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SECOND PHOTOFORMING
SYSTEMS SYMPOSIUM

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SCIENCE & TECHNOLOGY
JAPAN

SECOND PHOTOFORMING SYSTEMS SYMPOSIUM

93FE0169 Tokyo MODELING TECHNOLOGY ASSOCIATION, PHOTOFORMING SYSTEMS RESEARCH COMMITTEE in Japanese May 92 pp i-61

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Second Photoforming Systems Symposium

93FE0169 Tokyo MODELING TECHNOLOGY ASSOCIATION, PHOTOFORMING SYSTEMS RESEARCH COMMITTEE in Japanese May 92 pp i-ii

[Text] **Second Photoforming Systems Symposium**

Time, Date: 15 May 1992 (Friday) 9:30 am-5:00 pm

Location: Osaka Prefectural Industrial Technology Research Institute
Kenshu Kaikan Kodo
2-1-53 Enokojima, Nishi-ku, Osaka 550
Telephone 06-443-1121

Sponsors: Modeling Technology Association, Photoforming Systems Research Committee

Participants: Society of Polymer Science, Precision Engineering Society, Sokeizai Center, Japan Metal Mold Engineering Society, Japan Wood Mold Engineering Society, Japan Society of Mechanical Engineers, Japan Society of Plastics Technology, Japan Society of Plastic Process Engineering, Plastic Molding Engineering Society

Second Photoforming Systems Symposium

Program

1. Manufacturer Information 9:30-10:45

   A. Touching on Soliform
      Teijin Seiki Co., Ltd. — K. Tsutsumi
   B. Cubitals
      President I. Pomerantz Tokyo University — T. Nakagawa
   C. Very Fine Solid Creation System
      Sony Corporation — H. Harimaya
   D. Integrating Medical Image System and Photoforming System
      NTT Data Communications — T. Shimizu
   E. Interface for COLAMM-300
      Mitsui Engineering & Shipbuilding Co., Ltd.. — K. Tsuboi

2. User Information 10:45-12:15

   A. Fabrication, Application of Prototype Models Using Photoforming System
      Fujitsu Ltd. — S. Nishiyama
   B. Photoforming System and Application Examples
      Nissan Motor Co, Ltd. — Y. Onoguchi

Afternoon Program

3. Research Information 1:15-3:15

   A. CAD/CAM System for Jewelry and Art Objects
      Industrial Technology Center, Yamanashi Prefecture — S. Hagijara
   B. Surface Condition of Photoformed Models
      Production Technology Research Center, Tokyo University — M. Imamura, Y. Meng, T. Nakagawa
   C. Casting Models and Applications
      Production Technology Research Center, Tokyo University — M. Imamura, Y. Meng, T. Nakagawa
   D. Making Human Organ Models—Model Fabrication With MRI
      Engineering Department, Hokkaido University — F. Tanaka, T. Kishinami
   E. Brain Structure Model Strategy Using MRI Data
      Engineering Department, Tokushima University — N. Niki, H. Nishitani, Y. Marutani

F. Oral Surgery Simulation Using 3D Model

Dental & Oral Surgery Lab, Saga Medical School — Y. Goto, T. Katsuki

Image Data Engineering Research Facility, Tokyo Institute of Technology — N. Oyama, S. Oishi, M. Mimura

4. Foreign Information 3:30–4:00

Trends in Photoforming Systems in United States—Report on 2nd International Conference on Rapid Phototyping—

Matsushita Electric Industrial Co., Ltd. — H. Ariyoshi

5. General Discussion 4:00–5:00

Moderator Tokyo University — T. Nakagawa

Touching on Soliform

93FE0169 Tokyo MODELING TECHNOLOGY ASSOCIATION, PHOTOFORMING SYSTEMS RESEARCH COMMITTEE in Japanese May 92 pp 1-3

[Article by Kenichi Tsutsumi, Solid Image Department, Teijin Seiki Co., Ltd.]

1. Introduction

It has already been five years since the first U.S. company 3D Systems came out with the AUTO FACT SLA-1 photoforming system in 1987. During this time, in addition to 3D Systems, the Mitsubishi Corporation group (C-MET), the Japan Synthetic Rubber, the Sony group, and Mitsui Engineering and Shipbuilding, developed and put products on the market in Japan. These systems are based on modeling data created by three-dimensional CAD, and make solid forms of the subject in a laminar mode using a UV laser and resin that hardens when exposed to ultraviolet light.

The systems now being marketed are similar in that they all use UV lasers and UV-curing resins, but nevertheless employ quite different methods of image-making and are operated differently. The market response to these systems is one of mild disappointment; higher-grade systems using better resins are wanted.

Teijin Seiki saw the future in photoforming technology as early as 1990 and has conducted commercial feasibility studies. At the Optomechatronics Show '92 which was held in March of this year in Japan, we announced our Solid Forming System, thus becoming the fifth Japanese company to enter this market. Our system is based on technology developed in the United States by DuPont, modified for production in Japan. In terms of performance and the moldings produced, however, our system is a second-generation system which surpasses the other systems.

2. History of Technology Procurement

As everyone knows, DuPont has years of experience in the UV-curing resin business, and is a world leader in this field. At first DuPont planned to develop its resin business in this field by tying up with another system maker. There was no system which was compatible with DuPont's resins, however, so the company decided to develop its own system. The first prototype was finished in 1989. Various improvements were made subsequently, and DuPont first began marketing the system within its own group. Currently there are eight of these systems operating in the United States, Germany, and Switzerland.

In 1990 Dupont decided to alter their original plan and get out of the business of manufacturing and marketing the system. The reason for this move is still not altogether clear, but DuPont contends that the division handling the system experienced an overall decline in performance, and the policy decision was made to halt most new business ventures. DuPont notified Teijin in December 1990, of its desire to sell its manufacturing and marketing rights to us, and the negotiations began in January 1991. Over the next several months we evaluated the system technology, the resins, and the patents, while developing a cooperative working structure with DuPont. It was finally decided that Teijin would handle the development and sales of the system, while DuPont handled the development, manufacture, and sales of the resins. In September 1991, Teijin purchased the rights to manufacture and market the system, together with the patent rights thereto.

The reason why Teijin decided to purchase this technology is based on our high regard for the fact that Dupont, which has such vast experience in developing and manufacturing resins, developed the system based on the critical technological element of their own resin.

In other words, in photoforming technology, resin plays an enormous role, and Teijin realized that one must have a system that matches the resin used.

3. Overview of Solid Forming System

(1) System Configuration

Teijin has given the name *Soliform* to its solid forming system. The system consists of a computer (EWS) which functions to control the entire system, a control unit which controls the various pieces of hardware, a laser device, a high-speed shutter, a scanner, a coater mechanism which forms the subject, and a tank for containing the resin. The specifications are as follows.

Computer	SUN SPARC STATION SERIES
Laser	Type: Argon ion laser Output: 500 mW Wavelength: 365 mm Special features: Power tracking feature
High-speed shutter	AO modulator (Audio Engineering modulating unit) 3-axis translator
Scanner	X-Y digital scanner mirror type using high-precision motor encoder Laser encoder resolution: 1.28 million pulses
Coater mechanism	Table elevator: Ball screw type, 25.4 mm/sec Elevation Stroke: 310 m/s Resin supplying dipper: Pipe type Movement speed: 30 mm/sec Two scrapers to smooth surface of resin liquid, one in front, one in back
Tank	SUS 400(W) × 450(L) × 380(H) Capacity: 72 liters
System size	2665(L) × 1145(W) × 2240(H) mm

(2) Software

As the computer which operates the overall system, Soliform uses the Sun Sparc Station. OSF/MOTIF is used as the operating software, so operations can be done easily with a mouse. This feature sets Soliform apart from other system.

Three-perspective views of the object to be modeled can be displayed on the Sun screen, and it is possible to determine the layout, set the thickness of each layer, and set various other parameters.

The screen displays can be done in color, which is attractive and easy on the eye, and thus beneficial to the operator.

Software Specifications
1. UNIX-based X-windows system 2. User interface using OSF/MOTIF 3. CAD 1F is STL (binary or ASCII) format 4. Model shape display feature 5. Real-time slice processing feature 6. Slice simulation feature 7. Layer thickness settable to any value

(3) Making Moldings (Models, Parts)

This system is equipped with an exposure control feature (patented) which quantitatively controls the light exposure from the laser energy. As a result, the outlines of the molding are very precise. For this reason, a unidirectional scanning technique is adopted.

The system performs high-speed scanning at the amazing speed of 15,000 mm/sec. This is more than ten times faster than the scanning speeds of other systems. The system is thus a second-generation system which drastically shortens the time required to form the moldings. At present, the size of the molding is limited to a maximum of 300 mm^3. We plan to expand this limitation to 500 mm^3 by this fall. The system has a dimensional precision of 20 $\mu m/cm$ in the X, Y, and Z directions. Another feature is that it is highly shock-resistant.

(4) Resins

For this system, Teijin imports and markets two types of resin. SOMOS 2100 produces moldings which are milk white, elastic, and easily cutable with a cutter or other blade. These features are ideal for a wide range of applications including medical simulation models. However, in order to enhance the strength of the molding after it is formed it must be heat treated (150°C for 15 minutes).

SOMOS 3100 produces moldings which are transparent and tough. They can be machined or tapped. This resin features high efficiency at molding time, and requires no post-processing. After the molding has been made, it need merely be placed in a window and exposed to sunlight to completely remove the sticky feeling from the surface. Compared to conventional resins this resin is odorless and can be used in an office environment. Also, whereas conventional resins are too hard and susceptible to shock, this is a vastly improved resin which suffers no damage even when dropped on the floor. This tells us something about the superiority of DuPont resins. The resin specifications are:

Property	SOMOS 2100	SOMOS 3100
1. Viscosity (CPS)	5,300	1,500
2. Density	1.16	1.13
3. Strength (after curing)	D41	D80
4. Tensile strength (kg/mm^2)	0.73	2.2
5. Impact strength (kg•cm/cm)	16	1.6
6. Volume shrinkage (%)	1.5	2.1

(5) Future Potential

There are now some 50 of these systems in use in Japan. Considering the size and level of Japan's manufacturing industry, we believe that this is a very low proliferation rate in view of the 200 or so units now in use in the United States and another 80 or so in Europe. There may be any number of reasons for this, but our analysis suggests the following ones.

- The level of quality (precision, surface roughness, strength) of the subjects modeled by existing systems is poor, so it is only used in areas where there is little demand for dimensional precision.
- Three-dimensional CAD is now as well rooted in industry as is thought, and there is little software which is equipped with the 1F STL format for this system.
- The existing resins are poorer in mechanical properties than ordinary plastic material such as ABS and polypropylene and cannot be used as real parts.

It is also a fact, however, that the potential demand for this system is gradually growing. As computers become more advanced, and become increasingly attractive in terms of both performance and cost, more and more companies are introducing them in more and more areas. In order to meet the needs of diversifying markets, it is evident that the computer offers the most effective means of supporting both development and production. As more and more computers are introduced, naturally there arises the desire or need to modify conventional production approaches. The fabrication of models and prototype parts in the development and prototyping stages are areas that are most difficult to do with computer support, and at present are done mainly by manual machining operations. This photoforming system is particularly interesting as a new way to resolve this problem. In view of these background considerations, we understand that the 50 systems now being used were introduced as test platforms. As a result, some companies are finding that they can use the system, while others are finding that they still are not ready for it. In view of the speed of economic and environmental changes and technological innovation, however, we can foresee that the trend toward computerization will become stronger and wider. Thus we believe that the environment necessary for using our system is steadily being fostered. When this view is taken, we may also say that the proliferation of this photoforming system depends much on how we system manufacturers conduct our business. If the marketplace is demanding a system which gets a mark of 80, then the present system we suppose gets at best a mark of about 50. The remaining 30 points must be made up by developments and improvements made jointly by the CAD software vendor, system manufacturer, and resin manufacturer. Once this is done, we think that the market demand for this photoforming system will really take off.

Very Fine Solid Creation System SCS-1000HD

93FE0169 Tokyo MODELING TECHNOLOGY ASSOCIATION, PHOTOFORMING SYSTEMS RESEARCH COMMITTEE in Japanese May 92 pp 4-7

[Article by Hiroshi Harimaya, Sony Corporation]

1. Introduction

In the manufacturing industry, user demand for products is diversifying, making it increasingly imperative to produce many models in small lots with shorter turnaround times. Thus it is becoming increasingly important to shorten product development lead times. The Solid Creation System (SCS) is a system for responding to these needs in design and prototyping areas by fabricating solid plastic models directly from three-dimensional CAD data. The system was developed jointly by Sony Corporation and Japan Synthetic Rubber Co., Ltd. (now called D-MEC) and went on sale in April 1989.

The very fine solid creation system SCS-1000HD introduced here is a prestigious system which was developed to improve precision and enable finer delineation.

2. Operating Principle

Photoforming is a technique whereby an ultraviolet laser beam is focused on a photosensitive material (UV-curing resin), under the control of a computer, and the said material is hardened in layers, building up these layers one upon another until a solid form is produced. This technique is similar to preparing a three-dimensional relief map with contour lines in that it integrates planar (sectional) data to create a solid form. Accordingly, almost any structure (including hollow structures and moebius strips) can be fabricated. Not only should this facilitate greater design freedom, but can also be expected to contribute greatly to speeding up product development and improving quality. The operating principle is diagrammed in Figure 1.

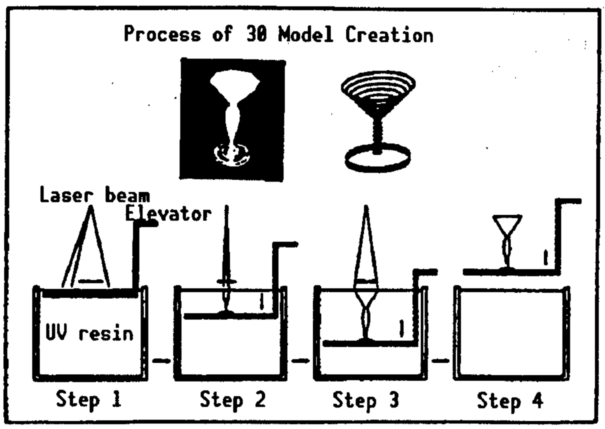


Figure 1. Operating Principle Diagram

Based on the input data, the UV laser scans the surface of resin in a tank, describing a sectional shape. The portion of the resin acted on by the laser beam hardens from liquid to solid, so that the first section is formed on an elevator. Next the elevator is dropped by the height of one layer, and the second layer is formed just as the first one was. By repeating this process, the sections are formed sequentially, from first to last. The elevator is finally raised, post-processing is performed, and the three-dimensional model is complete.

3. Very Fine SCS Features

The SCS hardware is called "solid creator," and is made up of a controller which includes an engineering workstation (EWS), a mechanism system, and an optical system.

3.1 Development Objectives

In developing the very fine solid creation system, we decided to implement fine precision to facilitate applications in recent "machine masters," to make it possible to mold such fine forms as rings (worn on fingers), and to make the system desk size to facilitate "desktop manufacturing," a wave of the future. These objectives are summarized below.

(1) Achieving Desk Size

1,380(W) × 850(D) × 1,590(H)

(2) Achieving High Degree of Fineness

(i) Laser delineation precision

□ 300 mm ±0.04 mm (with infield correction)

(ii) Adoption of variable field size mechanism

(3) Making It Compatible With Office Environment

(i) He-Cd laser/Ar laser selectable

(ii) Making it very safe with interlocking capability

3.2 Hardware Features

The hardware features implemented in the interest of fineness are listed below.

(1) High-Output He-Cd Laser

The laser used can be selected from among a 500-mW Ar laser and a 45-mW He-Cd laser to suit the application. Users who have 200V three-phase power and water for cooling the laser available can use the Ar laser, which is capable of high-speed laser delineation. Users who wish to place the unit in an office environment may select the He-Cd laser which is air-cooled and requires only 100V single-phase power. We adopted here the isotope-type high-output 45-mW He-Cd laser for very fine work.

(2) Acoustic Optical Modulator (AOM)

An AOM capable of high-speed switching is adopted, which does suffer the possible shortcoming of poor diffraction efficiency. We were able to improve the diffraction efficiency by about 15% (over the conventional type). This means a relative improvement in laser power of 15%, which makes even higher speeds possible.

(3) High-Precision Scanner

In this modification we have adopted a new scanner which contributes more than anything to improved precision. The unit precision is improved (compared to previously) about five times. The performance of the new scanner is noted in Table 1.

