Rapid manufacturing of dinnerware

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Abstract

Computer usage in the ceramic dinnerware industry has largely been confined to word processing, spreadsheets, database, payroll, inventory and statistical process control. CAD/CAM or Computer Aided Design and Computer Aided Manufacturing is slowly gaining ground in this industry. The relatively high speed of generating physical designs from conceptualization using CAD/CAM and Rapid Prototyping has suggested their use for the decoration of ceramic dinnerware. A CAD/CAM system developed for the design and manufacture of patterns to be decorated on ceramic dinnerware is described in this paper.

An industrial case study featuring ceramic dinnerware prototypes is carried out and presented to illustrate the various advantages. These advantages include significant time and cost savings. It also avoids the heavy reliance on traditional practices, and the experience and skills of craftsmen. The major contribution of the research is an innovative approach from art to part or, from conceptualization to realization, for the decoration of ceramic dinnerware. The solution of 3 Dimensional decoration and application of rapid prototyping are also described.

Keywords

Ceramic dinner, rapid prototyping, rapid manufacturing, CAD/CAM, craftsmen

1 INTRODUCTION

There are presently several commercially-available software systems for product design for a particular range of industries which include ceramic tableware (Chua, et. al., 1993), glassware, bottle making, both plastic and glass, jewelry (Lee, et.al., 1992), packaging, food processing, for molded products and products produced from forming rolls, coins and badges, and embossing rollers. All of these industries share a common problem: most of their products have elements of complex engraving or low relief on them. Traditionally, such work is carried out by skilled engravers either in-house, or more often by a third-party sub-contractor, working from 2D artwork. This process is costly, open to unwanted misinterpretation of the design by the engraver and most importantly, lengthens the time of the design cycle.

The CAD/CAM revolution has boosted the production and the performance of many industries everywhere for the past 15 years. However, its applications in the above industries are still at their infancy stage. Prototyping is still very much a manual process, which relies largely on the skills of an experienced craftsman who uses handtools such as a small chisel to carve and shape the model out of a plaster block. Little attention has been focused on the use of quick and accurate rapid prototyping equipment for building prototypes in this industry.

The use of CAD/CAM and Rapid Prototyping (RP) technologies such as Stereolithography Apparatus (SLA) and Laminated Object Manufacturing (LOM) reduces the time required for design modifications and improvement of prototypes. The steps involved in the art to part process are described in the following sections.

2 SCANNING OF ARTWORK

The function of scanning software is to automatically or semi-automatically create a 2D image from 2D artwork. It would normally be applied in cases where it would be too complicated and time consuming to model the part from a drawing using existing CAD techniques.

The 2D artwork is first read into ArtCAM, the CAD/CAM system used for the project, using a Sharp JX A4 scanner. Figure 1 shows the 2D artwork of a floral design, which has been generated using the circular adaptation, routinely. This combination of hardware and software allows for the direct production of a standard image from the artwork, which can be read directly into ArtCAM. The 2D artwork in such instances represents the designs to be used on the face of tableware item such as a dinner plate.

Figure 1 2D artwork.

In the ArtCAM environment, the scanned image is first reduced from a color image to a monochrome image with the fully automatic "Gary Scale" function. Alternatively, the number of colors in the image can be reduced using the "Reduce Color" function. A color palette is provided for color selection and the various areas of the images are colored either using different sizes/types of brushes or the automatic flood fills function.

3 GENERATION OF SURFACES

The shape of a dinnerware is modeled to the required dimensions in the CAD system for model building. A triangular mesh file is produced automatically from the 3D model. This is used as a base onto which the relief data is wrapped and later combined with the relief model to form the finished part.

4 GENERATION OF 3D DECORATION RELIEFS

The next stage in creating the 3D-decoration relief is to assign each color in the image a shape profile. There are various fields which control the shape profile of the selected colored region, namely, the overall general shape for the region, the curvatures of the profile (convex or concave), the maximum height, base height, angle and scale.

