Predicting the Separation Time of Semi-passive Mechanism in DLP Machine by CBR Method

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***Abstract*—In recent years, 3D printing technology has focused on the development of new materials and shortened manufacturing time. In the light curing process, the printing time of the surface projection molding technology called digital light processing (DLP) can be shorter than the point projection molding technology, and has better development. With the open-loop control system of bottom-up type of DLP machine, the user should set the rise time of printing platform in each layer according to the experience before the printing starts. Therefore, the user experience will determine the printing efficiency. This study proposes to use case-based reasoning (CBR) method to improve printing efficiency. The printing parameters of machine, the geometry of printing object and the separation time are all recorded in a case format. The printing parameters that affect the separation time become the characteristics of the index system. The most similar case is obtained from the case base through the similarity calculation, and rising time of the platform is obtained through the case correction rule. Finally, the effect of the inference system is confirmed by a case study.**

***Index Terms*—separation time, digital light processing, case-based reasoning, 3D printing**

I. Introduction

The machine of DLP is divided into two types: bottom-up and up-bottom [1]. The type of bottom-up is gradually increasing in the market because of its low material waste and faster printing speed. The influence of separation behavior is mainly reflected in the separation force and separation time. There is also a complicated relationship between the two factors [1], [2]. Now many research teams have proposed new ideas to improve separation behavior. Liravi *et al*. proposed using the concept of peeling to design a new mechanism to reduce the separation force [3]. Huang and Jiang used a highly elastic silicone material as the forming groove substrate, which reduces the vacuum problem caused by the molded object and the bottom surface of the vat [4]. Ye *et al*. [5] developed a mechanical model to represent the separation process and proposed a computationally efficient solution to estimate the required parameters. This model reliably predicts the separation force of the SLA process and improves the productivity and reliability of the process. Lin and Yang [6] developed a semi-passive mechanism that the effect of peeling and pressing is generated at the same time. This reduces the separation force between the molded object and the resin tank.

For DLP machines that use an open loop control system, the user must set the rise time of each layer of the printing platform based on experience. This rise time needs to make the separation process complete, so the amount of experience will determine the success or failure of printing and manufacturing efficiency. The above problem can be solved by recording the experimental data and obtain the best rise time of the platform by intelligent reasoning method. Cased-Based Reasoning (CBR) is one of the Artificial Intelligence (AI) methods. This method is a kind of analogical reasoning that simulates the thinking mode when human beings face new problems. Studies have shown that when scientists make inferences about unexpected discoveries, analogy is often an important element of thinking [7], [8]. In fact, the analogy not only occurs when science creates or solves problems [9], [10]. In daily life, people often associate new information with old knowledge and adapt relevant cognitive structures to obtain consistency of the overall knowledge structure [11].

In the above literature, the separation time is related to the mechanism and molding conditions. In this study, the semi-passive mechanism developed by Lin and Yang [6] as the basis for printing experiments, and Then the CBR method is introduced to improve manufacturing efficiency through the collection, recording, capture, correction, and storage of printing experience.

II. Material and Method

A. Experimental Planning

This experiment uses the machine of Titan 2 developed by Kudo, which is a bottom-up type [12]. The XY axis has a high resolution of 38 to 75 μm and the Z axis has a high resolution of 5 μm, as shown in Fig. 1. The resin tank used to hold the molding material is also a hard silicone type sold by Kudo. The printed material was selected from 3DM-ABS photosensitive resin sold by 3D-Materials SASU [13]. The separation mechanism of semi-passive is shown in Fig. 2 [6].

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The separation time between the printed object and the resin tank is calculated by the value collected from the load cell sensor. The data measurement system used in this study consisted of load cell (LC201) and signal conditioner (DMD4059) made by OMEGA [14] and data acquisition card (USB-6002) made by National Instruments [15]. Fig. 3 shows the sensor combined with the semi-passive mechanism.

Figure 1. The machine of Titan 2 [12].

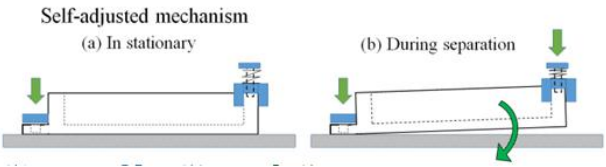


Figure 2. The semi-passive mechanism used in DLP [6].