Table 1. Scanner Performance Comparison

	New	Conventional
Position precision (mrad)	0.4	2.0
Duplication precision (mrad) 1 minute 24 hours	 ±0.012 ±0.2	 ±0.12 ±1.5

(4) Adoption of Variable Field Size Mechanism

We have adopted a mechanism which makes the focal length variable. By making the focal length variable, the system can now be used where very fine delineation is required, such as in rings. This latest SCS-1000HD is variable between 150 × 150 mm and 300 × 300 mm.

(5) Adoption of High-Precision Squeegee

By adopting a new squeegee, the system can now layer in 10-μm units, a level of performance not previously possible. Although it will take more time, we believe that layering in 1-μm units is possible. This will facilitate ring (jewelry) and denture applications.

(6) Automatic Power Control (APC)

In order to achieve a high degree of fineness, we have made it possible to vary the diameter of the laser beam during molding. To facilitate this added feature, we have incorporated the ability to automatically control the laser power so as to keep the energy density constant at the liquid surface. This has made it possible to make moldings which have no warps or flaws. Thus the user can be expected to have improved dimensional precision.

3.3 Software Features

The SCS software is diagrammed in Figure 2. The double-line boxes indicate new functions.

The new features and functions are described below.

(1) CAD Interface

One feature of the SCS (as diagrammed in Figure 3) is the ability to handle diverse types of data. With the new features, the system can now handle NURBS curved surfaces, ruled surfaces, and cylindrical surfaces.

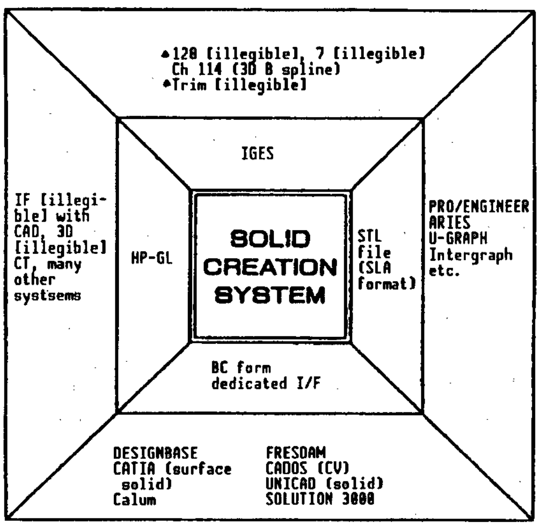


Figure 3. SCS Data Interface

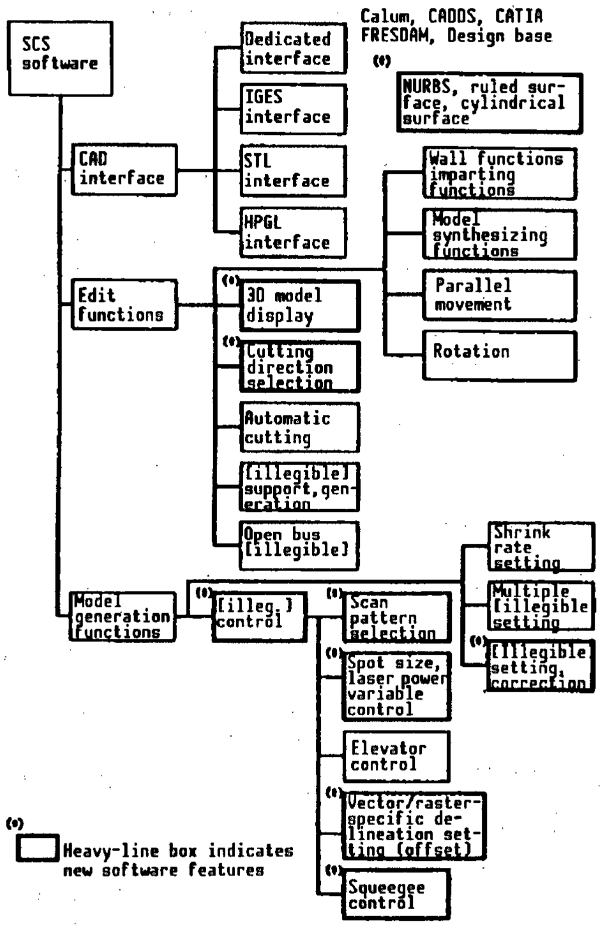


Figure 2. Software Diagram

(2) EDIT Functions

In addition to the usual EDIT functions, it is now possible to display the model in three-dimensions before subjecting the CAD data to automatic power cutting, so that the cutting direction can be visually instructed. The support generating functions have also been upgraded, adding functions to detect the portions needing support, to automatically generate lattices, and to provide pedestal support from the stage surface to the model shape. Significant improvements have been made to speed up operations with automatic cutting and automatic wall-thickness impartation, so that process times can be shortened.

(3) Model Generating Functions

In order to make it possible to generate high-precision models, we implemented layer-by-layer control so that the fabrication parameters can be set independently for each layer. In addition to the usual fabrication parameters,

we have added scan pattern selection, beam diameter and laser power controls, and vector/raster-specific delineation settings.

3.4 New SCS Resins

The resins used with SCS is the Desolite SCR Series. This is a urethane-acrylate UV-curing resin which has been used to coat optical fibers. The reaction site in urethane acrylate is the acryl radical. Since the urethane bond is inside the molecule, great variation in physical properties is possible, from hard, tough substances to elastic substances. The sensitivity is high and the reaction speed is fast, thus permitting the laser scanning speed to be fast also.

In Table 2 [not reproduced (illegible)] are listed the physical properties of the new resins and other resins now on the market.

4. Application Examples

The samples produced with SCS are used for 1) design mock-ups, 2) functional models (models put together to check functions), and 3) process/machining masters, etc. The examples published to date are listed in Table 3.

Table 3. SCS Application Examples

Example	Application
1) Toyota Motor Corp	In engine development, models made with SCS are used to good advantage in determining design specifications, stress analysis (an example in which the results of stress analysis with the model agreed well with the results of aluminum parts analysis), and air flow [illegible] analysis.
2) Sanyo Electric Co	With the procurement of the SCS system, the time needed to obtain working models was cut to one fourth what it was previously. Effectiveness of three-dimensional CAD implementation has been demonstrated.
3) Sumitomo Rubber Indus	Procured SCS for tire tread design. Tread design is now more efficient.
4) Keio University	Using the cranial CT scanner data, skull frameworks are made with SCS, presurgical simulation is performed, and difficult cranial operations are done successfully.

At Sony, the system has been used more and more in the upstream design and prototyping stages, and there are many examples which cannot be announced yet because the product has not yet reached that level of perfection, but there is the recent example of using the system to create a functional model for a color TV deflection yoke. Suitable in-house examples may be announced soon.

5. Future Tasks

We can categorize the tasks for the future into those concerning 1) equipment (hardware, software), 2) resins, and 3) molding technology. We cannot possibly list all the particulars. The main items are noted below.

(1) Equipment

- Discrimination with key devices
- M/M interface with good operability

(2) Resins

- Variation equivalent to that in engineering plastics

(3) Molding Technology

- Analysis of basic curing behavior
- New scanning algorithms

Photoforming is a new technology which has just come on the scene. We think its range of applications will continue to broaden in the future. We wish to increase the pace of R&D now and shorten design and prototyping times.

References

1. A. Kobayashi, *The Second International Conference on Rapid Prototyping*, 23-26 June, pp 334-341.

2. M. Horiuchi, *et al.*, *AACE* (10-12 July 1991) pp 63-64.

3. T. Nikado: *Kasutairingu 82*, May 1991, pp 109-120.

4. M. Kobayashi, *et al.*, Dai-34 kai nippon keisei geka gakkai sokai gaku-jutsu shukai, No. 25, 22-24 May 1991.

Interface for COLAMM-300

93FE0169 Tokyo MODELING TECHNOLOGY ASSOCIATION, PHOTOFORMING SYSTEMS RESEARCH COMMITTEE in Japanese May 92 pp 8-12

[Article by Keiichi Tsuboi, Mitsui Engineering and Shipbuilding Co., Ltd.]

1. Introduction

Photoforming systems are being viewed with great interest in industrial design and prototyping areas as society needs diversify.

In this field, complex shapes are designed using three-dimensional computer aided design (CAD). The shapes drawn by three-dimensional CAD are nothing more than two-dimensional images, however, and cannot be directly grasped by the designer.

It is hoped that photoforming systems which create three-dimensional models directly from CAD data will shed much light on the problems faced by designers and prototypes.

Photoforming systems create solid shapes by building up thin horizontal slice layers from CAD data. A standard format has been provided for three-dimensional CAD for reading data in with photoforming systems.

Meanwhile, CT and magnetic resonance imaging (MRI) diagnostic systems are being used in the medical field.

In this article we introduce a CAD interface and an interface for fabricating organ and cranial models from CT data.

2. Photoforming System 'COLAMM-300'

At Mitsui Engineering and Shipbuilding (ME&S), we manufacture and market a photoforming system based on UV curing which we call the COLAMM-300.

In Table 1 we list the main specifications for the COLAMM-300.

Table 1. COLAMM Specifications

Name	Specification
Laser	He-Cd laser 325 nm
Scanning speed	Max 300 mm/sec
Work size	0.3 m × 0.3 m × 0.3 m
Layer thickness settings	0.1 mm~0.5 mm
Laser beam [diameter]	0.5 mm
Resin tank capacity	Normal 5 ℓ, Maximum 14 ℓ
Main resin component	Acrylate-based
Standard EWS	SUN SPARC
System dimensions (mm)	1450 × 700 × 1600
Power consumption	AC 100V 30A or less

The system is made up of an ultraviolet light generating unit, a laser scanning unit, an elevator unit, a resin tank and control unit, and the host computer.

The main features provided in COLAMM are as follows.

(1) Liquid surface settings can be done in a short time with the restricted liquid surface mode.
(2) Small size ideal for the office
(3) Modestly priced system
(4) Allows anybody to fabricate design models easily
(5) Easy maintenance
(6) Ample work size of 300mm × 300mm × 300mm
(7) Good interface compatibility

COLAMM interfaces with input data that include CAD data, CT data, and three-dimensional measurement data. We now describe the CAD and CT data interfaces.

3. CAD Interface

Shape data designed with three-dimensional CAD are converted to a standard STL (or SLA) for mat for photoforming and then output.

The STL format expresses three-dimensional solid models as completely covered with triangular polygons. An example is given in Figure 2.

The model data files are in ASCII code. The syntax rules are as follows.

(1) File type: '.STL'

(2) Word restrictions: Nine reserved words

solid, endsolid, facet, endfacet, loop, endloop, normal, vertex, outer

(3) Model name:

14 bytes or less (a-z, A-Z, 0-9)

(4) Coordinate data (X, Y, Z)

[-] d.dddddde±dd' format

Table 2. STL File Syntax Rules

```
solid model name
  facet normal (X no) (Y no) (Z no)
    outer loop
      vertex (X) (Y) (Z)
      vertex (X) (Y) (Z)
      vertex (X) (Y) (Z)
    endloop
  endfacet
  facet normal (X) (Y) (Z)
    outer loop
      vertex (X) (Y) (Z)
      vertex (X) (Y) (Z)
      vertex (X) (Y) (Z)
    endloop
  endfacet
          :

        repeat

          :

          :
endsolid model name
```

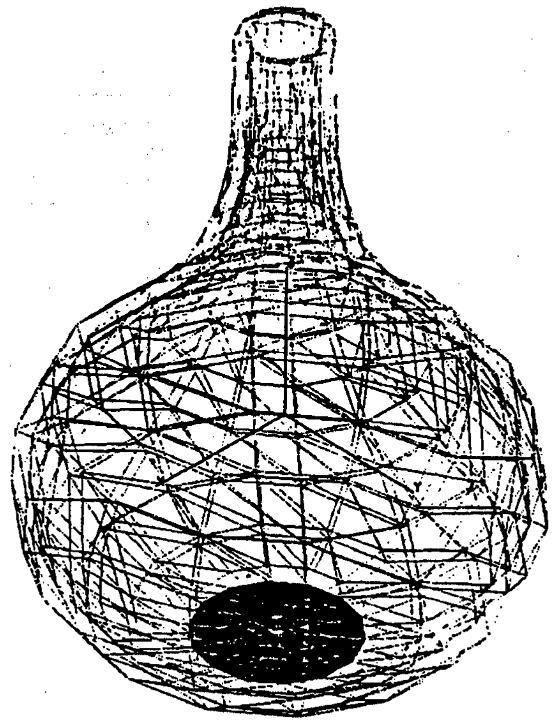
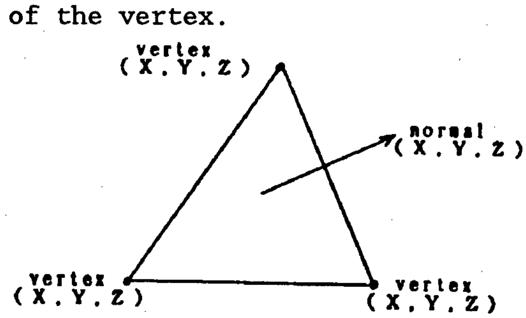


Figure 2. Example of STL Format Representation

The syntax rules are indicated in Table 2. Each covering triangle is represented between a *facet* and an *end facet*, *normal* represents a triangle normal vector, and (X_{no}, Y_{no}, Z_{no}) represents normal vector components. The size of the normal vector is "1."

The word "vertex" denotes a vertex of the triangle, and (X, Y, Z) the coordinate values of the vertex.



The model data also must satisfy the following conditions.

(1) Each vertex of the triangle(s) must be different.

(2) The vertexes of the triangle(s) must not all be on the same straight line.

(3) For any given side of a triangle, there can only exist one other triangle having a side of the same length.

(4) Normal vectors are unit vectors which point outside the solid model.

4. CT Interface

Photoforming systems are beginning to be used in the field of medicine as well as in industrial design.

CT and MRI image diagnostic systems are used widely in medicine, and a large number of medical images are produced by these systems.

Medical images are two-dimensional sectional image data. Computer processing can now turn these data into three-dimensional solid images.

Solid images cannot be taken directly in hand for evaluation purposes. Hence the use of photoforming systems to create solid models from medical image data is very significant in that it allows technicians to simulate surgical operations right at the treatment site.

CT data that were produced by professor Y. Goto of the Dental & Oral Surgery Laboratory at Saga Medical School were image-processed by Professor N. Oyama of the Image Engineering Research Facility at Tokyo Institute of Technology. Using these results, we used COLAMM to fabricate skull models.

These models were made full size with a Z pitch of 0.2 mm. The process for making the photoformed models from the CT data is diagrammed in Figure 3.

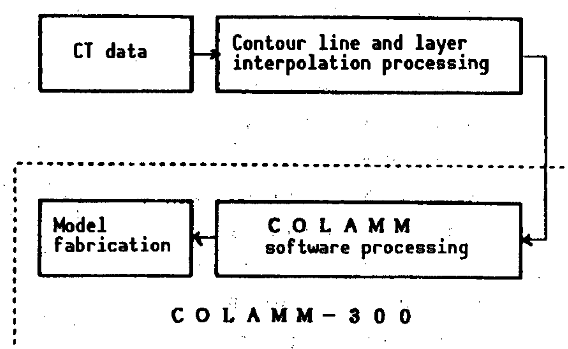


Figure 3. Fabrication of Models From CT Data

Because raw CT data are captured in 2mm intervals, and contain noise, they are not suitable for photoforming as they are.

For this reason, these data are subjected to contour-line processing and layer interpolation processing at Oyama's laboratory. It is then possible to fabricate models from these data.

The COLAMM CT data processing software handles the contour-line data as the input model. In Figure 4 is given an example of contour-line data representation.

Table 3. CT File Syntax Rules

```
model model name
  z_pitch   Z value
  layer
    polygon
   start point X , Y, normal X , Y,
    next point X , Y, normal X , Y,
          . . . . . . . . . .
     normal X , Y, end point X , Y
    endpolygon
    polygon
   start point X , Y, normal X , Y,
    next point X , Y, normal X , Y,
          . . . . . . . . . .
     normal X , Y, end point X , Y
    endpolygon
             :
             :
          repeat
  endlayer
  layer
    polygon
   start point X , Y, normal X , Y,
    next point X , Y, normal X , Y,
          . . . . . . . . . .
     normal X , Y, end point X , Y
    endpolygon
    polygon
   start point X , Y, normal X , Y,
    next point X , Y, normal X , Y,
          . . . . . . . . . .
     normal X , Y, end point X , Y
    endpolygon
             :
             :
          repeat
  endlayer
             :
          repeat

endmodel model name
```

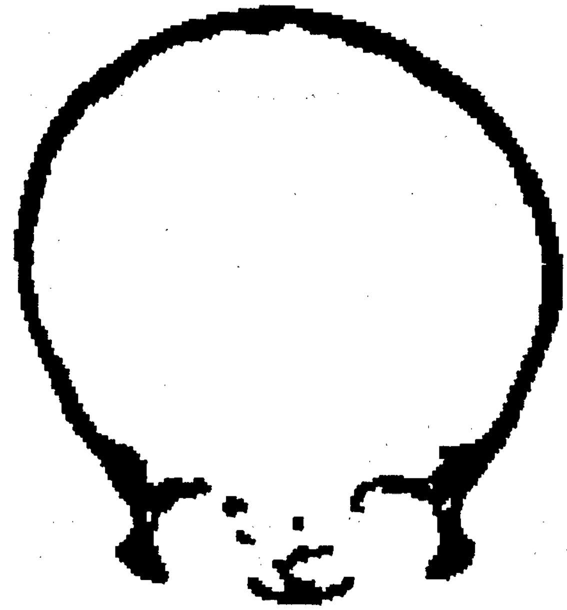


Figure 4. Contour Line Display for Skull Model

Closed polygons are assumed, and the contour lines are built up to fabricate a solid model.