There are three possibilities for the overall general shape; a plane shape profile will appear completely flat, whereas a round shape profile will have a rounded cross section and lastly, the square shape profile will have straight angled sides. For each of these shapes, there is an option to define the profile as either convex or concave.

The square and round profiles can be given a maximum height. If the specified shape reaches this height, it will 'plateau' out at this height giving in effect a flat region with rounded or angled corners,

depending on whether a round or square shape was selected for the overall profile respectively.

The overall profile height which covers the respective region can be controlled by specifying the required angle of the profile which represents the tangent angle of the curve at the edge of the region. An alternative to control the overall profile height is to use the 'scale' function to flatten out or elevate the height of the shape profile. The relief detail can be examined in a dynamic Graphic Window within the ArtCAM environment itself. Figure 2 illustrates the 3D-decoration relief of an artwork.

Figure 2 3D-decoration relieves of an artwork.

5 WRAPPING OF RELIEFS ON SURFACES

The 3D-decoration relief is next wrapped onto the triangular mesh file generated from the tableware plate surfaces using the command Wrap. This is a true surface wrap and not a simple projection. The wrapped relief is also converted into triangular mesh. The triangular mesh files can be used to produce 3D model suitable for color shading and machining. The two sets of triangular mesh files, of the relief and the coin shape, are automatically combined. The resultant model file can be color-shaded (see figure 3) and used by the SLA to build the prototype.

Figure 3 Color-shaded resultant model file.

6 CONVERTING TRIANGULAR MESH FILES TO AN STL FILE

The STL format is originated by 3D System Inc. as the input format to the SLA, and has since been accepted as the *de facto* standard of input for Rapid Prototyping systems. Upon conversion to STL, the object's surfaces are triangulated, which means that the STL format essentially consists of a description of inter-joining triangles that enclose the object's volume. The triangular mesh files are also triangulated surfaces, however, of a slightly different format. Therefore, an interface program written in Turbo-C language is developed for the purpose of conversion. The converted triangular file adheres to the standard STL format. It has the capability of handling triangular files of huge memory size.

7 BUILDING OF MODEL BY RAPID PROTOTYPING METHODS

Many computer-aided manufacturing methods are available such as CNC machining and rapid prototyping (RP) methods. However, for complex 3D shapes, the CNC machining will be disadvantaged when compared to RP. Coupled with complex engineering relieves where a large amount of removal is required and yet the machining cutter diameter must be small to reach those small intricate relieves, rapid prototyping has a definite edge. Rapid prototyping, though, has the disadvantage of limited materials. If, however, given a restricted material type, the functions and applications - design, engineering and manufacturing (or tooling) - can still be carried out, then rapid prototyping would have proved its usefulness and relevance.

While many RP methods are available commercially (Chua, 1997), the world's top two selling RP machines are used in the study. They are the SLA (number 1) and LOM. The SLA has the advantages of being a pioneer and a proven technology with many excellent case studies available. It is also advantageous to use in tableware design as the material is translucent and thus, it allows designers to view the internal structure and details of tableware items like tea pot and gravy bowls. On the other hand, the use of LOM has also its own distinct advantages. Its material cost is much lower and because it does not need support in its process (unlike the SLA), it saves a lot of time in both pre-processing (deciding where and what supports to use) and postprocessing (removing the supports). The use of both systems allows the evaluation of both systems for ceramic tableware. The main criteria for evaluation are speed

(time for pre-processing, building and postprocessing), accuracy and surface finish, and suitability for tooling applications.

7.1 Using the SLA

Californian company 3D System Inc., pioneered the RP technology when they released their commercial RP system in December 1988 - the SLA-250 model of their Stereolithography Apparatus (SLA). Stereolithography technology was first developed by Chuck Hall, 3D's founding president, in 1982. Stereolithography works by using a low-power Helium-Cadmium laser or an Argon laser to scan the surface of a vat of liquid photopolymer which solidifies when struck by a laser beam. The dinner plate design with its floral relieves is built using the SLA and the resin model is shown in figure 4.

