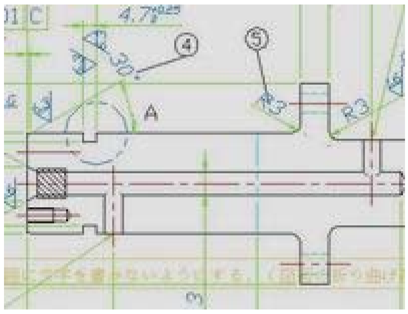

Figure 6　Indication of design information by leader and balloon

(2) Search of design information

The design support system contains a search function for entered design information. The following three methods are available with the system.

• Search of design information by keywords
Design information is searched by entering the keywords using a keyboard. It is the most basic utilization method.

• Search of design information by entering indicated comment number
This function is used in the case when designers wish to obtain design information related to certain graphic data. By entering the drawing number and the comment number given in a balloon, the desired design information is searched and displayed.

• Search of design information by indexes
This is a searching function from the indexes shown in Table 3. It is useful to obtain the same information distributed in different drawings. Design information is shown in a list, and the drawing number related to the information concerned is obtained.

(3) Printing function

This function is prepared to print the searched information in the form of a report.

4. Discussion of Performance

In order to objectively evaluate the proposed system, it is essential to experience entering and searching of design information while actually designing and drawing using this system. Here, to make the proposed search function operate effectively, design information must be accumulated prior to operation. To this end, it is first necessary to accumulate information using the system. This is a chicken-and-egg relationship. Under these circumstances, as the second best option, we decided to explain the functions while demonstrating the operation of the system to actual designers, then we asked how they evaluated the performance of the system.

We obtained good evaluations regarding the necessity and effect of the three functions above. The designers' comments are classified in the order of the numbers of similar opinions, and Table 4 summarizes them with the method of dealing within the system, the possibility of realizing requested functions, problems and difficulties. The method to locate design information has already been realized by this system, thus the addition of a new feature is unnecessary. Regarding other comments, when a feature is highly realizable, the realization method is indicated in the table. In contrast, when the realization of the feature is difficult, the reason is presented. For example, regarding the user's comment "A function to display certain information in the section where it is necessary should be added", we consider that this can be realized by adding the following function. First, the sections and needed information are classified as shown in Table 3, the section to which the information should be addressed is added to the design information; the necessary design information is displayed using the section name at the time of browsing the drawings.

Table 4 Comments on the prototype support system

Comments	Method of dealing within the system	Possibility, realization	Problems, difficulties
How to locate design information in drawing	Indication using leader and balloon Highlighting the related graphic objects		
Display certain information at the section where it should be necessary	N/A	The section and needed information are classified as shown in Table 3, and they are added to the design information	
Hard to enter design information	N/A	Difficult	No appropriate method of easy entering using keyboards. Presenting information already entered as entry candidate
How to extend to 3D-CAD system	N/A	Information is added to features instead of graphic data	

On the other hand, there is no appropriate method to ease the entering of design information using the currently available keyboard. It is possible to obtain information by scanning idea sketches and hand written memos and register them as image information. However, to search them through a database, it is necessary to register keywords together with the image information; this issue must be resolved. There are also many instances where similar information to that already entered must be entered. It may be possible to reduce the input workload by presenting information already entered as entry input candidates on the screen when the object for information recording is selected.

Even in design work using 3D-CAD, the record and reuse of the bases of the designer's thinking and decision making are important. Most 3D-CAD systems adopt a feature-based system in which the relationships among the assembly, parts and features are managed hierarchically. Accordingly, in 3D-CAD, it is desirable to add information to features instead of graphic data. Since a model can be easily rotated in 3D-CAD, the user friendliness of the system may be improved if the most easily recognizable direction is added in design information.

In the prototype system, the design information database is constructed using MS-Access, independent of the CAD, and operated using a GUI for programming reasons. However, if design information such as designers' bases of thinking and decision making are treated as part of CAD data, the loss of data can be prevented; thus it is desirable to contain design information on the CAD.

As mentioned in the Introduction, the support system developed in this study provides suggestions for the advancement of PDM. To utilize design information accumulated in the CAD system as a database, functions for information search and data management are required; these are to be included in PDM. To accomplish this, an interface which sends text data of design information from CAD to the PDM is required. CAD systems which include PDM functions have been introduced, and the exchange of information between CAD and PDM is expected to become easy. These will make it easy to construct the design support system discussed here.

5. Conclusions

The importance of the accumulation of design information and its reuse is widely recognized. Generalization of accumulated design information as design knowledge should be extremely useful not only for modifying design but also for new designing. In this study, we presented a method to increase the value of parts drawings and assembly drawings as design information sources assuming the use of CAD. The study is summarized as follows.

- To reuse drawings as design knowledge, it is necessary to record and be able to refer to bases of designers' thinking process and decision making. For this purpose, we analyzed designer's comments in parts drawings and recorded design information included on a relational database.
- We constructed a design support system which correlates design information and 2D-CAD data, and realized a function to manage design information through a user interface, a search function using keywords, and a printing function for search results. Furthermore, we discussed the improvement of this system performance.

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For more information please contact:

Katsumi Inoue, Graduate School of Engineering, Tohoku University, Aramaki-aoba 01, Sendai 980-8579, Japan
Tel: +81-22-217-6910, Fax: +81-22-217-6911, E-mail: inoue@elm.mech.tohoku.ac.jp