The CT input data file consists of ASCII code. COLAMM converts this ASCII file to a binary file.

In Table 3 are indicated the syntax rules for CT input data files.

The syntax rules are as follows.

(1) File type: '.ctl'

(2) Word restrictions: Six [sic] reserved words
model, endmodel, layer, endlayer, polygon, endpolygon, z_pitch

(3) Model name:

14 bytes or less (a–z, A–Z, 0–9)

(4) Numerical data (X, Y, Z)

[–] d.d dddde±dd' format

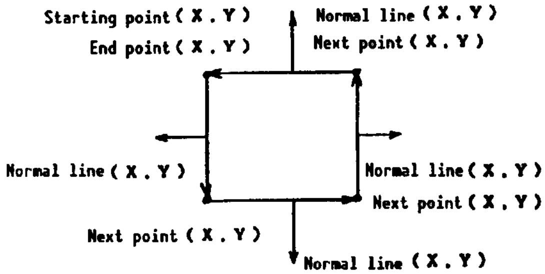


Figure 5. Model Coordinate System

Also, the model data must satisfy the following conditions.

(1) The Z values are in decreasing numerical order.
(2) No polygon intersects itself.
(3) The polygons in one layer do not intersect each other.
(4) Normal vectors are unit vectors which point outside the solid model.
(5) The model coordinate system is a righthanded system.
(6) The model dimensions do not exceed the work size.

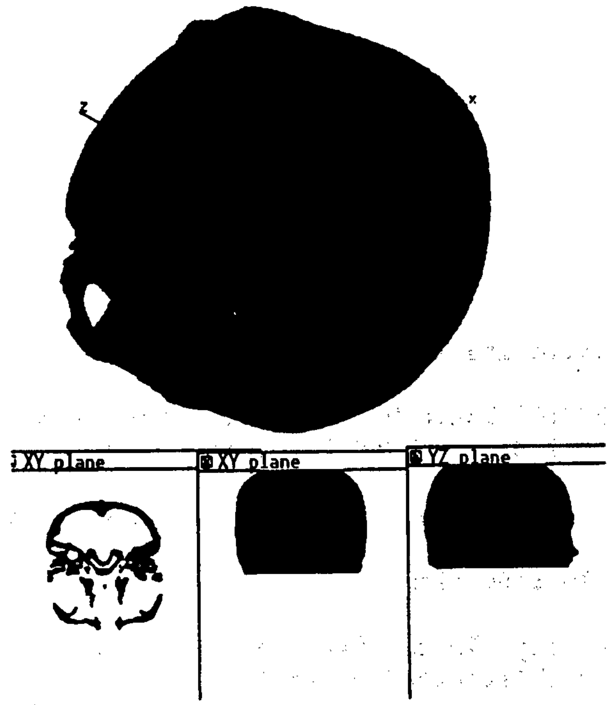


Figure 6. Skull Model Fabrication Condition

In COLAMM, the degree to which model fabrication has progressed can be learned from the host computer's display monitor. In Figure 6 the fabrication state of a skull model is depicted.

5. Concluding Remarks

We can be sure that three-dimensional CAD will be increasingly used in the field of industrial design. There is a trend toward three-dimensional CAD systems featuring a photoforming output interface as standard equipment. The software should also be available for wider use of photoforming systems.

In the medical field, meanwhile, there are a number of developments which suggest wider use of COLAMM in medicine. One of these developments is wider use of the on-line Picture Archiving and Communications System (PACS) designed for patient record systems and medical image filing systems.

Another is the proliferation of the off-line Image Save and Carry (ISAC) system which stores large volumes of image information on portable media such as optical disks. Yet another is the growth of surgical operation simulation using computers.

References

1. Y. Maruyama, *Hikari Zokeiho*, Nikkan Kogyo Shimbunsha, 1990, p 83.
2. *Nikkei Mekanikaru*, 16 March 1992.
3. Plastics, *Nippon Purasuchikku Kogyo Renmeishi*, March 1992.

Integrating Medical Image System, Photoforming System

93FE0169 Tokyo MODELING TECHNOLOGY ASSOCIATION, PHOTOFORMING SYSTEMS RESEARCH COMMITTEE in Japanese May 92 pp 13-15

[Article by Takashi Shimizu, NTT Data Communications]

1. Introduction

Recently, in the field of advanced clinical medicine, wide use is being made of sophisticated medical equipment which can output reconfigured images from the multilayer images made by X-ray CT scanners and MRI equipment.

Meanwhile, as wonderful advances are made in computer graphics technology, such technology is being applied enthusiastically in medical fields, and higher levels of medical diagnostic support is now possible.

Even more recently we have seen the development of interesting model fabrication systems (such as the SOUP system) which utilize the new technology of photoforming. Applications of this new technology in medical fields have been publicized, and there is every indication that such applications will soon be practicable. As to subject matter, most of these applications involve full-scale models of diseased bones or organs.

The MEIPR system is a medical diagnostic support integrating system which uses these technologies and features consistent operation.

2. System Concepts

The MEIPR system is an integrated medical diagnostic support system which takes the data from such image output devices as CT scanners or MRI equipment and does everything from centrally displaying the images to performing simulations and full-scale model fabrications.

In Figure 1 are diagrammed the application system function concepts.

3. MEIPR System Configuration

The MEIPR system is basically configured with the following two sets of features or functions (Figure 2).

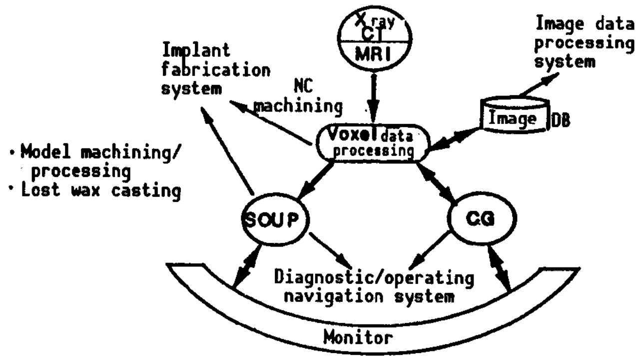


Figure 1. System Concept Diagram

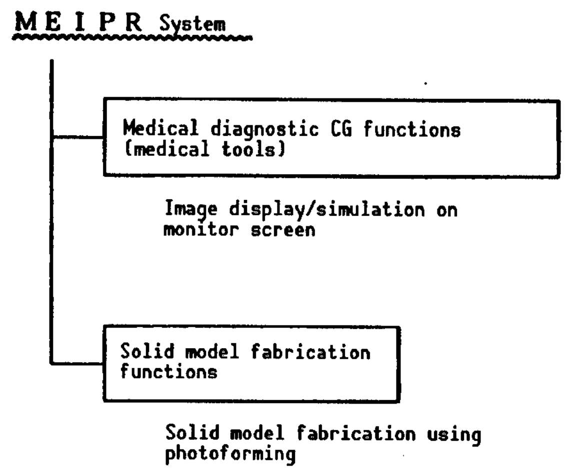


Figure 2. MEIPR System Features

(1) Image Synthesis

This feature has functions for performing three-dimensional positioning and synthesis for CT scanner and MRI image data. By using these functions, the bone data from a CT scanner and the skin or brain data from MRI can be synthesized and used in integrated diagnostics and treatment.

(2) Diseased Area Display

This is a feature for displaying diseased areas on the monitor screen. The displayed data can be rotated, enlarged, or reduced, and any desired location can be seen from any direction.

It is also possible to modify the display method. For example, the skin can be made translucent by altering the transmissivity at the desired location. It is also possible to show the positional relationship between bone and skin three-dimensionally.

(3) Surgical Simulation

Surgical operations can be simulated on the monitor (display).

For example, one can measure the volume of a tumor or brain, or the distance between the diseased tissue and various locations. Pre-operative checks are can also be done.

Three-dimensional cut & paste functions are also provided. A section of a bone can be cut out and moved around, for example.

(4) Solid Model Fabrication

By integrating a three-dimensional solid model fabrication system which uses photoforming, the operator can create solid models of things that it is difficult to see clearly on the monitor or things which have been modified with feature (3) above. Using such models, it is possible to simulate surgical operations while holding a solid model in one's hands. These models can also be made the basis of fabricating custom implants. In all these ways, a finer degree of support is provided to the diagnostician.

4. MEIPR System Process Summary

The MEIPR system processes are summarized in the diagram below (Figure 3).

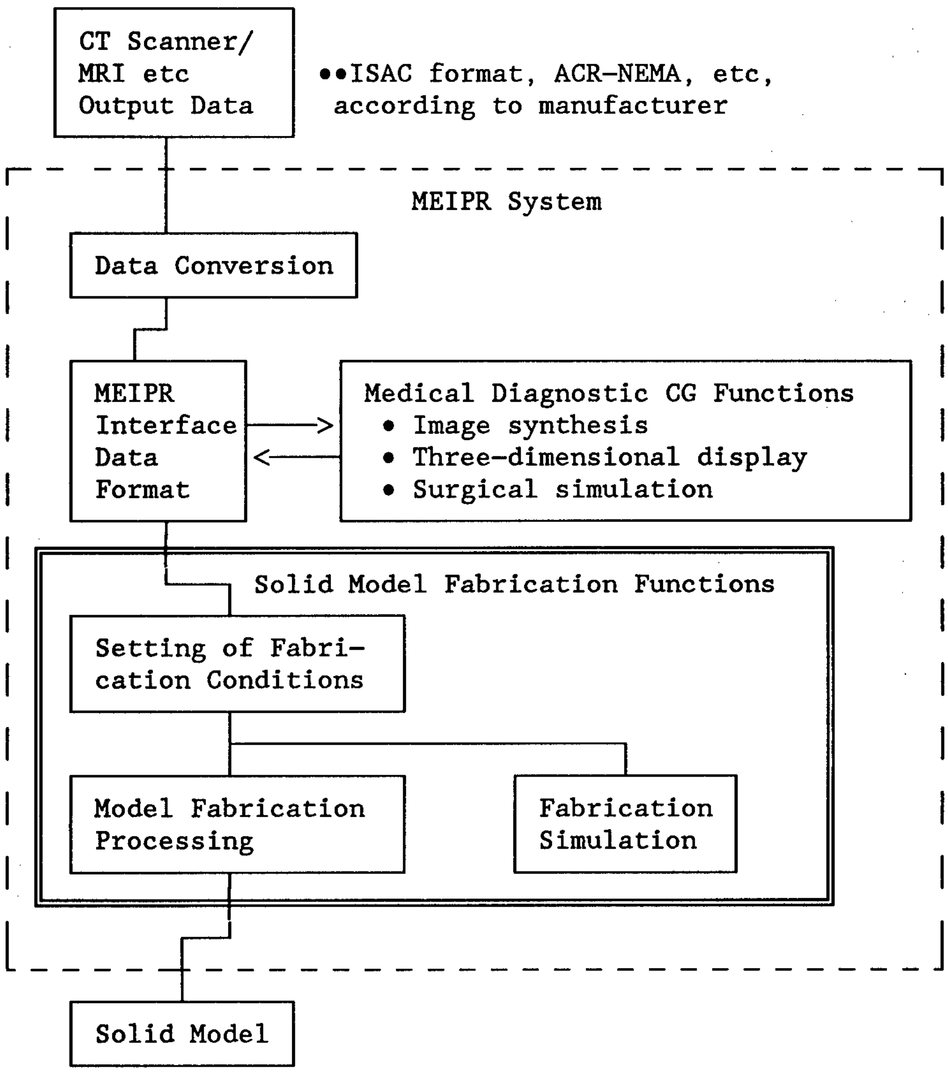


Figure 3. MEIPR System Processes

5. Solid Model Applications

The following applications are possible for solid models fabricated with the MEIPR system from CT scanner or MRI output data.

(1) Education
(2) Presentations to patients (pre-, post-operative)
(3) Surgical operation simulation
(4) Master models for fabrication of custom implants

The configuration of some of these applications are diagrammed in Figure 4.

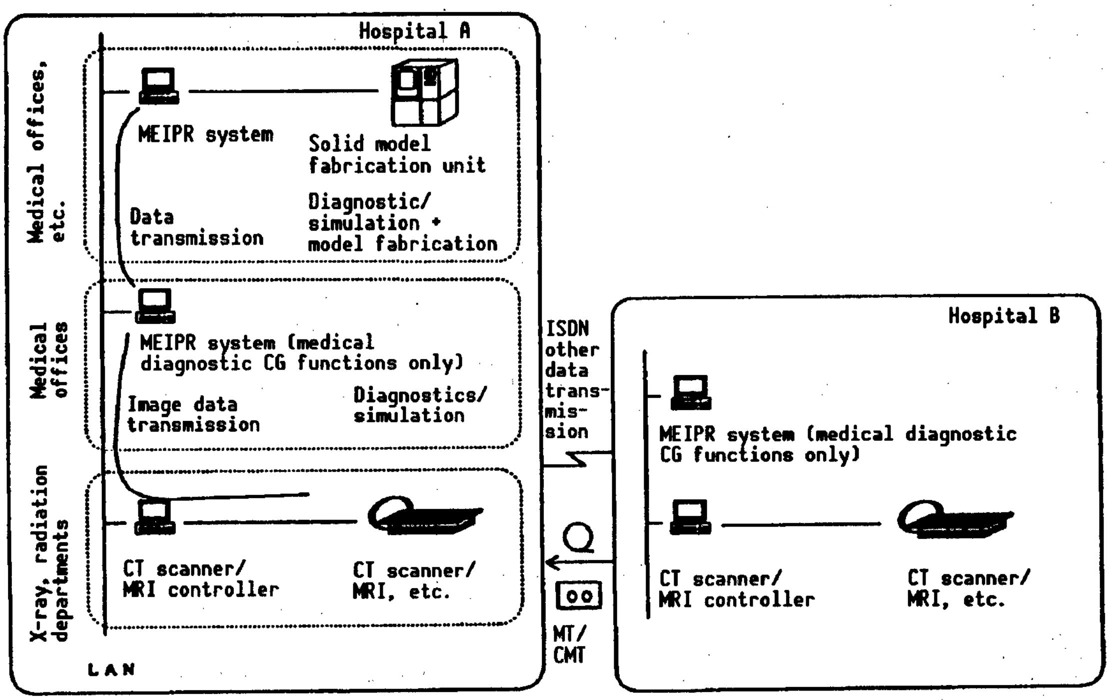


Figure 4. MEIPR System Application Configurations

6. Concluding Remarks

The MEIPR system is an integrated system which features consistent operating procedures and is capable of providing computer-graphics (CG)-based diagnostics, surgical simulation, surgical plan drafting based on solid models, and master models for custom implants, all using CT scanner or MRI image data.

This system makes it possible to enhance pre-operative simulations which until now have been done on a CG screen, allowing the CG screen data to be compared with a solid model.

When the system is used to produce a master model for fabricating a custom implant, the time required to make the implant is shortened. Hence the system provides comprehensive support for clinical therapy.

Fabrication, Application of Prototype Models Using Photoforming System

93FE0169 Tokyo MODELING TECHNOLOGY ASSOCIATION, PHOTOFORMING SYSTEMS RESEARCH COMMITTEE in Japanese May 92 pp 16-20

[Article by Shusaku Nishiyama, Fujitsu Ltd.]

1. Introduction

Word processors, personal computers, and other data processing equipment is now being used in the home, and we now see in these products some of the same trends observed in conventional electric appliances, namely product diversification and shorter life cycles. Thus it is important for a manufacturer to offer products with better features and designs, and to develop such products faster, in order to maintain product superiority.

Against this background, survey and developmental work is being done on technology for fabricating prototype models quickly to enhance the efficiency of product development efforts in design departments. In October, 1989, Fujitsu procured the photoforming system SOUP. This system represents new technology for achieving short-turnaround fabrication of prototype models.