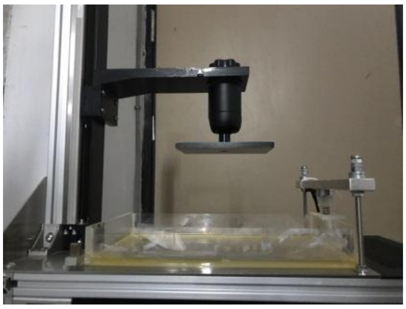


Figure 3. The semi-passive mechanism for measuring separation force.

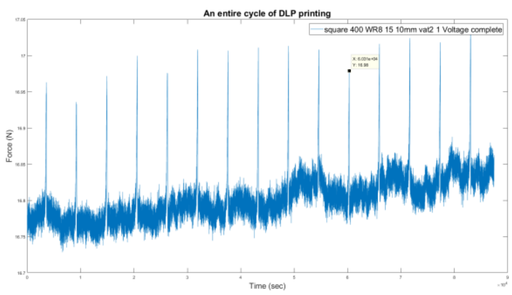


Figure 4. Separation force of complete printing cycles.

Fig. 4 is a square printed with a layer thickness of 0.05 mm, 15 printing cycles, and an area of 400 mm^2. The Other printing parameters are: the exposure time is 20 seconds, the delayed exposure time is 4 seconds, the rise height of the platform is 5mm, rise speed of the platform is 0.1mm/sec, and descent speed of the platform is 1.5mm/sec. Fig. 4 is the eighth printing cycle of Fig. 5, which can be used to estimate the separation time. According to such an experimental procedure, the printed results obtained by different experimental parameters can be accumulated to form a case library.

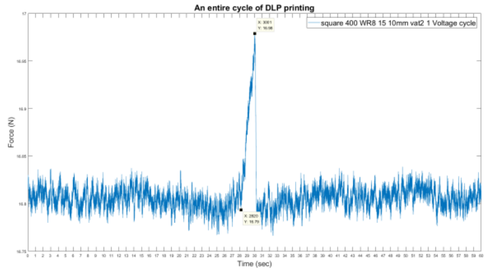


Figure 5. Separation force of the eighth printing cycle.

B. *Introduction of the CBR Method*

The concept of case-based reasoning is to modify the answers of previous old cases to help solve new problems. The core of this method is the case base and the case revises method. If there is a similar problem after comparing with the case library, apply the same solution. If not, find a feasible solution by revising the most similar case.

If the latest solution is feasible, it will be stored in the case library as a new case. Even if it is not feasible, those failed experiences or shortcomings will be stored in the case library as a reference case. If there are similar cases in the future, they will remember the lessons of the old failures to avoid repeating the same mistakes.

The process of case-based reasoning is shown in Fig. 6. This method consists of six steps, including knowledge representation, index system, case retrieve, case reuse, case revise and case retain. Among them, the four elements of case retrieve, case reuse, case revise and case retain are the most important. These four steps are also referred to as 4R [16].

1) *Knowledge Representation*

The knowledge representation is the case description of the case library. The description of the case has three parts, namely the problem description, the countermeasure and the result. The problem description needs to clearly explain the case status, the countermeasure is to explain the solution, and the result needs to explain the situation after the solution.

2) *Index system*

The indicator system is an important bridge between external information and case libraries. The characteristics of the search need to have appropriate attributes to identify and describe the problem. Therefore, it must has the functions of "predicting the results of external messages" and "connected cases are practical"

3) *Case retrieve*

This step is to find the most similar case from the case library as the source of the solution. The way is to sort all the cases in the case library by defining the problem features and using the calculation of the similarity formula. The case with the highest similarity will be selected as the source of the solution.

4) Case reuse

The step is to copy the solution of the case retrieved in the case library to solve the new case. In general, there is no way to capture the case directly in the new case. Therefore, it is necessary to judge and modify with user own experience or knowledge.

5) Case revise

Since the new case is not exactly the same as the old case, it is not appropriate to apply the information of the old case directly to the new case. Therefore, the differences between the old and new cases must be found first, and then modified to apply to the new case.

