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INTEGRATION OF KNOWLEDGE ENGINEERING AND 3D PRINTING FOR DIGITAL DESIGN AND MANUFACTURING – A CASE STUDY

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ABSTRACT: Product design is more and more challenging and intellectual nowadays. To satisfy the dynamic customer requirements and improve manufacturing process, both Artificial Intelligence (AI) technique such as Knowledge-Based Systems (KBS) and product modeling technologies such as 3D printing (3DP) have attracted much research attention. Hence, it is rational to integrate KBS and 3DP for facilitating the design process. However, a design KBS often fails to generate graphical computer models of design prototype automatically after consultation sessions. Therefore, how to integrate a design KBS and a prototyping system remains as a research gap. To tackle this problem, a graphics generation method is proposed in this article. Through organizing alphanumeric outputs of the consultation session with a design KBS into parametric format, the consultation results can be directly used by Computer Aided Design (CAD) tools to generate graphical models which can be further exported into a 3DP system to produce physical objects. Based on a case study on wood head golf club design, it appears that the proposed method is promising in integrating a KBS and a 3DP system.

Keywords. Knowledge-based design system, 3D printing technology, Graphics generation

1. Introduction

Product design is a challenging intellectual process. The dynamic and global marketplace has increased the number and variety of requirements as well as competitiveness (Gadh, 1993). The manufacturers are forced to deliver their products within a limited lead time, at lower cost and higher quality. As such, effective utilization of AI technique such as Knowledge-based Systems (KBS) plays an important role, as a design KBS could generate design specifications directly according to customers' requirements based on design knowledge and expert experiences. In addition, various rapid prototyping (RP) technologies are emerging to assist in improving design manufacturability and reducing the lead time. As one of the innovative developments in RP technology, 3D printing (3DP) enables the rapid visualization of design ideas and provides the opportunities to simply test the manufacturability of design ideas (Rayna et al., 2014).

Based on the understanding of the roles KBS and 3DP play in product design, it arouses interests that it might be promising to integrate a design KBS and 3DP in order to achieve more satisfactory design results. However, there are still some challenges of connecting these two techniques, such as the alphanumeric outputs of a design KBS cannot be directly read and used by Computer Aided Design (CAD) tools to generate graphical computer models which are the prerequisite of 3DP. In this article, the issue of integrating a design KBS and 3DP is focused, and a graphics generation method is developed to overcome the problem mentioned. Furthermore, a study of wood head golf club design is performed to illustrate the proposed method.

2. Theoretical background

2.1 Knowledge-based design

Knowledge-based design is a computer based technique where the design procedures are captured as a set of algorithms and design rules. Artificial intelligence such as KBS may also be applied. A KBS tend to represent knowledge via two primary means: rules and frames (Miller, 1993). Rule-based systems are the most popular mode of knowledge representation, due to ease of understanding for both the developer and user; ease of modification; and widespread availability of rule-based KBS development packages and shells. Frames or object-oriented representations, on the other hand, provide a more efficient means of structuring complex knowledge. Generally, knowledge-based design has application in the embodiment, detail and manufacturing planning stage of product design. Oftentimes, it is used in adaptive design environments where the conceptual design is well defined and the design procedures are well understood (Miller, 1993). As well as speeding up repetitive design work, it is a valuable tool for incorporating manufacturing knowledge into the design process.

2.2 3DP for rapid manufacturing

Actually, 3DP is one approach of RP (Chua & Leong, 1997). In general, the prerequisite of RP is a solid model, created by CAD tools. The solid model is then converted to STL format. The RP machine with embedded software will retrieve the STL file and redefine the object as a number of slices, i.e. 2D surface with constant thickness. As a matter of fact, 3DP covers a number of closely related technologies, all of which produce a 3-dimensional physical object from a computer model by building it up in successive layers (Segerman, 2012). These technologies were developed primarily for use in RP for industrial design. Basically, 3DP adopts a computer model of prototype and converts it into physical object quickly. From the perspective of manufacturing, 3DP does not need large initial setup costs and largely reduces the lead time in contrast to conventional manufacturing processes.