The system requires no special technology or skills to operate. It can make models directly from three-dimensional CAD design data of objects which cannot be represented on a flat drawing, including freely curving surfaces. In other words, in the artistic design stage, this system fabricates models for use in design studies (called "design models").

In the fine design stage, moreover, the system produces models for studying and enhancing actual structures (called "engineering models"). In general, models fabricated on a photoforming system are brittle and fragile, making it difficult to repeatedly use them in system mock-up and disassembly. There are usually a wide variety of tests and evaluations which must be made, necessitating several dozen models. For this reason, Fujitsu has adopted a vacuum injection molding method for model duplication, and uses photoforming to create the master model.

2. Photoforming System Configuration

In Figure 1 we diagram the configuration of the photoforming system used at Fujitsu. The three-dimensional CAD system used is the Pro/ENGINEER system made by the U.S. company Parametric Technology Corp. The photoforming system is SOUP, manufactured by Shimetto.

In selecting this photoforming system, we gave priority to the following considerations.

(1) The photoforming system should be able to use product design data without intermediate modification.

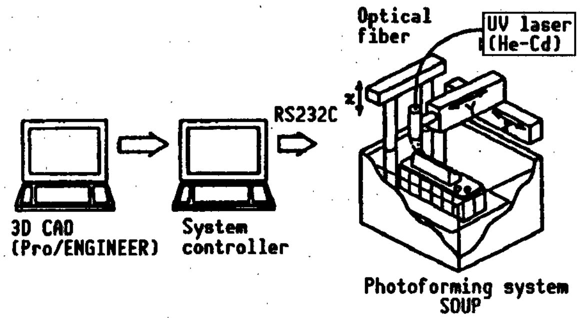


Figure 1. Photomodeling System Configuration

(2) Setting the processing conditions in the photoforming system should be simple.

(3) Processing precision should be high.

3. Photoforming System Problems, Corrective Measures

3.1 Re Model Production Direction

One of the problems which results in poor quality in the models fabricated by a photoforming system are the step patterns which develop in the surface. In design models, in particular, where there is a need to evaluate sensibly the outer appearance and texture, step patterns in the model surface are undesirable and require finishing processing.

The step patterns result, of course, from the basic processing principle used in photoforming, and are unavoidable. However, the width of the step patterns can be decreased and the patterns can be made less conspicuous by altering the orientation and angle of the object during fabrication. The following two points are important in this regard.

(1) When outer appearance is important, the model should be oriented so that step patterns are not produced on the most important surfaces.

(2) When both interior and exterior are important, the model should be oriented so as to simplify the finishing process.

The orientation and angle of the model during fabrication are determined in light of these considerations. When the angle with the horizontal exceeds 60°, for example, the step patterns in inclined or curved surfaces become less conspicuous, and finishing is simplified (Figure 2(a)). When modeling covers and other boxed shaped objects, if the inner surfaces facing upward when fabricated, there will be less interior portion requiring finishing, and that finishing will be relatively simple (Figure 2(b)).

3.2 Re Processing Conditions

The basic processing conditions in photoforming are laser beam intensity, scanning speed, and temperature of photosensitive resin. In setting the laser output level, scanning speed, and laser spot diameter, respectively, the relationships of these to the photosensitive resin's curing behavior needs to be ascertained, and the use to which the model will be put needs to be considered.

Almost all of the photoforming systems which use photosensitive resins employ either an argon or a helium-cadmium ultraviolet laser generator. These UV lasers have small output power and are unstable. For this reason, laser power has fluctuated during processing, resulting in indifferent model quality. Recently, however, progress has been made in rendering laser output more powerful and stable, making it possible to fabricate models of higher quality.

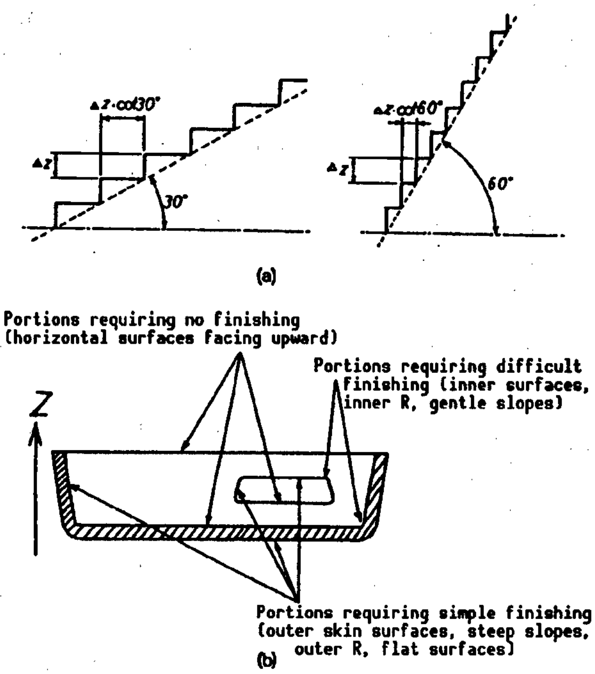


Figure 2. Orientation, Angle of Model

The higher the temperature of the photosensitive resin, the faster it will cure, resulting in better adhesive properties with the lower layers and adjacent portions. When the temperature of the resin is low, curing is inadequate, the resin becomes soft, adhesion to the lower layers and adjacent portions fails, and the model may fail to materialize.

The coefficient of thermal expansion in liquid-form photosensitive resins is large, moreover, so the height of the liquid surface will vary considerably with fluctuations in room temperature. This variation in liquid surface height causes the curing radius to vary, and results in process precision deterioration.

In order to overcome these problems, the photosensitive resin must be kept at a sufficiently high temperature so that the curing reaction and deterioration do not occur. Drafts or other air flows can cause the liquid surface temperature to become uneven, resulting in waves, so the forming must be done with the photoforming equipment stopped. The processing is also performed with the liquid resin constantly in an overflowing condition so that the liquid surface height remains constant.

3.3 Re Support Production Methods

In photoforming, the method used to produce supports to hold up overhanging portions of the model is an important element in improving the quality of the model shape.

With the photoforming system procured by Fujitsu, it is not necessary to add support shapes with CAD data. By entering the support width and inter-support pitch when setting the process conditions lattice-shaped supports are automatically generated.

When supports are produced close to the sides of the model, however, the following two problems are encountered.

(1) The supports can adhere to the sides of the model because the distance between model and support is not taken into consideration.

(2) When the angle subtended by the model side and the support is small, the mark left when the support is removed is large.

This results in a deterioration in model forming precision and makes finishing difficult.

In the first system, supports were only produced inside a small rectangle surrounding the model, sometimes making a process necessary to broaden the area of support production, depending on the orientation and angle of the model during fabrication.

In order to prevent the supports from adhering to the sides of the model, we utilized the positional relationship between the lattice-shaped support intersections and the model, and came up with an idea for a method which had features for deciding whether or not to produce supports close to the model.

This method consisted of 1) determining the area of support production, and 2) a portion for deciding on support production at each layer.

(1) Determining Area of Support Production

In Figure 3 is diagrammed the method of determining the area of support production. With this method, the shape of the area of support production is determined

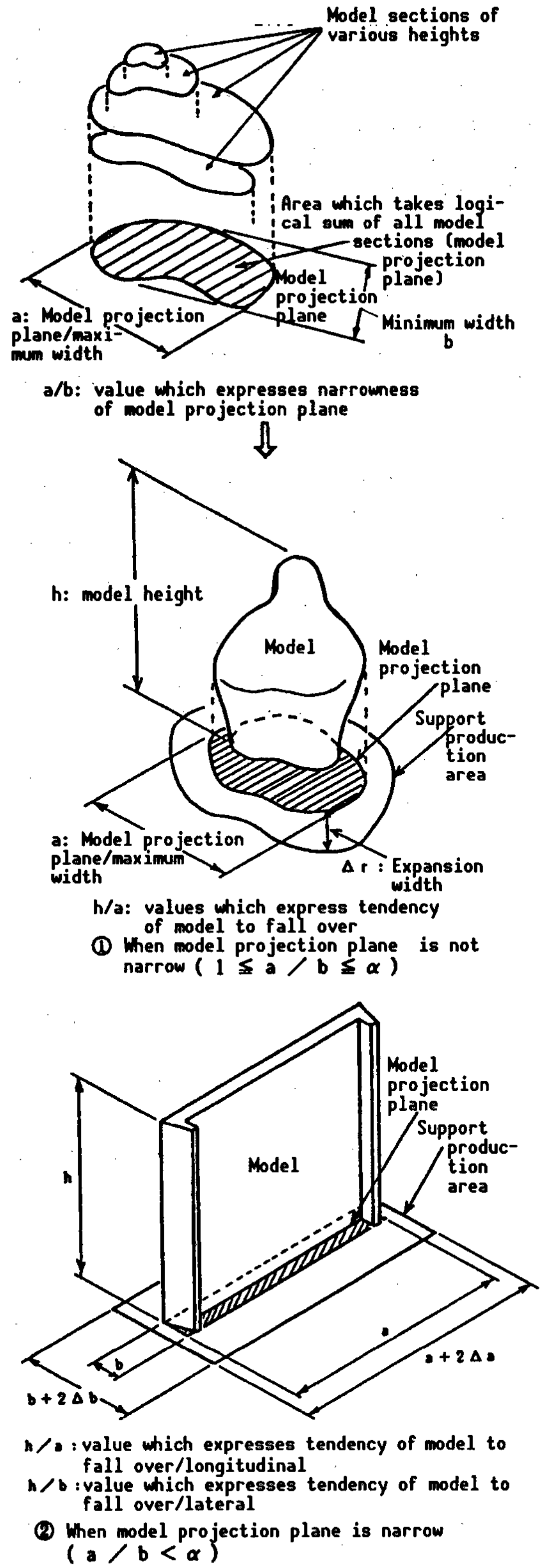


Figure 3. Method of Determining Support Production Area

by the narrowness of the area (called the model projection plane) which takes the logical sum of the section areas in the model. The value used to express this narrowness is the ratio a/b where a is the maximum width and b the minimum width.

Next we determine the support production area, giving consideration to model tip-over. As measures of the tendency of the model to fall over, we use the ratios h/a and h/b between the height (h) and the maximum width (a) and minimum width (b).

We now discuss an example. Experience teaches that a value of between 3 and 5 is suitable for the threshold value α used in determining the shape of the support production area. The expansion width of the support production area is determined by a suitable function whose variables are the tip-over tendencies (h/a, h/b) and the height (h).

(1) When model projection plane is not narrow

$$(1 \leq a/b \leq \alpha)$$

The expansion width Δr is given by the equation

$$\Delta r = f\ (h,\ h/a) = h^{1/2} \cdot \ln(h/a)$$

where $\Delta r \geq 0$.

(2) When model projection plane is narrow

$$(a/b < \alpha)$$

The expansion widths Δa and Δb are given by the equations

$$\Delta a = g(h,h/a) = h^{1/2} \cdot \ln(h/a)$$
$$\Delta b = g(h,h/b) = h^{1/2} \cdot \ln(h/b)$$

where $\Delta a \geq 0$, $\Delta b \geq 0$.

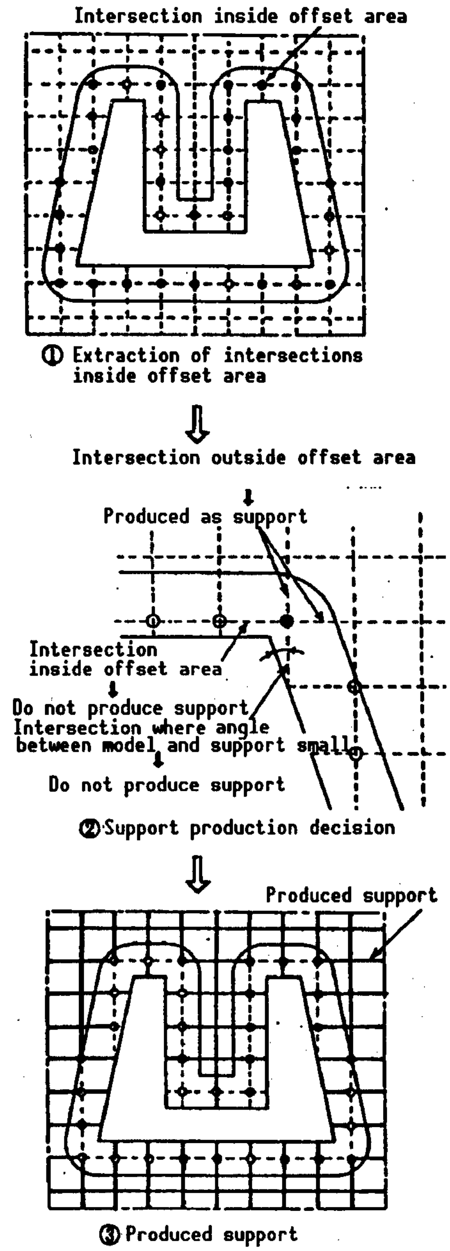


Figure 4. Support Production Decision Method

(2) Deciding on Support Production in Each Layer

The decision method is explained in Figure 4. First, in order to determine the supports close to the model, the lattice intersections of the supports near the model are extracted. The support is then thought of as the line segment having these intersections as its two ends, and the decision to produce or not produce the support is based on the attributes of the intersections at the two end points. The attributes considered are the following two.

(1) Distance from model
(2) Angle subtended by model and support

The decision conditions are noted in Table 1.

Table 1. Support Production Decision Conditions

Adjacent intersection type	Number of intersections w/model	Angle	Decision
Intersection outside offset	→	→	Produce
Intersection inside offset	→	→	Do not produce
Intersection with Model	1	$0° < \theta \leq \beta$	Do not produce
		$\beta < \theta \leq 90°$	Produce
	$2 \leq n \leq 4$	→	Do not produce

4. Photoforming Applied to Vacuum Injection Molding

As discussed already, we fabricate engineering models by vacuum injection molding but fabricate the master models used in the vacuum injection molding process by means of the photoforming system.

The vacuum injection molding method is a technique in which urethane resin reproduction models are fabricated using a silicon-rubber form to which the master shape is transferred.

In this process, firstly, unhardened silicone rubber is poured into a form so that a master fixed therein will be submerged, and hardened. This silicone rubber is then cut open, the master removed, and a silicon rubber form thus made to which the shape of the master has been transferred. Into this silicone rubber form is injected a two-liquid-system curing urethane resin in a vacuum, and the duplicate model is fabricated.

However, unhardened photosensitive resins interfere with the hardening of silicone rubber, the form which comes immediately from the photoforming unit cannot be used as a vacuum-injection master without modification. The model which is produced is therefore washed with warm water, and then subjected to second-stage curing in a UV oven.

Even after performing all these processes, however, uncured resin sometimes seeps out from the interior of the model. To prevent this, a thin coating is applied to the surface of the model.

5. Concluding Remarks

We have explained in the foregoing the way that prototype models are fabricated at Fujitsu using a photoforming system.

What is needed now is the ability to make models of higher quality in a shorter amount of time. To do this will require the elimination of the finishing processes and model appearance enhancement measures.

Such systems are now also being used in fields where the master for the vacuum-injection form or casting must exhibit higher process precision than the finished product, thus demanding even higher levels of process precision. Most urgently needed are improvements in the processing precision of photosensitive resins in the curing direction.

Meanwhile, compared to the time required in fabricating prototype models with mock-ups, the time required with photoforming systems is considerably shorter. However, we need to make this time even shorter in order to use such systems with plotter sensitivity in checking design data generated by three-dimensional CAD.

In order to resolve these problems and fabricate high-quality prototype models more quickly, we need to develop a new photoforming principle, improve our systems, and improve the properties of our resins.

Photoforming System, Application Examples

93FE0169 Tokyo MODELING TECHNOLOGY ASSOCIATION, PHOTOFORMING SYSTEMS RESEARCH COMMITTEE in Japanese May 92 pp 21-25

[Article by Yoshio Onoguchi, Nissan Motor Co., Ltd.]

1. Introduction

As society becomes more sophisticated and information-oriented, and user demand more diversified, the need intensifies to more quickly produce products that meet the latest user demands. This means that product development turnaround must be shortened. Heightening the problem is the necessity of shortening work hours and making work more efficient.

Against this background, in the automobile industry, computer aided design/ computer aided manufacturing/computer aided engineering (CAD/CAM/CAE) is widely employed in the infrastructure from development to production, contributing immeasurably to the shortening of product development lead times and the reduction of development costs.

Advanced photoforming systems which integrate computer, laser, and resin technology are believed to hold tremendous potential as a CAE tool, with a wide scope of applicability and effectiveness.