6) Case Retain

After case revising, if the result is effective, all the information will be saved in the form of a case in the case library. As the case library accumulates more and more cases, the ability of solving problems will increase.

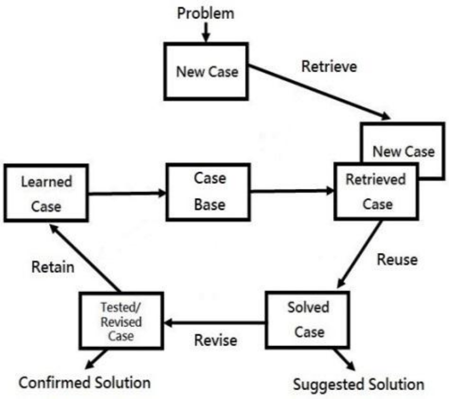


Figure 6. The framework of CBR [16].

III. Result and Discussion

A. Development Results of the CBR System

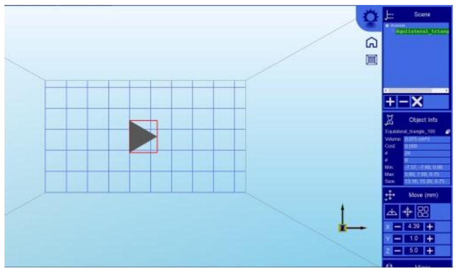
There are four description features of the relevant cases in the index system, namely the size of printing area, geometry of the printing object, spring elastic coefficient (k value) and the length of the spring after compression. From the cases collected so far, a set of codes can be given through the feature description, and the coding method is referred to Table I. For example, if there is a case with a printing area of 400 mm^2, geometric feature is isosceles right triangle, k value of the spring is 0.3, and a length after spring compression is 10, the obtained code is 2111.

TABLE I. The Coding of a Case

Indicator	feature	description
1	Printing area	1.100mm^2 2.400 mm^2 3.900 mm^2 4.1600 mm^2
2	geometry	1. Isosceles right triangle 2. square 3.Circle 4. Pentagon
3	k value of the spring	1. 0.3N/mm 2. 0.1 N/mm
4	the length after spring compression	1. 10mm 2. 7mm

The description of the case is to let the user know the detailed information of the printing. Therefore, in addition to the above four features, it also includes the printing layer thickness, the number of printing layers, the placement of the printed objects, the rise height of the platform, and the rise speed, descent speed and delayed exposure time. Table II is the detail information of case 7.

TABLE II. The Detail Information of Case 7

case number	7	print position	Standard
code number	2111	separation time	3.69
printing area	100 mm^2	layer thickness	0.05mm
geometry	Isosceles right triangle	number of print layers	8
k value of the spring	0.3	rise height of the Platform	5
the length after spring compression	10	ascent speed of the Platform	0.1mm/s
exposure time	20 sec	falling speed of the Platform	1.5mm/s
Graphic image			

The formula for calculating similarity is shown as Formula 1. The importance of each feature is set equal in this study (weightings are $w_1=w_2=w_3=w_4=w_5$) but users can also adjust the importance when needed.

$$\text{Total similarity} = \frac{\sum_{i=1}^{n} w_i \times \text{sim}_i(f_i^1, f_i^R)}{\sum_{i=1}^{n} w_i} \quad (1)$$

The way to judge each similarity value is, if $f_i^1 = f_i^R$ then $\text{sim}_i = 1$, else $\text{sim}_i = 0$. w_i is the weight of the i th index. i is the subscript for i th index. n is the number of indices. sim_i is the similarity of the i index between new case and previous case. f_i^1 is the value of index i of the new case. f_i^R is the value of index I of the retrieved case.

Basically, the most similar case taken from the case base by the index system would not 100% match. So some methods are needed to do the case correction. For example, the most similar case has a different printing area than the input. The correction of the case is to fine tune the separation time by adjusting the printing area. The equations calculated by the basic linear regression are currently used. Fig. 7 is an equation of "printing area-separation time" calculated from a square, a spring modulus of 0.3 (N/mm), and a length of 10 mm after compression. Therefore, when the number of indicator in the retrieval case is different from the input, it can be done according to the suggested correction method.