Figure 4 Dinner plate design built using the SLA.

7.2 Using the LOM

Helisys, Inc. was founded in 1985 with a charter to provide state-of-the-art, three-dimensional modeling capability to a wide range of industrial applications. Early R&D activities were financed in large part by DARPA grants, resulting in the development of the Laminated Object Manufacturing (LOM) process. Helisys introduced the LOM machines in 1991. The dinner plate design with its floral reliefs are built using the LOM and the paper model is shown in figure 5.

Figure 5 Dinner plate design built using the LOM.

8 EVALUATION OF THE SLA'S AND LOM'S MODELS AND PROCESSES

8.1 Technical evaluation

Technical evaluation is done through the execution of a benchmark test. The benchmark test piece, in this case the dinner plate, is analyzed through some tests including visual inspection and dimensional measurement. In general, two types of measurements can be taken namely, main (large) measurements and detailed (small) measurements.

The record of the measurement results is based on the deviations of the built part from the CAD model. These deviations of both the main and detailed measurements are tabulated for both the SLA and the LOM. The record of the time results is based on three components - data preparation, building time and postprocessing. The total time is based on the addition of the three components. A Table of all four times results can be tabulated for both the SLA and the LOM. The time component by itself gives one an idea of the length required for a task and directly affects the cost factor. Therefore, the time data can become useful for a full economic justification and cost analysis.

The measurements taken are linear dimensions - diameters, heights and thicknesses. Two parts of the test piece are considered for evaluation. The first part includes the plate's top and base surfaces. The second part is the delicate design of the floral patterns which includes the flowers, leaves and others. The results are sub-divided into main measurements (> 10 mm) and detailed measurements (≤ 10 mm). For both the readings, the deviations from the actual reading are computed and tabulated. The deviations for both the measurements are compared.

8.2 Results of technical evaluation

From visual inspection, it is apparent that the floral patterns of the LOM part are more distinct and correctly formed than those of the SLA part. Even under close examination, the flowers, leaves and stems on the SLA model are indistinguishable. As the focus of the research is on the 3D decoration, this means that the LOM model meets the requirements whereas the SLA model does not. Tables 1 and 2 list the measurements taken and their deviations from the nominal values. The Cs (diameters) and Ts (thicknesses) are taken with a vernier caliper and the Hs (heights) a height gauge.

The reason for taking two values each of the diameter, for example, C1 and C2 is for the purpose of establishing the circularity of

the plate. For the same reason, two values of the height H1 and H2 are taken as seen in Table 1. Similarly, in Table 2, several values of the plate thickness are taken off different parts of the plate. The results show that LOM displayed better accuracies or lower deviations as compared to the SLA for most of the main measurements and all of the detailed measurements. In particular, the T values for the LOM model are very consistent, unlike those of the SLA model.

Table 1 Main measurements (>10mm) of the 2 benchmark test pieces

Main Measurements						
Design Dimensions (mm)			Measurements (mm)		Deviations (mm)	
			SLA	LOM	SLA	LOM
Top Surface of Dinner Plate	C1	186	187.00	185.62	1.00	-0.38
	C2	186	186.78	185.72	0.78	0.38
	C3	130	129.65	129.28	-0.35	-0.72
	C4	130	129.63	129.01	-0.37	-0.99
	H1	27	27.58	27.05	0.58	0.05
	H2	27	27.62	26.95	0.62	-0.05
Base Surface of Dinner Plate	C5	82	82.32	82.29	0.32	0.29
	C6	82	82.56	82.31	0.56	0.31
	H3	18	18.69	18.56	0.69	0.56
	H4	18	19.06	18.71	1.06	0.71