In this article we discuss Nissan's approach to the use of such photoforming systems, focusing on preparations and applications, and also discuss future problems and tasks in this field.

2. Position of Photoforming System

In the automobile industry, CAD/CAM/CAE is applied to various analytical operations, including vehicle and engine strength analyses and thermal analysis. This is done both to reduce the work loads in the prototyping and testing stages, and to speed up and improve the feedback of information to the design teams.

More recently, manufacturing operations are simulated using CAD data. This allows manufacturing problems to be detected early and processability/ machinability and integratability to be evaluated more effectively.

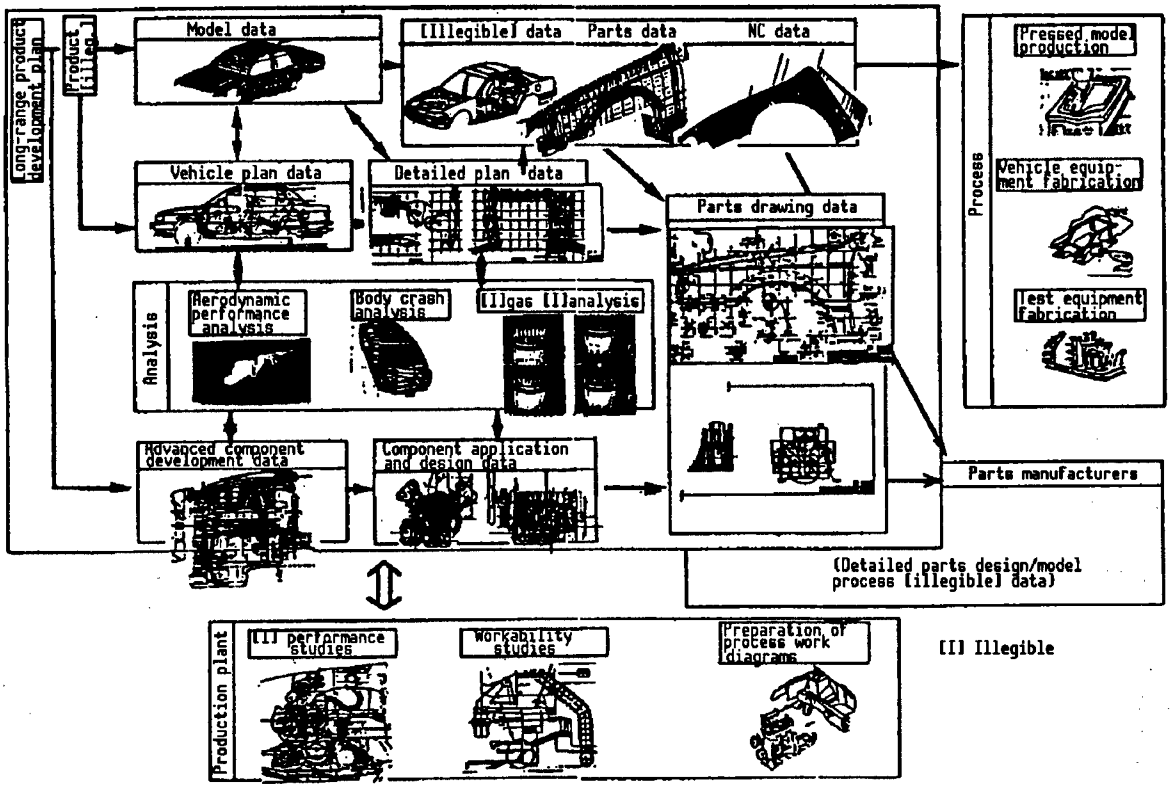


Figure 1. Flow of CAD Data in Development

There are limits to the analysis and simulation which can be performed on a computer, however. In the final analysis, much verification work still has to depend on studies based on three-dimensional models.

This being the case, the best way to sharply shorten development lead times and reduce development costs is to shorten the time needed to make the three-dimensional models.

And to implement comprehensive time- and cost-reduction measures, we need to vigorously move ahead with so-called simultaneous engineering, an approach which integrates development and production.

Against such a background as this, we at Nissan have positioned the photoforming system as a technology which will radically change our operations from development to production. We have stolen a march on our competitors in procuring such a system, and are now engaged in gaining experience and accumulating know-how as a user.

The system we procured is the solid lithography system SLA-250 made by three-dimensional Systems.

3. Photoforming System Applications

We here explain the needs for the photoforming system at Nissan in terms of product development steps.

In Figure 1 we have diagrammed the flow of CAD data in vehicle development.

Vehicle development begins with an exterior design based on the development concept, and is followed by parts planning, detailed planning, parts design, prototyping, and testing. Other processes are going on at the same time, preparatory to production, such as the fabrication of press molds, dies, jigs, and other tools.

In the midst of this product development flow, the photoforming system can produce shape models directly from CAD data, so there are applications at virtually every step of the way, including design, prototyping, testing, and preparations at the production plant (Figure 2).

Figure 2. Photoformed Model Needs

Application	Purpose	Specific examples
Models for studying and evaluating shapes	•Shape defect check •Appearance evaluation •Operation evaluation	•Engine parts •Small internal parts •Steering
Models for layout studies	•Assembly studies •Maintenance studies •Interference studies	•Pedal area parts •Engine parts
Models for evaluating functions/ features	•Flow test evaluation •AC test evaluation •Wind noise test evaluation	•Intake manifold •Vehicle front end •Door mirrors
Models for equipment studies	•Shape verification •Function evaluation •Interference studies	•Jigs, etc •Robot hands •Conveyor systems
Form, mold models	•Shape verification •Wood mold replacement •Master model	•Metal molds, dies •Wood mold replacement •Application to lost-wax process

(1) Models for Shape Study, Verification, Evaluation

There are three-dimensional lithographic applications, mainly for shape study, verification, and evaluation in the design and design [sic] stages. In order to experience a real object sensibly, the system can be used in checking for shape defects and evaluating both appearance and operability. This is helpful in cutting down the time required for design and shape determination and reducing the number of post-prototype design changes.

(2) Models for Layout Studies

In the design and prototyping phase, the models can be used as layout-study models for evaluating assembly and maintenance characteristics and checking for parts interference. This is effective in reducing prototyping time and cost.

(3) Models for Function Evaluation

The models can be used as test-prototype models in the development stage for evaluating the functioning of steering systems, switches, and moving parts, and in evaluating the results of air-conditioning tests and manifold flow tests, etc. Models are made available quickly, so it is possible to conduct all sorts of tests.

(4) Models for Equipment Studies

The models can be used for studying equipment in the production-preparation stage. This is useful in designing processes, conveyor systems, robot hands, jigs, and other tools.

By fabricating models of the jigs and hands, etc, after they are designed, moreover, the functioning of these pieces of equipment can be evaluated.

(5) Mold Models

By using the models as mold models, it is possible to implement design changes while the molds are still on the drawing board, thus reducing the number of mold modifications and shortening fabrication times.

The models can also be used to replace wood molds in casting processes, and can be applied to lost-wax processes.

4. Photoforming System Application Examples

We are currently seeking to broaden the scope of the applications to which our photoforming system is put in the product development and FA technology development fields. We are gaining a wealth of processing know-how as we apply the system at various development stages. Typical examples are introduced below.

(1) Engine Parts

One example is seen in the models we fabricate for layout studies of intake manifolds. These models are used for the following specific purposes.

- To check interference with other parts
- To verify workability of assembly processes
- To verify maintainability

(2) Vehicle Parts

In the development stage, the ventilation characteristics of the radiator are checked on an actual vehicle equipped with a prototype bumper. The problems with this are excessive bumper prototyping costs and excessive prototyping time. We built a one-fourth scale model of the vehicles' front ends and use this in obtaining data.

(3) Metal Mold Applications

In the design press mold area also, CAD/CAE technology is being implemented to improve design quality and shorten design turnaround. With the technology currently used, it is difficult to evaluate die face compatibility or to grasp excess-material shapes on the computer. To do such evaluations, we fabricated a one-fourth scale study model from process design CAD data.

The conventionally used plaster becomes unnecessary, and fewer steps are required in mold design.

(4) FA Development Field

Another application, this one in the field of FA technology development, is in fabricating models of internally made robot arm housings. These models are used for shape and assembly-characteristic verification.

In the planning stage is the use of such models to replace the wooden molds in aluminum casting prototyping (small-lot production).

5. Tasks for Future

We have introduced above some specific examples of photoforming system applications. In order to make such systems even more useful in the future, however, there are some problems which need to be solved. These are outlined below.

(1) Data Link

At Nissan there already exist various CAD/CAM systems in the various departments, as diagrammed in Figure 3.

In order to respond to all the needs in all these departments, we need to have a dependable integrated data link between the various CAD/CAM systems and the photoforming system.

(2) Larger Molding Sizes

In the automobile industry, it is sometimes needful to make full-scale models of large parts such as bumpers or instrument panels.

Thus there is a need to make models which are larger, and also to make these models faster.

NISSAN CAD/CAM SYSTEM		
CAD–I		
BSP	(3D surface definition)	•Body–install shape definition •Surface shape fairing
GNC	(3D NC)	•Master model•mold•NC data preparation
SMART	(FEM model fabrication)	•Shell model mesh data preparation
CAD–II	(3D layout design)	•Engine–room layout planning •Window operability •Tire tread
	(3D planning design)	•Engine mount planning •Cam–operated valve system planning •Suspension system planning
	(3D parts design)	•Inner, outer body panels •Engine chassis parts •Transmission parts
	(Integrated design of separate parts)	•Wire harness design •Main engine component design
CADAM *	(2D drawing)	•Drive system parts design & drafting
INCAM	(CAD/CAM system for machine plant)	•Metal mold design •Preparation of NC data for mold machining •Body assembly jig design •Body panel inspection data preparation
SAS Graphics	(FEM pre–, post–system)	•Stand–alone FEM modeler •Drawings and displays from analysis results
CAEDS *	(FEM pre–, post–system) (Solid model)	•General–purpose FEM modeler •Drawings and displays from analysis results •Solid modeler for analysis •Solid modeler for layout

* Commercially marketed software

Figure 3. CAD/CAM Software Configuration

(3) Precision Casting

The following applications will be developed for precision casting operations.

- Replacements for wood molds
- Adaptation to lost-wax process
- Models for use in fabricating wax models
- Models for use as wax models

In robot development, for example, it is often necessary to prototype an arm housing with an aluminum casting. In such cases, the resin model will be used instead of a wood model to shorten the time required to fabricate the prototyped article.

(4) Accumulating Molding Know-How

In order to use the photoforming system effectively, user-based know-how must be accumulated.

This might involve the following.

- Determining molding direction according to shape
- Designing support stays
- Setting thickness of slices
- Division of large components

These parameters affect the precision, strength, and fabrication time required for the model fabricated. Hence, know-how must be accumulated one piece at a time in the course of actually prototyping models.

(5) Education Program

All kinds of processes are involved in going from CAD data to model formation, and there is a shortage of personnel with the qualifications to handle these operations. Hence an urgent need is to train operators to meet the growing demand.

This being so, the know-how needed to operate photoforming systems and the procedures involved should be put into manuals so that anyone can use the systems.

6. Concluding Remarks

In the foregoing we have introduced the reader to the use of photoforming systems in product development processes and in applications in FA technology development zones, and considered how such systems can result in shorter development turnaround and reduced costs.

In the future, while continuing to gather data and seeking even wider applications, we will seek to develop new engineering techniques based on real needs.

We also expect that such systems will be useful in developing new materials and making various devices and systems more highly functional.

CAD/CAM System for Jewelry, Art Objects

93FE0169 Tokyo MODELING TECHNOLOGY ASSOCIATION, PHOTOFORMING SYSTEMS RESEARCH COMMITTEE in Japanese May 92 pp 26-31

[Article by Shigeru Hagihara, Industrial Technology Center, Yamanashi Prefecture]

1. Introduction

In recent years, the demand has grown for developing artistic designs that can express human sensibilities. Along with this, a lot of work has been done on the development of artistic-design computer aided design/computer aided manufacturing (CAD/CAM) systems. In fact, CAD/CAM systems are already being used to develop artistic-design products in many design/production fields, including automobile bodies, household electrical appliances, and eyeglass frames.

In Yamanashi Prefecture, there are many locally based businesses which produce such jewelry and art objects as rings and broaches. Such products, by nature, must be produced in small lots and many different shapes and sizes, but their cost must not be so high that they are beyond the reach of the individual consumer. It is very difficult to mechanize such production. Even now, when it is becoming increasingly possible to use artistic-design CAD/CAM systems, most of the work continues to be done by hand. Hence there is a great need to implement CAD/CAM systems for this purpose.

At the Industrial Technology Center in Yamanashi Prefecture, we are doing developmental research on a special CAD/CAM system for supporting the design and production of jewelry and art objects. This project is being done in cooperation with experienced scientists (Makoto Ito of Chuo University, and Susumu Furukawa, *et al.*, of Yamanashi University) and business interests.

2. System Overview

In developing this system, we sought to realize five goals, as follows.

(1) Develop a compact system in which CAD and CAM are integrated.

(2) Equip the system with primitive generating functions necessary for cutting stones, forming rings, and making cusps, etc, and for making model production easy.

(3) Provide functions for generating flexible curved surfaces fast, with quick response time.

(4) Provide high-speed rendering functions.

(5) Provide repeat functions based on command history data.

In this section we discuss the configuration of the hardware and software in this system.

(1) Hardware Configuration

The hardware in this system is configured in two groups, as diagrammed in Figure 1.

(A) Graphic workstation (GWS)
(B) Laser lithographic unit

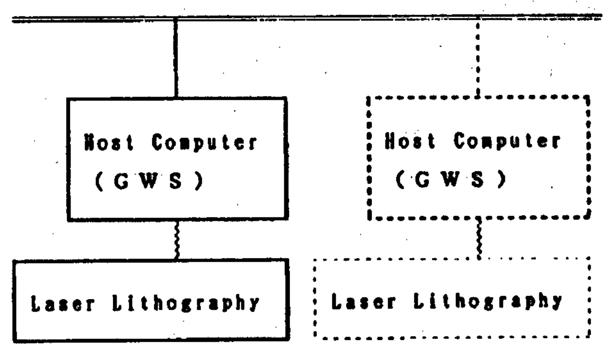


Figure 1. System Hardware Configuration

The graphic workstation and laser lithographic unit are connected via a communications cable, and it is possible to control the laser lithographic unit on the GWS monitor screen. It is also possible to use graphic workstations configured on a network.

(2) Software Configuration

The software is made up of three units, as diagrammed in Figure 2.

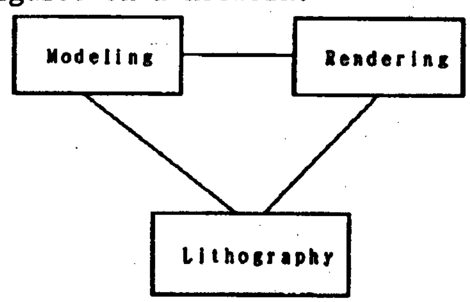


Figure 2. Software Configuration

(A) A form modeler which is able to generate solids in which the multi-faceted shapes and curves typical of jewelry are combined in complex ways

(B) A rendering system which presents a predicted complete diagram to the operator in interactive fashion by means of expressions of qualitative, quantitative, and transparent sensations and setting the position of the light source

(C) A laser lithographic unit which produces actual models made of UV-cured resin from the data provided by the solid generated by the shape modeler

3. Shape Modeler and Editing Functions

When performing shape design, the three-dimensional shape modeler plays the central role. In this section, we discuss the interactive shape-model operating environment, the generation of graphic configurations and models, the editing functions, and the data structures.

(1) Man-Machine Interface Design Philosophy

The man-machine interface is concerned primarily with the question of how best to communicate the intentions of the human operator to the computer.

We designed a man-machine system that allows even a novice to perform simple operations in a short time. The principles informing this design are as follows.

1) Curtail Use of Keyboard

When a keyboard is used to convey the intentions of the operator to the computer, many problems ensue, resulting sometimes in confusion and wasted time. The problems include entry errors caused by striking the wrong key, frequent movement of operator's focus back and forth between keyboard and monitor screen, and the difficulty of obtaining a one-to-one correspondence between the image in the operator's mind and what is being input.

2) Graphicalization of Linguistic Characters

It is often true that something is easier to understand if it is represented graphically (in two dimensions) rather than expressed only in strings of text (characters). In particular, when use is made of parts that have been generated beforehand by a system or solids generated in the past, those data need to be represented graphically rather than as character strings.

3) Representation of three-dimensional Space in Two-Dimensional

The usual method of representing three-dimensional space on a display screen is to use the three-drawing method. We decided to enhance the spatial awareness of the operator by employing a method which enables any position in space to be represented by the three-drawing method.