Considering the integration of design KBS and 3DP, it appears that once an effective computer model of design prototype is attained based on consultation results with the design KBS, 3DP is able to convert the design model into physical object. However, for commonly used KBS, they do not provide a built-in CAD system or compatibility with other CAD software. If a graphical design model is desired, the designer will have to construct manually. Therefore, how to link the KBS with CAD software is still a problem. To bridge this gap, a graphics generation method is proposed in this article to create graphical models automatically based on design specifications obtained after a consultation session with a design KBS and, hence, to integrate the design KBS and 3DP system.

3. A graphics generation method for connecting KBS with 3D printing

3.1 The establishment of shared data

This study is conducted based on a rule-based KBS named GLOFES for wood head golf club design. The GOLFES was developed by Chen & Occeña (1995, 1999) and comprises 4 major functions. The function of *Initialization of a new design* is adapted in this work.

To link the KBS with CAD software, a “shared data” needs to be established. Firstly, the modification of rules will take place. Through rule modification, the parameters that will be output

as shared are: *loft angle*; *lie angle*; *clubhead height*; *vertical face roll*; *horizontal face bulge*; *face progression*; *club length*; and *sole radius* ($y = 4$ ways, $n = 2$ ways). The shared data are written in text form with a given file name and extension. As per CAD software's requirement, the format of text file is: Para_name = value or expression (number or y/n). To create the data file automatically, a built-in command Blackboard (BB_WR), which enables knowledge-based system to store small volume of data, is used. Data can be written with string or ASCII form. Based on the modification of rules and the help of BB_WR, shared data file can be created (Figure 1).

Figure 1. Comparison of Screen Output and Shared Data file “wood-1. dat”

3.2 The establishment of ProProgram

Having the shared data in text format, suitable CAD software should be identified. Most of the CAD software available in the market are inherited with programming capability, and these CAD software are able to perform the graphical construction with text input. Pro/Engineer is chosen as CAD software for this study. The reason is that no any form of professional training is required. Moreover, Pro/Engineer is prevalent in the market.

Secondly, all data should be reformatted so as to achieve direct correlation between specifications, attributes, dimension names and average values. Only then, it will be meaningful for the 3D model construction and ProProgram. The dimension name for each specification can be obtained from feature information of the graphical model. The table is created as shown in Table 1. With the information and known outline of the wood head golf club, the “basic model” of the wood head golf club can be constructed. Meanwhile, the programming of ProProgram for the wood head golf club can be constructed with the attributes, dimension names and values listed in Table 1. The data file (share data) contains attributes vs. values which was created earlier after running the *New Design Initialization* function of GOLFES (Refer to Section 3.1).

To generate a graphical model as specified in the data file, the pre-constructed basic model of the golf club shall be opened. Next, regenerate the model and the file names of the data files will be prompted to enter. Upon key in the data file name with extension, the desired configuration of the graphical model for the wood head golf club will be created.

4 Validation study on wood head golf club design

In this section, the system validation is effectively planned and verified. The purpose of validation is to ensure that all configurations of specification defined in the GOLFES are constructible. It ensures that the graphical model generates precisely as per specifications listed in the data files.

Actually, the total golf club configurations are more than one million. To validate these golf club configurations manually could be extremely time consuming. However, from a practical point of view, by running the combination of high, medium and low value of each specification is enough to reflect the reliability of the system. With reference from Table 2, the combination of specifications will be further reduced to $3^7 \times 2 = 4374$ configurations.

Table 1. Average value of golf club specifications

S/N	Specification	Unit	Attribute	Dim Name	Average Value
1	Loft Angle	°	loft	d553	16.7
2	Lie Angle	°	lie	d82	55.5
3	Vertical Face Roll	inch	v_roll	d556	12
4	Horizontal Face Bulge	inch	h_roll	d561	11.833
5	Face Progression	inch	fc_prog	d555	0.781
6	Clubhead height	inch	height	d2	1.465
7	Club length	inch	length	d638	41
8	Sole Radius-4way	inch	sole4	y/n	n

Table 2. Low, medium and high value of golf club specifications

Specification	Value		
	Low	Medium	High
loft	10	16.7	24
lie	53	55.5	58
v_roll	10	12	16
h_roll	8.5	11.83	15
length	39	41	43
fc_prog	0.625	0.75	1
height	1.181	1.457	1.772
sole4	y	n	

The procedures of performing the validation are as follows:

- (1) Identify and tabulate all configurations of the design, refer to Table 2, 4374 configurations of the golf club can be tabulated in Table 3.