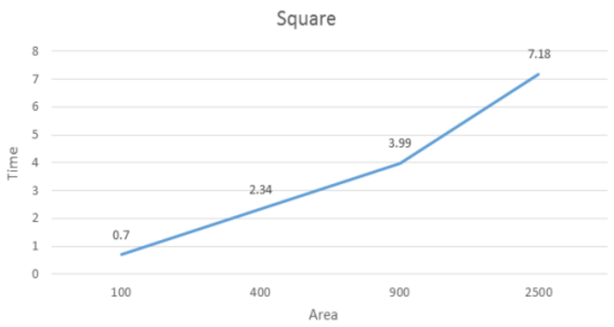
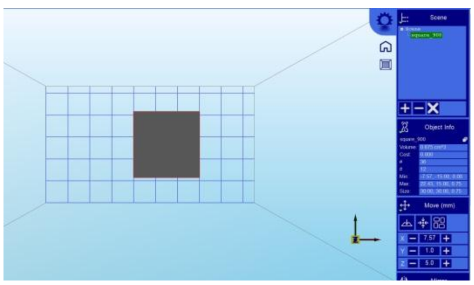


Figure 7. The Equation of "printing area-separation time"

B. *Reasoning Result of the Separation Time*

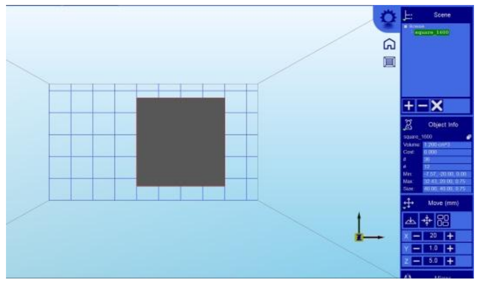
There is a printing requirement, the goal is to print the case is 1600mm^2, square, the spring elasticity coefficient is 0.3, and the length after spring compression is 10, the code obtained is “4211”. Through the similarity calculation, case 5 (Table III) is the most similar case form the case base. The code of it is “3211”. The similarity is 0.75 and the printing area of feature 1 is not consistent.

TABLE III. THE DETAIL INFORMATION OF A CASE

case number	5	print position	Standard
code number	3211	separation time	3.99
printing area	900 mm^2	layer thickness	0.05mm
geometry	square	number of print layers	8
k value of the spring	0.3	rise height of the Platform	5
the length after spring compression	10	ascent speed of the Platform	0.1mm/s
exposure time	20 sec	falling speed of the Platform	1.5mm/s
Graphic image			

Therefore the separation time cannot be directly applied. Through the case revising rule (Fig. 7), the separation time can be estimated to be 5.38 seconds. After the actual printing experiment, the separation time obtained from the data measurement was 5.89 seconds with an error of 9%. According to the rules of CBR, newly printed cases (Table IV) should be stored in the case library as needed for future reasoning.

TABLE IV. THE DETAIL INFORMATION OF NEW CASE

case number	50	print position	Standard
code number	4211	separation time	5.89
printing area	1600 mm^2	layer thickness	0.05mm
geometry	Isosceles right triangle	number of print layers	8
k value of the spring	0.3	rise height of the Platform	5
the length after spring compression	10	ascent speed of the Platform	0.1mm/s
exposure time	20 sec	falling speed of the Platform	1.5mm/s
Graphic image			

IV. CONCLUSION AND FUTURE WORK

The use of CBR to reason the separation time has achieved initial results. However, the effect of reasoning still has error rate. The case correction method can only be used on a single feature. How to adjust two or more features at the same time needs further discussion. The choice of the K value and compression length of the spring also needs to be increased.

In order to improve the effectiveness of this inference system, there is much work to be done. The first is to increase the number of cases, because the rich number of cases can improve the system to find the most appropriate retrieval case. The second is to consider adding more features in the index system, such as the shape of the graphic, the number of printing layer and the material type. These three features help to expand the application of the system. The third is to improve the case revising rules of the system. The more precise the correction rules can reflect the accurate prediction of the printing time. The better revising rule can predict a more accurate separation time.

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