(2) Screen Configuration

The display screen is divided into the following five areas, as depicted in Figure 3.

1) Solid (input graphics) display
2) Command menu
3) Message display
4) System status display
5) Screen control commands

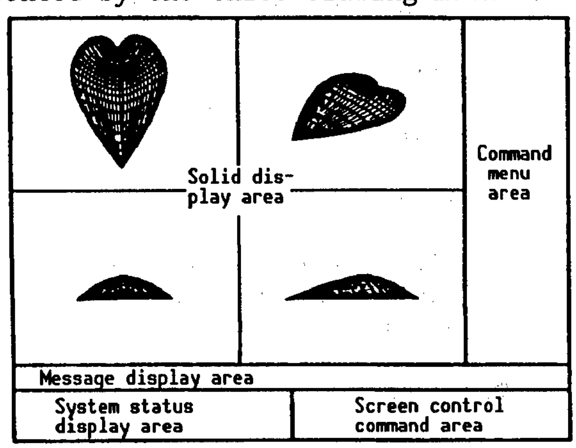


Figure 3. Screen Configuration

In the solid display area, the plan is at the upper left, the front elevation at the lower left, the side elevation at the lower right, and the perspective at the upper right. The command menu is a two-level menu made up of the main menu and sub-menus. Identification is aided by changing the colors of these display areas.

In the system status display, the current mouse position, view position, and focus position are represented by coordinate values. In the screen control command section are shown menus for changing the view position, changing the focus position, changing the solid magnification, designating grid display, and designating curved surface control point display. Messages resulted from executing commands are displayed in the message display area.

(3) Using Commands To Generate Shape Models

In generating shapes with the shape modeler, commands and their necessary parameters are given, the basic shape is generated, and then partial correcting operations are performed and repeated until the desired shape is complete. We next describe the features used to generated a basic shape by issuing commands.

1) Basic Solid

Two-dimensional graphics are pulled up, rotated, and swept, and the three-dimensional solid is generated. The two-dimensional graphics include rectangles, polygons, ellipses, and free curves (S curves[4]).

The pull-up bodies include those which pull up two-dimensional graphics perpendicular to the height dimension, inclined thereto, with altered magnitude, and at a point (polygonal or circular cone).

2) Curving Primitives

The shapes peculiar to jewelry and art objects are divided into two categories, namely concrete and abstract. Typical concrete objects are leaves, flower petals, shells, rain drops, etc. Examples of abstract objects are hearts, crescents, ellipses, and other geometric shapes. The most important of these shapes are already resident in the system as curving primitives for control point strings or locus point strings. The operator can easily generate curved surfaces rich in variation by changing the positions of points based on these point strings.

3) Jewelry Shape

Characteristic jewelry shapes include cut stone shapes, cusps, and stone settings. These can be automatically designated by merely designating the type and size. Twelve different cut stone shapes are resident, including the emerald cut and rose cut. Cusps and settings can be generated in shapes appropriate to the stone used. Two different ring shapes are provided, the flat ring and the rounded ring.

(4) Editing Functions

We next describe the main functions for operating on solids and groups of solids.

1) Move

Rotates, reverses, and parallel-moves solids and groups of solids.

2) Copy

Reproduces solids or groups of solids at equal intervals on a line or spiral. Can also perform reverse copies.

3) Enlarge, Reduce

Changes magnitude of subject solid in X, Y, and Z axes, respectively.

4) Delete

Deletes solids or groups of solids.

5) Group

Associates a number of solids into one group. Also used to cancel groups.

6) Slice

Divides or slices solids or groups of solids along planes.

7) Cut

Cuts out designated forms from curved surfaces.

8) Local Deform

Performs local deforming operations on polyhedrons. These operations include the addition of vertexes, division of corner (ridge) lines, division of planes, and pulling up of planes.

9) Local Curved Surface Revision

Performs local shape revisions by moving control points with the mouse.

(5) Shape Model Data Structures

Directional surface models are adopted as the method of representing three-dimensional shape models. The Internal data structures are designed so that histories can be kept of solid geometric information and interactive operation information.

Solids are described (programmed) in terms of vertex loops configured with planes and three-dimensional coordinate values for each vertex, and both ends of corners (ridge lines).

The solid attributes which are recorded include coefficients of ambient light, diffused light, reflected light, and penetrability. Interactive operation histories are retained in the form of command data (command name and parameters).

The internal data structures for the shape models are diagrammed roughly in Figure 4. The double-line boxes in the figure represent static array structures while the single-line boxes represent dynamic variable structures. The solid-line arrows represent pointers. The broken-line arrows represent the corresponding address in the array.

When there are a number of solids, a data structure depicted in the figure is prepared for each one and these are connected with a list structure.

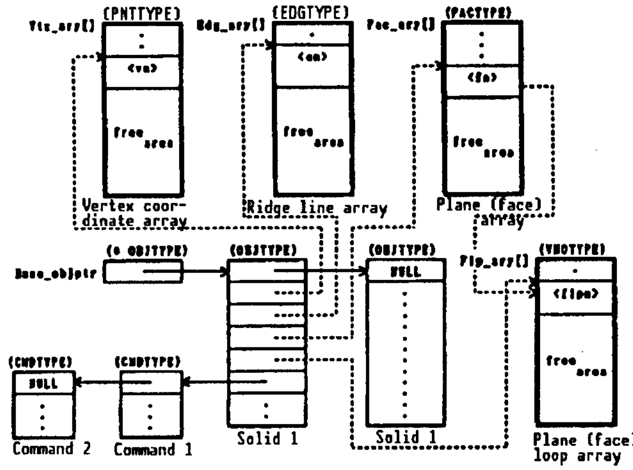


Figure 4. Internal Data Structures

4. Rendering

In this section we discuss the rendering techniques used in this system.

(1) Scanning Technique

Many techniques are possible for rendering solids. For jewelry and art objects, ray tracing is an effective technique because it provides renderings which are very faithful in representing precious stones. This technique requires much processing time, making it difficult to use at the shape design stage which involves much trial-and-error work.

In this system we use a scanning method which enables relatively fast processing speeds and involves processing procedures which are common to laser lithography (discussed below). We now summarize the three elements in this scanning technique. Each plane (face) is ordered according to the coordinates of the highest vertex in it.

1) While moving the scanning plane in the height dimension, cutting-plane lines are found for each plane (face).

2) The cutting-plane lines are scanned in the horizontal dimension. A display area is determined, firstly, at the end-point coordinates of the cutting plane. Next, if within this area there exists a cutting-plane intersection, the area is divided.

3) The line segment(s) closest to the perspective(s) (viewing point(s)) of the (multiple) cutting-plane lines contained in the area is/are displayed. If this line segment has the attribute of penetrability, however, the color of the second-closest line is mixed in. When this is

the boundary of a surface (face), moreover, the color of the boundary line is output.

After performing processes 1) and 2), above, the planes (faces), ridge lines, and cutting-plane lines in the processes are held in a list structure.

(2) Light Model

An extremely important question when making realistic displays is how to color the surfaces of a solid when light strikes them. We calculate the color intensity for the surface by the equation

$$I = Ka*Amb + Kd*Dif + Kr*Ref + Kt*I'$$

Amb represents ambient light, Dif diffused light, and Ref reflected light. In curved surfaces, the normal vector of the plane is interpolated using the normal vector of the vertex (the mean value of the normal vectors in the planes around the vertex). When the plane is penetrable, it is necessary to calculate the light intensity I' of the next plane.

The various coefficients are set at initial values based on the surface properties and constant file(s).

5. Laser Lithography

Most jewelry and art objects are products which have complex shapes. They usually cannot be machined with cutting tools at an NC machining center. Laser lithography which forms solid objects by irradiating photo-curing liquid resins with a UV laser beam, however, can generate resin models quietly and rapidly, and without imposing any special shape restrictions other than the necessity of additional operations to add auxiliary supports for overhanging or suspended portions.

For this system, we developed a laser lithographic unit for fabricating resin models which can be controlled on-line in order to have immediate access to shapes made inside the computer and be able to study them more closely. We now discuss the processing method used with the laser lithographic unit, and its utilization after processing.

(1) Processing Method

Two laser lithographic methods are generally known, namely the restricted liquid surface method and the free liquid surface method.[3] The restricted liquid surface method is able to operate at high speeds irrespective of the viscosity of the photo-curing resin, but suffers the shortcoming of requiring expensive equipment.

The free liquid surface method features simplicity of equipment, ease of handling, relatively few failures even when the operator is unfamiliar with the system, and other advantages. On the other hand, this method requires an additional operation to smooth the surface of a highly viscous resin, and requires longer processing times than the restricted liquid surface method.

In this system we employ the free liquid surface method which is simple to operate and produces resin models inexpensively. The free liquid surface method is depicted in Figure 5. The surface layer of a resin stored in a storage tank is irradiated with an ultraviolet laser beam, and the platform supporting the resin after curing is then submerged. By repeating this process resin models are obtained.

The laser light is beamed along the outline of a section in a plane that is at right angles to the height dimension of the solid. At the places where a number of solids are superimposed, the outer outline is taken.

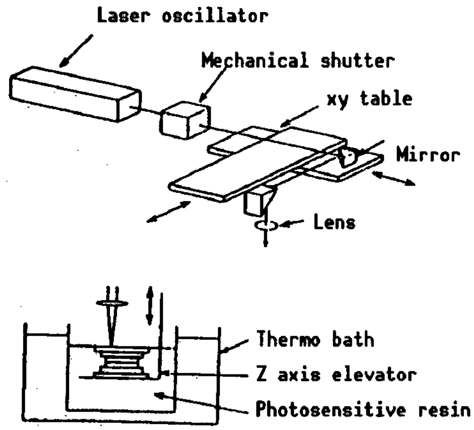


Figure 5. Laser Lithography

When scanning along the outline, a smooth surface cannot be obtained unless special measures are implemented to permit the resin to bond immediately, without leaving any gaps, even when the solid is such that the outline shape of the sections which appear sequentially in the height direction change precipitously.

There are two possible ways of resolving this problem, as follows.

1) Regulate the amounts by which the support platform moves so that the outlines of each section will bond without leaving any gaps.

2) Maintain the intervals with which the support platform is submerged constant, and, when a gap develops when the outlines are bonding, perform scanning to paint over that gap.

Based on our experience, procedure 1) results in a smooth surface, while procedure 2) takes a little less time.

In this system, either of the two methods noted above may be selected according to the objectives of the user. If models are needed quickly during shape design operations, then procedure 2) would be selected.

(2) Use as Casting Mold

If the resin moldings obtained are plated with a metal and implanted with precious stones, it is possible to produce mock-ups which are like the real thing. However, if these resin moldings can be used as casting molds just as they are, this would permit metal mold production times to be further reduced. We experimented with making casting molds from these resin models for that purpose. The procedure we used was as follows.

1) A rubber mold is made using soft silicone rubber.

2) Wax is poured into the rubber mold to form a wax mold.

3) The product is fabricated by means of the lost-wax technique using plaster of Paris.

Based on our findings after conducting fabrication tests according to the procedure outlined above, we draw the following conclusions.

1) This technique requires significantly less time than does the production of metal parent forms as practiced currently.

2) The cost is lower.

3) This technique provides great shape creating powers.

4) There is a slight problem with the strength of the soft silicone rubber. The same object cannot be mass-produced using the lost-wax method. For mass production, one needs to consider the process of making a metal parent form.

5) The small undulations which form during resin layering must be smoothed out during the wax stage.

Conclusions 4) and 5) constitute shortcomings when resin is used to make parent forms for casting. Jewelry and art objects involve multiple-model, small-lot production, so conclusion 4) should not be that much of a problem.

6. Concluding Remarks

We developed an integrated CAD/CAM system for jewelry and art objects which involve multiple-model, small-lot production, have low unit cost, and require complex design work. The system supports the various processes involved from design to fabrication. The system is now being tested and evaluated at the Industrial Technology Center in Yamanashi Prefecture.

References

1. S. Shimizu, *et al.*, "Hoshoku Kogeihin no CAD/CAM shisutemu," *Dai-6-kai NICOGRAPH Ronbunshu*, 1990, pp 298–307.

2. M. Abe, *et al.*, "Hoshoku Kogeihin no CAD/CAM shisutemu," *Dai-7-kai NICOGRAPH Ronbunshu*, 1991, pp 232–238.

3. Y. Marutani, "Hikari zokeiho no genri," *Hikari kokasei jushi niyoru mokei no jido zokeiho ni kansuru chosa kenkyu hokokusho*, Sokeizai Center, 1990, p 12.

4. S. Furukawa, *et al.*, "Ishoyo CAD/CAM shisutemu no shisaku," *Nihon Kikai Gakkai Ronbunshu*, Ed C, Vol 56, No 526, 1990, p 1632.

5. S. Hagihara, *et al.*, "Hoshoku kogeihin no sutereoringurafi," *Seimitsu Kogakkai Shuki Taikai Koen-Ronbunshu*, M37, 1990, p 923.

Surface Condition of Photoformed Models

93FE0169 Tokyo MODELING TECHNOLOGY ASSOCIATION, PHOTOFORMING SYSTEMS RESEARCH COMMITTEE in Japanese May 92 pp 32-36

[Article by Masato Imamura, Yang Meng, and Takeo Nakagawa, Production Technology Research Center, Tokyo University]

1. Introduction

Among the new three-dimensional rapid prototyping systems for creating three-dimensional forms directly from digital shape data without a metal mold, photoforming laser stereolithography has been developed to the most practical level.

Outline data on surface shapes is extracted from computer aided design (CAD), magnetic resonance imaging (MRI), CT, or finite element method (FEM) data, this is converted to 2.5-dimensional NC data, and forms are produced. In actual product fabrication, scanning is done in the X and Y directions with a single laser beam, and the cured object is built up into a solid form by multiple-layering in the Z direction. In terms of mechanical structure, therefore, the basic problem is the shape of the cured object based on beam control. We focused on this point in our experimental study and report here on the results.

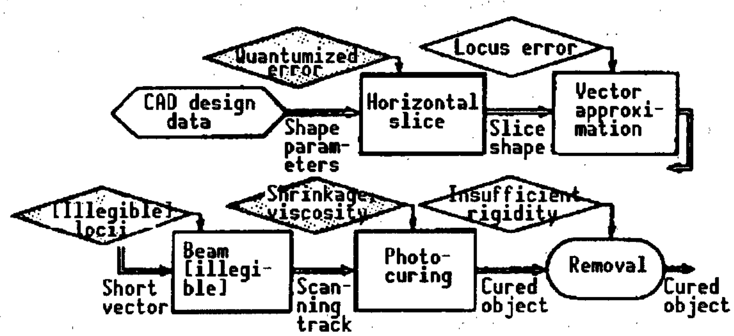


Figure 1. Causes of Shape Error in Photoforming Processes

In order to employ photoforming in all kinds of applications, it is necessary to achieve the necessary and sufficient precision, to reduce error, and improve the surface condition. According to Maekawa, the practical level of precision for photoforming is 0.1~0.3mm, or ±0.05mm for metal mold masters.[1] We employed these ranges as initial benchmark values for this study.

The various factors which are involved in this have been diagrammed as in Figure 1 by Marutani, *et al.*[2]

The factors looked at in our study were the following, analyzed from changes in shapes in molded objects.

(1) Re Hard[ware]

- Mechanical and physical factors

  → Scanning conditions + resin properties
  (Beam control + photo-curing)
  → Shape of cured object

(2) Re Soft[ware]

- Numerical data processing factors

  → Quantumizing error (horizontal slice)
  → Step differential

We decided to obtain some hints on precision on hardened objects formed under these various conditions from the data.

2. Experimental Apparatus

The photoforming system used in these tests was not a mirror-type unit but rather an XY-plotter-type unit (SOUP 530RH made by C-MET) which uses an He-Cd laser having an output power of 25mW (initial value). The UV-curing resin used was an epoxy resin.

3. Shape of Continually Formed Cured Objects

We have the reports of Marutani and Narahara, respectively, on the shapes of cured objects made with a single beam.[1,2] As may be seen in Figure 2, there are some resins which when irradiated with a UV laser beam in a photoforming process form cured layers that, depending on their composition, are from six to 30 times the beam diameter in the depth direction, and from two to six times the beam diameter in the lateral direction. In terms of dimensional precision, however, it is preferable that the cured object have the same dimensions as the beam diameter, and that the shape thereof be basically a cylindrical shape as discussed below.