Table 3. 4374 Configurations of wood head golf club

File Name Specification	0001.dat	0002.dat	0003.dat	0004.dat	0005.dat	0006.dat	...	4373.dat	4374.dat
loft	10	10	10	10	10	10	...	24	24
lie	53	53	53	53	53	53	...	58	58
v_roll	10	10	10	10	10	10	...	16	16
h_roll	8.5	8.5	8.5	8.5	8.5	8.5	...	15	15
length	39	39	39	39	39	39	...	43	43
fc_prog	0.625	0.625	0.625	0.625	0.625	0.625	...	1	1
height	1.181	1.181	1.457	1.457	1.772	1.772	...	1.772	1.772
sole4	y	n	y	n	y	n	...	y	n

- (2) Create and name the data files for all configurations. For example
loft=10; lie=53; v_roll=10; h_roll=8.5; length=39; fc_prog=0.625; height=1.457; sole4=yes

(3) Start up Pro/Engineer and open the basic model of wood head golf club (Figure 2). The modeling mode does not reflect the specification of the golf club. Therefore, the drafting mode should be initiated to precisely reveal the specification of the golf club (Figure 3). The value of the specifications shown in the drawing is referred to in Table 1.

(4) Regenerate the model and select “Read File”, the system will prompt for the data file name to be entered.

(5) Enter a data file name, e.g. 0003.dat. The basic model will be modified as specified in 0003.dat, see Figure 4.

Figure 2. Basic model of wood head golf club – Modeling mode

Figure 3. Basic model of wood head golf club – Drawing mode

(6) Open the drawing mode of the model, see Figures 5 and 6, the detail dimensions will be shown clearly. Verify the dimensions with the content of data file.

(7) Regenerate the modified model and key in another data file name for next validation.

Figure 4. 3D model 0003.dat

Figure 5. Detail drawing of 0003.dat – Page 1 of 2

Figure 6. Detail drawing of 0003.dat – Page 2 of 2

In step 5, upon entering the data file name, if the system does not respond with errors messages (e.g. regeneration failure or intersection not found etc.) and all dimensions shown in the detail drawing are tallied with the data file. The configuration of the golf club is successfully generated and validated. Creating of 4374 data files can be achieved by writing a simple C or BASIC programming. However, the verification of CAD models needs to perform manually.

Results show that the integration of GOLFES and CAD software is successfully achieved. The CAD system can effectively construct the desired golf head’s 3D modeling after the consultation session with GOLFES. Moreover, only minimal storage space is required (less than a megabyte)

for the graphical model. The time elapse to generate a new model of golf head is within tolerable limits using a normal personal computer.

5. Conclusions and discussion

To better satisfy dynamic customer requirements and visualize design ideas in physical objects, the integration of a design KBS and 3DP has attracted research interests. However, it is still a challenge to convert design results with a KBS into a graphical computer model which is the acceptable and necessary input file of 3DP. To overcome this problem, a graphics generation method is developed in this article. Through the establishment of shared data files and proper ProProgram, the design KBS is connected with CAD software, and a CAD model can be created automatically based on the consultation results with the KBS. Therefore, the connection between the KBS and 3DP is developed, and it is expected to improve customer-centric design and manufacturing process through integrating a design KBS and 3DP.

However, there are still some limitations of this work. For example, a wood head golf club can be considered a simple product with a small number of components. However, in real life situation, a product may comprise many components. It can come with multi-components, multi-features and multi-variations. As such, the design system for this type of product requires much more complicated analysis in the KBS and utilizes higher level of assembly technique in CAD system. In future research, it will be studied to further improve the proposed method.

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