Table 2 Detailed measurements (<10mm) of the 2 benchmark test pieces

Detailed Measurements						
Design Dimensions (mm)			Measurements (mm)		Deviations (mm)	
			SLA	LOM	SLA	LOM
Base Surface of Dinner Plate	T1	4.00	4.87	4.51	0.87	0.51
	T2	4.00	4.85	4.48	0.85	0.48
	T3	4.00	3.29	3.99	-0.71	-0.01
	T4	4.00	3.19	3.95	-0.81	-0.05
	H5	3.50	3.21	3.58	-0.29	0.08
	H6	3.50	3.28	3.59	-0.22	0.09
Floral Patterns on Plate	Flowers		Not	Dis-	NA	
	Leaves		distin-	tinctly		
	Stems		guish-	repro-		
	Others		able	duced		

8.3 Economical evaluation and other considerations

Besides technical evaluation, economical evaluation is also important. The cost of a machine or a part made by the machine is an important factor. Compared to SLA, the LOM is a much cheaper machine, at about US\$100,000 cheaper. In addition, the material cost of paper used by the LOM is cheaper than the photosensitive polymer used by SLA. In fact, amongst all commercial rapid prototyping systems, the LOM has probably the lowest material cost.

In terms of the speed of processing and building a part, it is typical to categorize into: Pre-processing, Building and Postprocessing times. Pre-processing time is the time taken to prepare, verify and correct the data file (usually an STL file), as well as the time taken to specify slicing and building parameters and setup the machine for building. Building time is strictly the time taken for the machine to build the part from beginning to end. Finally, postprocessing is taken to include all activities after building. For example, activities such as removal of excess resin, cleaning using solvent, removal of supports, posturing, etc., are required for the SLA model. For the LOM process, it means removing all the excess wood/paper which can be fairly tedious because care is needed not to damage the part.

Table 3 shows the results obtained from the building of the dinner plate model. In all categories, the LOM takes longer than the SLA. However, the difference is not very significant. Thus, though in terms of the labor cost, the SLA will cost less, the higher cost of the SLA and its photosensitive resin make it more economical to use the LOM. This is also confirmed by service bureau sources in Singapore and Germany, where the typical charge for a SLA model is 1½ - 2 times more costly than a LOM model for the same part.

Table 3 Results of processing times for the SLA and LOM models

Times	SLA	LOM
Pre-processing	0.5 hours	5 minutes
Building	15.5 hours	18 hours
Postprocessing	2 hours	4 hours
Total	18 hours	22 hours and 5 minutes

Other advantages associated with the LOM process includes the fact that it is clean and can operate in an office environment. Material used such as paper need not be shielded from sunlight and does not have an objection smell. Finally, supports are not required in the process,

making it less constrained in the decision process of orientating a part for building.

9 CONCLUSION

The research and development work carried out indicates that a tableware designer can use CAD/CAM for the decoration of tableware items by molded or incised decoration. Patterns are 3-dimensional (3D) and lie on the surface of a 3D-tableware item. Using commercial relief creation software, the 3D patterns are generated and mapped onto an already modeled tableware item such as dinner plate. Experiments using rapid prototyping (RP) technology have proven to be successful. Amongst the many RP methods, the SLA and LOM were used for the trials. From the results and based on technical and economical evaluation, the LOM was chosen for its better performance and affordability.

10 REFERENCES

- Chua, C.K., Hoheisel, W., Keller, G., and Werling, E. (1993) Adapting decorative patterns for ceramic tableware. *Computing and Control Engineering Journal* 4(5): 209-217.
- Lee H.B., Ko, M.S.H., Gay, R.K.L., Leong K.F. and Chua C.K. (1992) Using computer-based tools and technology to improve jewelry design and manufacturing. *International Journal of Computer Applications in Technology* 5(1): 72-80.
- Lee, Han Boon. (1993) Computer-aided and manufacturing for the jewelry industry. M.Eng. diss., Nanyang Technological University, Singapore.
- Chua, C.K. and Leong K.F. (1997) Rapid prototyping: Principles and applications in manufacturing *John Wiley*.

11 BIOGRAPHY

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