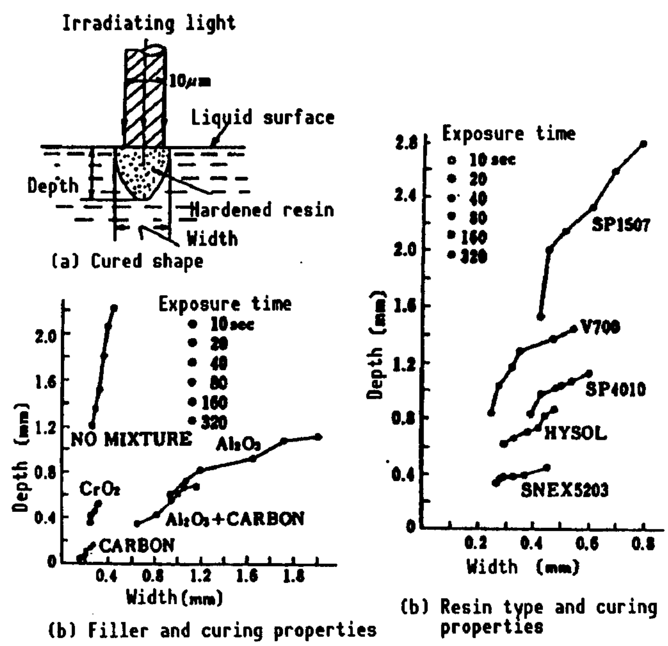


Figure 2. Cured Shape for Narrow Laser Beam[2]

In order here to perform basic property verification in an actual continuous scanning and molding process,[4] we fabricated a box form as depicted in Figure 3 using single-laser-beam scanning with a constant Z pitch of 0.2mm, a laser beam diameter of 0.1~1.0mm, varying the laser beam scanning speed between 10 and 40mm/min, and checked the forming properties of the cured object. In order to increase the stability of the side walls, we added internal supports. The fabrication conditions are noted in Tables 1 and 2. In Figure 4 [not reproduced] is depicted one example of a molded form that was fabricated. We can see clearly the Z-dimension layering profile characteristic of 2.5-dimensional moldings. The moldability under these conditions is noted in Table 3.

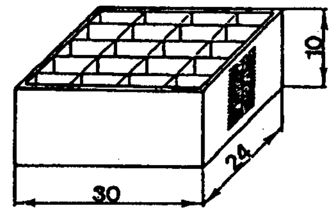


Figure 3. Box Form Used in Tests

Table 1. Laser Conditions Used in Tests

	Body	Internal supports
Laser beam diameter (mm)	0.1~1.0	0.1
Laser scan speed (mm/sec)	10~40	100

Table 2 Modeling Conditions Used in Tests

Laser scan speed	Model type	Internal support interval
10 mm/sec	Surface	6 mm
20 mm/sec	Solid	6 mm
30 mm/sec	Solid	3 mm
40 mm/sec	Surface	6 mm

Table 3 Model Exterior Evaluation Under Various Conditions

Beam width (mm)		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Laser beam scanning speed (mm/sec)	10	×	△	△	△	○	○	○	○	○	○
	20	×	×	×	△	○	○	○	○	○	○
	30	×	×	×	△	△	○	○	○	○	○
	40	×	△	△	○	○	○	○	○	○	○

Side: ○ → △ → ×

Then, in order to measure the change in the shape of the longitudinal surfaces of the cured object (i.e. in the outline of the shape cured by one laser beam), shape measurements were made with a surface roughness meter perpendicular to the scanning direction, and measurement values were taken for the surface roughness Rt and the length per cycle Sm = Z pitch. Changes in the laser scanning conditions change the properties of the surfaces produced, that is to say, when the laser beam diameter is large and the scanning speed is high. and this will diverge from a completely flat surface. This is due to the fact that the surface shapes of the cured object are not always perpendicular to the liquid surface. Depending on the conditions, the unevenness in the side surfaces can become large (Figure 5) and the shape of the cured object can change. This is believed to be due to the fact that curing delay occurs in the liquid resin, resulting in large changes. In general, cured layers do not form perfect columns but exhibit rather an indeterminate shape such as a Gaussian or trapezoidal distribution. As a consequence, in actual molding operations, a reverse truncated cone shape is repeatedly built up in the Z dimension. This is due to the fact that the fabrication of cured objects with laser irradiation is determined by the curing properties of the resin and the energy irradiation efficiency (beam shape in liquid resin = laser beam diameter ϕ × scanning speed v × Z-pitch z = curing unit). The generation cured object E should ordinarily coincide with the curing unit V in the condition where the laser P is irradiated. In such cases

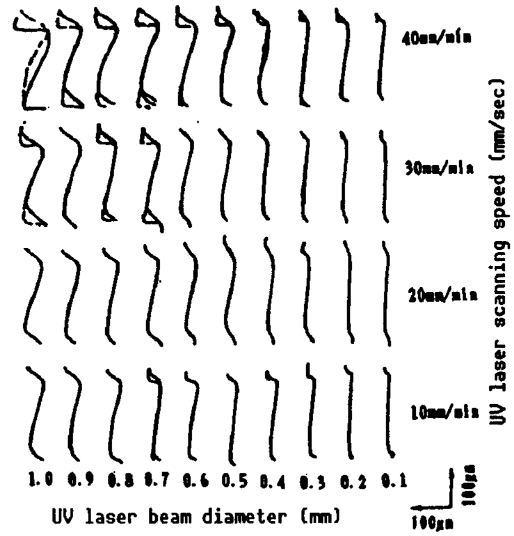


Figure 5. Change in Longitudinal Surface Shape of Object Cured by He-Cd UV Laser

$$
\begin{aligned}
E &= C \cdot f\ (P\ V) \\
&= C \cdot f\ (v \cdot \phi \cdot z)
\end{aligned}
$$

In addition, the curing properties of the UV-curing resins themselves are different. In actuality, the curing efficiency is altered by each factor, so that the shape is further changed in the Z dimension according to some curing efficiency C corresponding to the several conditions, so that, in this vicinity, even though Z (= section length L) be constant, the depth R will exhibit some large value so the R/L ratio will appear to become large. The shape effects of these cured objects themselves will become as plotted in Figure 6. In the range of our tests this was about 100 μm even at maximum, which is within the error range noted earlier. At laser beam scanning speeds below 30mm/min, moreover, molding can be done stably in a nearly stable state within a range of unevenness of 6~15% with respect to the beam diameter. Controlling this point is very effective in stabilizing the shape.

The uppermost surface of the molded object is nearly flat, but, in cases like this where the object being molded is built up in the Z direction, portions thought to be liquid (= resin) pools have been observed.

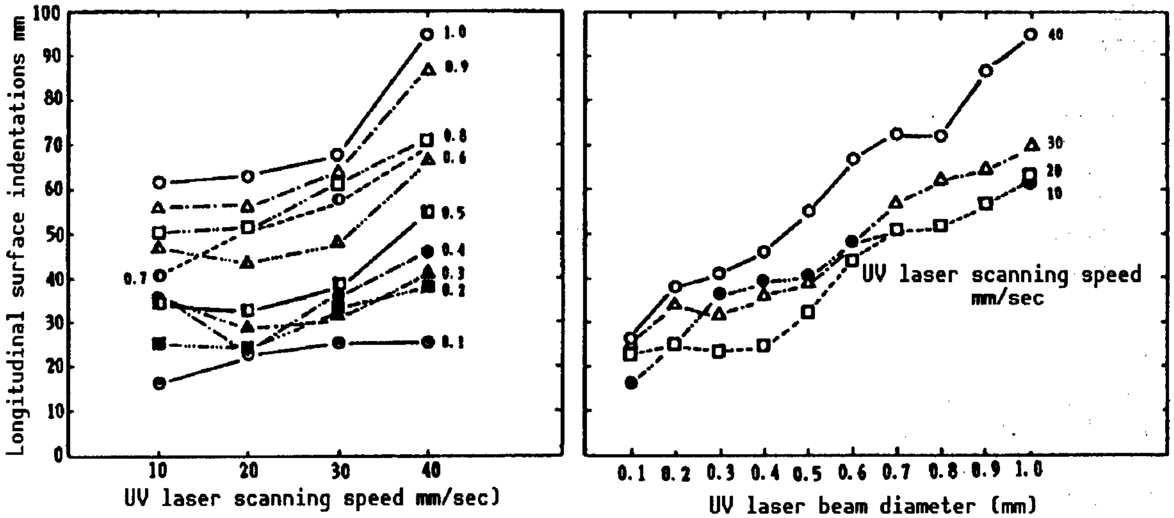


Figure 6. Effects of He-Cd UV Laser Beam Diameter and Scanning Speed on Shape of Cured Resin

4. Quantumization Error[5]

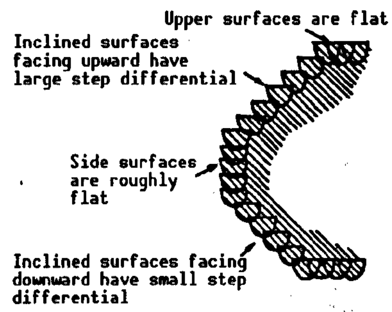


Figure 8. Effect on Surface Flatness of Step Differential and Beam Shape

First, in order to simply indicate the effect of angle, we fabricated a sphere having a diameter of 30mm, and measured this shape. The results are indicated in Figure 7 [not reproduced]. Even though slicing was done at a constant Z pitch of 0.2mm, the shape of the step differential is completely different with the north polar and equatorial data. In the equatorial plane, the surface is roughly facing the perpendicular, so the step differential in planes perpendicular to the Z axis will be small. However, at the polar points the surfaces of the sphere are roughly facing the horizontal, so the step differential in planes perpendicular to the Z axis will be large. Marutani, *et al.*, interpret these effects as diagrammed in Figure 8. We measured the effects specifically.

The method adopted was to form inclined surfaces by inclining flat surfaces at a constant angle, in place of free curved surfaces, and then measure the step differential which developed. The model used in this instance was not a freely curved surface but a rectangular parallelopiped of dimensions 20 × 20 × 10mm. Using a laser scanning speed of 20mm/min and Z pitch of 0.2mm, we fabricated a model, inclining this solid 10° at a time relative to the horizontal plane ($\theta = 0°$). Then we measured the shapes of the XY flat surface and the two XZ flat surfaces perpendicular thereto. Since the angle of each surface in this drawing is 90°, two surfaces forming a ridge line indicate surfaces having inclination angles of θ and $90-\theta$.

In measuring the shapes, we performed shape measurements of the model surfaces, calculated the step differentials by triangulation approximation as diagrammed in Figure 9 from the roughness data (taking the depth of Rt as R as noted earlier, and the period Sm as the section length L), and finally calculated the shift from the numerical data.

Depth	: $R = Z \cos \theta$
Section length	: $L = Z/\sin \theta$
Section shape ratio	: $R/L = \cos \theta \sin \theta$
Section product (volume)	: $RL/2 = Z^2 \cos \theta/\sin\theta\ 2$
	$= Z^2 \cot \theta/2$

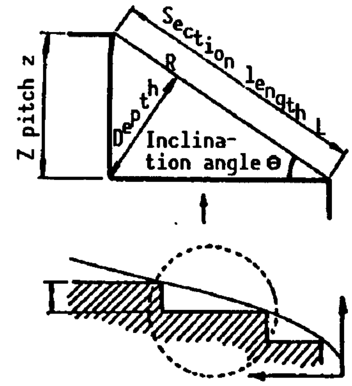


Figure 9. Definition of Step Differential and Measurement Points in Freely Curving Surfaces

In order to model such a shape, we inclined the flat surfaces 10° at a time and made moldings. The results of the surface shape measurements are plotted in Figure 11. The numerical data obtained by measuring roughness from this are plotted in Figure 12. When the angle of inclination approaches 0° without limit, the section length approaches infinity and scatters, so the step differential is very large. As the inclination of a surface changes from the horizontal (0°) to the vertical (90°), we see that the step-differential section length and depth of period become smaller. Accordingly, as we would naturally expect, the quantumization error is indicated as a step shape. In this case, the main reason why a symmetrical shape is not indicated at 45°, geometrically, has to do with the large influence caused by the curing unit of the laser beam, described above, being of indeterminate shape. Liquid run is also thought to have an effect.

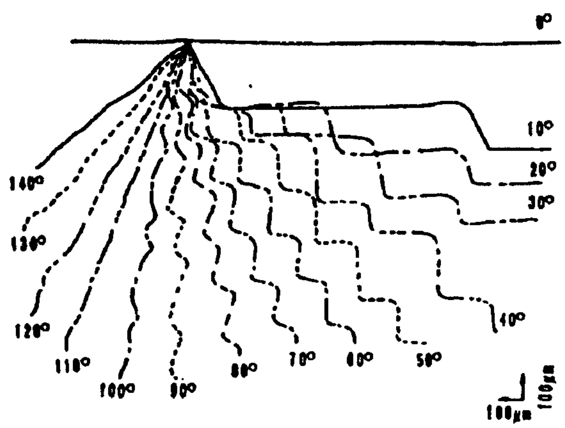


Figure 11. Changes in Inclination Angle, Section Shape

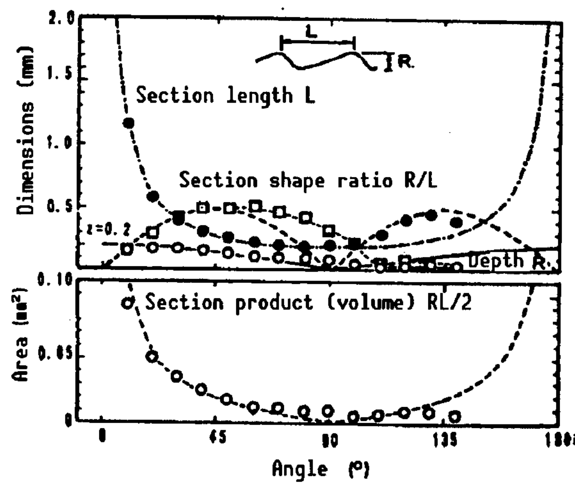


Figure 12. Surface Shape, Inclination Angle

We can also see that in flat surfaces which face downward at an angle of inclination greater than 90° the step differential becomes even smaller. This indicates numerically as well that the step differential is smaller in downward facing inclined surfaces than in upward facing inclined surfaces. Basically this is due not only to the fact that the beam shape presents a curved surface but perhaps also to the fact that the step differential becomes even smaller due to overcuring during layering. The epoxy resin used in these tests has a high curing ratio of 90% or more, so the shape variation is small. With resins of small curing ratio, however, this effect may be large.

5. Concluding Remarks

The side surface shapes of moldings show repeat outlines caused by the layering of the UV-laser cured objects which configure them [syntax obscure in original]. This is greatly influenced by the various specifications of the laser beam. When output is constant, the curing energy will also be constant, so it is necessary to select conditions appropriate to laser beam control which will stabilize curing. This will also result in shape stabilization.

With respect to quantumization error in the Z dimension, there will not be much of a problem if the Z pitch is changed according to the slope of the curved surface with the photoforming control software. In order to minimize this error, however, the direction in which the molding is layered needs to be determined in view of the shape of the model being fabricated.

References

1. S. Maekawa, "Hikari zokei shisutemu no oyo kenkyu: seido chosa," *Dai-1-kai Hikari Zokei Shisutemu Shinpojiumu*, 11 November 1191 [sic], p 51.

2. Y. Marutani, *et al.*, *Hikari Zokeiho, Reza niyoru 3-Jigen Protta*, Nikkan Kogyo Shimbunsha, 1990, p 128.

3. H. Narahara, *et al.*, "I20 Hikari zokeiho niyoru rittai koka jushi no koka seicho sochi no kaihatsu," *1992-Nen Seimitsu Kogakkai Shunki Taikai Gakujutsu Koenkai Koen-Ronbunshu*, 1992, p 313.

4. M. Imamura, *et al.*, *Seikei Kako '92* (to be published) 1992.

5. Ibid., "I22 Shigaisen koka jushi moderu no hyomen seijo," *1992-Nen Seimitsu Kogakkai Shunki Taikai Gakujutsu Koenkai Koen-Ronbunshu*, 1992, p 317.

Casting Models, Applications

93FE0169 Tokyo MODELING TECHNOLOGY ASSOCIATION, PHOTOFORMING SYSTEMS RESEARCH COMMITTEE in Japanese May 92 pp 37-41

[Article by Masato Imamura and Yang Meng, Takeo Nakagawa Production Technology Research Center, Tokyo University]

1. Introduction

As the demand for molds and models for making products (including prototypes) grows year after year, it is becoming ever more necessary to provide these rapidly and at low cost. This trend is expected to continue and strengthen as the needs for computer aided design/computer aided manufacturing/computer aided engineering (CAD/CAM/CAE) implementation increase in product design and fabrication, and for metal molds and models, as digital data is used in place of drawings. Photoforming systems are used to embody shapes at various stages in the manufacturing process. We here discuss applications of such systems for fabricating models, forms, and products in the casting field. We look particularly at examples of wood-mold models for casting and disappearing models for precision casting.

2. Photoforming System

The photoforming system used in the tests is the SOUP 530 RH made by C-MET. This system employs an He-Cd laser having an (initial) output of 25mW, and an XY plotter mechanism which continually assures precise positioning in the XY plane. Thus the process precision does not depend on the size of the model. Because of the characteristics of the XY plotter, it is possible to fabricate models both as hollow structures of surface shapes alone and as solid structures. We also implemented, in software, support leg generating functions to make it easy to remove the fabricated model, functions to generate supporting frames to support the model inside the resin liquid, copy and merge editing functions for fabricating multiple models simultaneously, and enlarging and reducing functions to change the size of the models. The UV-curing resins used were epoxy resins.

3. Casting Applications[1-3]

It is of course possible to use the resin models as resin molds just as they are. However, if there is a possibility of eventually moving up to metal molds, the benefits are even larger. We here consider casting as the method of converting the resin models to metal. We first made replicas having the same shapes as the resin models, but, as is diagrammed in Figure 1, it is not at all difficult to fabricate reversed shapes.[4]

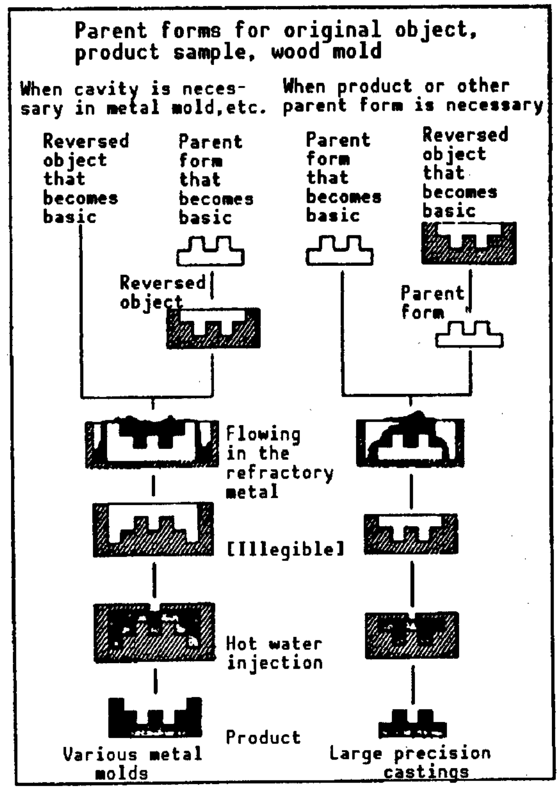


Figure 1. Relationship Between Parent Form, Metal Mold, and Product in Precision Casting

With ordinary machine parts, the value added is not very great, but use is made of models made by analog procedures (masking techniques) for custom products made exactingly, so the needs are great. And if we are talking about molds or forms then the cost is high, and so economic feasibility is thought to be very adequate. The effectiveness is particularly great for prototypes or small-lot production items, or large castings having freely curving surfaces. We next discuss examples of applications to forms or molds used in mass production, and use in product fabrication processes.

Photoforming can fabricate a model directly from design data, so master models can be molded easily without fabricating metal molds from wax forms. For this reason, it is possible to drastically shorten the trial process— even in the prototyping stage—which is demanded for precision castings. The minimal necessary condition for precision casting is the fabrication of sound casting molds. In other words, the casting molds used in precision molding are sintered casting molds coated with multiple layers of ceramic slurry and stucco. They can be heated to correspond to the metal injected, so, except under special conditions, they can be used with almost any metallic material. Accordingly, we conducted these tests and experiments with a focus on finding the configurational conditions for the resin models used for fabricating sound casting molds.

3.1 Using Resin Models as Wood Molds (Wood Mold Replacements)[5]

In Japan, the number of skilled model fabrication technicians will decline. With this trend in the background, more and more model making is being converted from analog operations by skilled workers to digital operations using CAD, and much attention is being given to photolithography which can make use of numerical data. The use of this technology should grow, particularly for non-mass-production items such as one-of-a-kind heavy electrical components having large dimensions.

In these tests, we focused on verifying the practicality of using this technology to replace wood molds. For this purpose we modeled a molding form for a floor covering used in automobile interiors and used this as a master model. In the tests, we employed various different molding techniques and observed the condition of the casting forms thus molded as well as the surfaces of the castings. The current system is a 2.5-dimensional digital processing unit which scans a liquid UV-curing resin with a laser beam in the XY dimensions, thereby inducing localized curing in the resin, and builds up layers in the Z dimension. Hence the moldings exhibit quantumization errors in their surfaces.

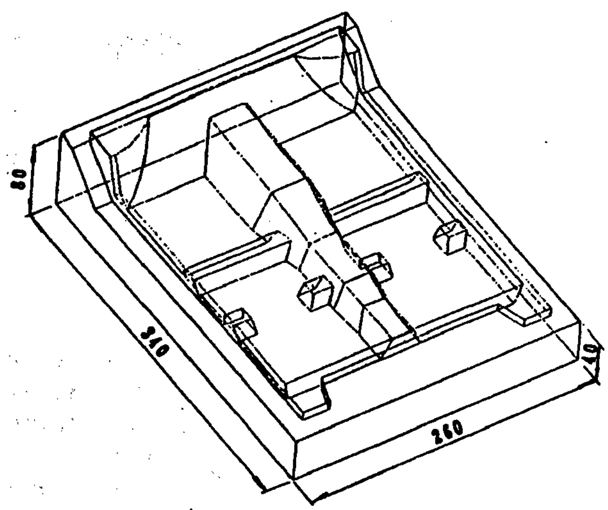


Figure 3.1 Dimensions of Master Model

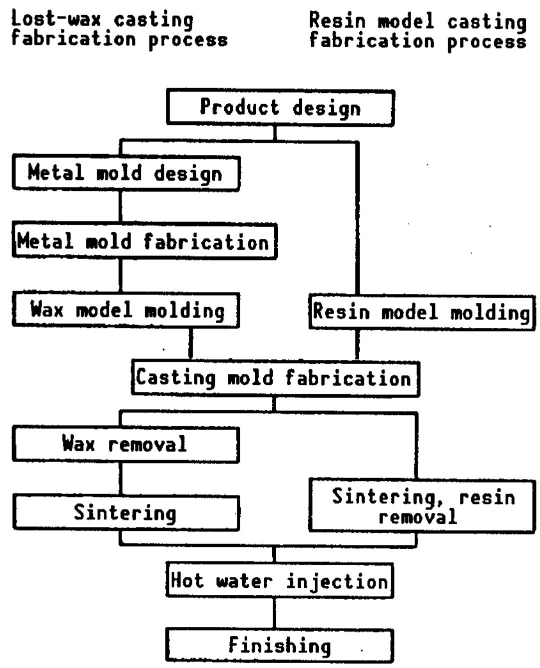


Figure 2. Comparison of Precision Casting Processes

The molding procedure used in the tests were based on green sand molds and Fran self-curing casting molds (No 5 and No 7 silica sand). The FC200 and AC4C were molded. When the silica sand has high granularity (fine sand), a layering step differential is partially transferred in along the Z axis. When coarse sand is used, however, we found that a finished surface is obtained in which coating forms and shot blast marks are almost invisible.

3.2 Application to Lost-Wax Precision Casting[7]

Lost-wax precision casting is one of the few methods by which complex shapes (which cannot be molded by ordinary methods) can be transferred to metal. We performed precision casting tests using models fabricated on the photoforming system in place of the wax forms of the lost-wax method. The resin model disappears during casting form sintering, so the wax removal process is eliminated, and there is no need to design or fabricate the complex jigsaw-puzzle-like metal molds used in fabricating wax molds. Hence fabrication time is reduced and costs are lowered.

We first fabricated resin models under all kinds of conditions, then used these in making casting forms with the conventional lost-wax molding process. We knew from preliminary experiments that the casting forms tended to break with solid models, so we first tried making thin-walled forms. Since the basic configuration of the models used in the tests imparted wall-thickness fluctuation, we attached rectangular projections, 7mm wide and from 10mm to 20, 30, and 50mm long, varying the height between 3, 5, 7, 10, and 15mm, to the sides of a gate stick that is 30mm on a side (Figure 4). Since there were worries about completely removing the resin, we fabricated models, [varying] the laser beam diameter from 0.1~0.4mm at 0.1mm intervals, and at 0.9, 1.2, and 1.5mm. At this time, we also tested materials which had thin supports inside the model in order to increase the handling strength. When this was done, the projection lengths became larger, so we added external supports to the projections when making the models in order to obtain stable resin models. We also made solid models in which everything was filled with resin and hardened.

Using these models, we fabricated casting forms for precision casting as follows. We first immersed the model in a ceramic slurry and applied one coating of ceramic powder stucco. Then we immersed it into the ceramic slurry again, and immersed the ceramic slurry after stuccoing the ceramic particles. After repeating this about six times we dried the object and then subjected it to sintering and wax-removal processes.

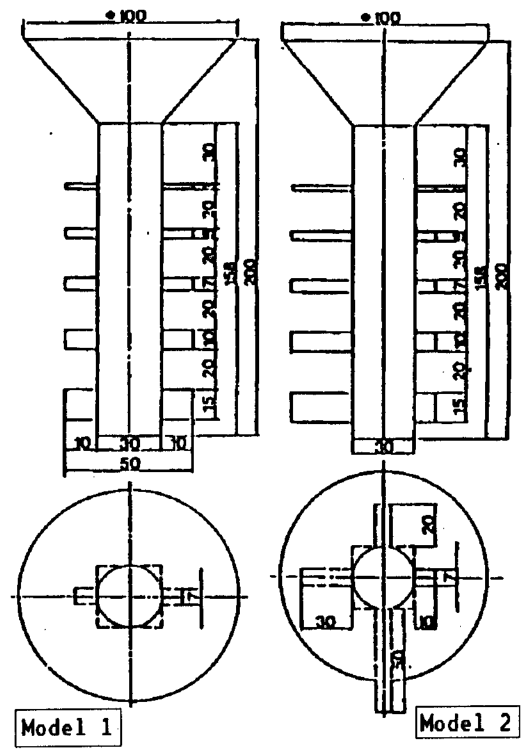


Figure 4. Models Used in Tests

For systems having projection lengths of 10mm, with a beam diameter of 1.0mm or less (which can be thought of roughly as the wall thickness), we were able to sinter sound casting forms. However, with a beam diameter of 0.1mm, when we tried to fabricate casting forms having no internal supports, the resin model broke, there was seepage of slurry to the interior of the model, and the molding operation failed (Figure 5 [not reproduced]). With a beam diameter of 1.5mm, cracks developed as in the solid model which broke into pieces. With a laser beam diameter of 1.0mm, we were able to fabricate the casting form 100% of the time with projection lengths up to about 20mm, and 50% of the time up to 50mm (Figure 6 [not reproduced]). These results are summarized graphically in Figure 1. We considered the conditions for fabricating sound sintered casting forms in terms of the following points. The ceramic shell breaks during wax (resin) removal because the difference in the coefficient of thermal expansion in the shell and in the resin model is very large (Table 1). In conventional lost-wax casting, the dewaxing is done with a high-pressure autoclave. Epoxy resins are thermally hardened, however, so they do not soften

Table 1. Coefficients of Thermal Expansion for Various Materials, K^{-1}

Ceramic molds	$0.5\sim8.0 * 10^{-6}$
Epoxy resins	$160\sim250 * 10^{-6}$
Wax	$48\sim90 * 10^{-6}$

at high temperatures but rather disintegrate. This means that it is necessary to process the resin on the inside very rapidly (Figure 7). It is particularly needful in such cases to provide slits for gas escape. With wall thicknesses of 3 mm and a laser beam diameter (wall thickness) of 1.5 mm there is no place for the gas to escape to. At 1.2 mm [wall thicknesses] and [beam diameters of] 0.6 mm and 1 mm, 1-mm slit spaces open, so the gas has a way to get out.

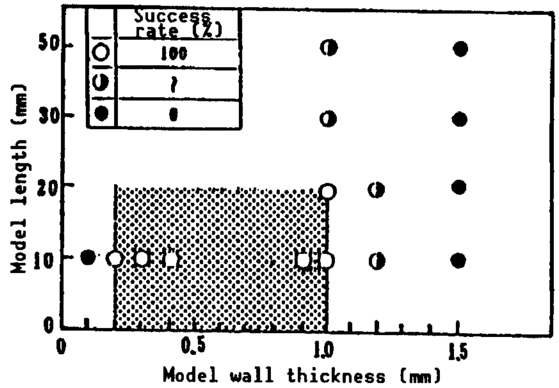


Figure 7. Surface Model Casting Form Moldability

Using these casting forms, we cast aluminum alloy (AC4H), carbon steel (S50C), and stainless steel (SCS13) (Figure 8 [not reproduced]).

We are also developing applications for other casting processes. One of the processes currently being tested is an application to disappearing model (lost-form) technology in which casting is performed with a resin model buried inside the casting form. The resin model is caused to disintegrate with the hot casting water and removed.

4. Concluding Remarks

We applied models fabricated by photoforming to two casting fields and obtained the following results.

(1) We indicated an example of applying three-dimensional photoformed resin models as replacements for wood molds. In the future we expect to see photoforming applied to the fabrication of metal molds in short times, in the context of the trend to use CAD for product design and to make complex models based on CAD data.

(2) We studied the conditions for using UV-cured resin models fabricated by three-dimensional photoforming as substitutes for the wax models used in precision casting. With completely solid models, we could not make perfect casting forms due to the difference in thermal expansion coefficient between resin and form, but when we used surface models fabricated with thin skins, we were able to mold casting forms under certain conditions and to fabricate precision castings.

References

1. [Illegible], *et al.*, "Hikari zokeiho oyobi seimitsu chuzo eno oyo," *JACT News*, No 415, 20 July 1991, p 32.

2. [Illegible], *Shisutemu Seigyo Joho Gakkai Interijento FA Kenkyu Dai-88-kai Kenkyu [illegible]-kai Koen-Ronbunshu*, 1991.

3. S. Nakagawa, "Hikari zokei shisutemu," *Nippon [illegible] Gakkai Koenkai Shuzai* (No 910-72), "Kanegata seisaku ni okeru saikin no gijutsu to shisutemu," 7 November 1991, p 39.

4. Nippon Precision Casting catalog.

5. T. Otani and [illegible] Hoshino: "Hikari zokei gijutsu no chuzoyo mokei eno oyo," *Sokeizai*, Vol 31 No 12, 1990, p 7

6. M. Imamura, *et al.*, "Hikari zokei shisutemu to sono chuzo eno oyo," *Dai-121-kai Nippon [illegible]-kai Zenkoku Koen Taikai [illegible]-shu*, 29 May 1992.

7. Meng, Imamura, *et al.*, "1233-jigen hikari zokei moderu no rosutowakkusu seimitsu chuzo eno oyo," *1992-Nendo Seimitsu Kogakkai Shunki Koen Taikai Koen-Ronbunshu* 25 March 1992.

Making Human Organ Models--Model Fabrication With MRI Data

93FE0169 Tokyo MODELING TECHNOLOGY ASSOCIATION, PHOTOFORMING SYSTEMS RESEARCH COMMITTEE in Japanese May 92 pp 42-45

[Article by Fumiki Tanaka and Takeshi Kishinami, Engineering Dept, Hokkaido University]

1. Introduction

In surgical operations, it is a great help to developing a surgery plan and perform surgery simulation if the three-dimensional shape of internal organs and the relative positional relationships between tissue in the body can be recognized.

In this article we report on an organ modeling system in which photoforming is used to fabricate organ (and especially brain) models from magnetic resonance imaging (MRI) data.

2. Organ Modeling System--Problems and Solutions

A system which can extract the shape of an organ from MRI data and fabricate a model thereof is useful in surgical operations. However, there are many problems and shortcomings with the input devices used in such systems, namely the MRI equipment. These problems arise from differences in the solidness and complexity of physiological shapes. When configuring an organ modeling system, more specifically, the following problems must be resolved.

1) Due to the characteristics of MRI units and differences in the solidness of physiological shapes, it is not possible to build models of intricate organ shapes with conventional automated MRI processing alone because the organs are intricately connected with other tissue.

2) In order to process physiological shapes which are complex and have voids in them, cutting or machining processes are not suitable.

In this research project, we employed two techniques to resolve these problems, as noted below.

1) Using an interactive technique between computer and physician, specific organs are extracted according to the physician's judgment.

2) Since object sections are built up in layers, the models are made using the technique which is excellent for fashioning hollow or complex shapes.

We next describe the configuration of this system.

3. Configuration of Organ Modeling System

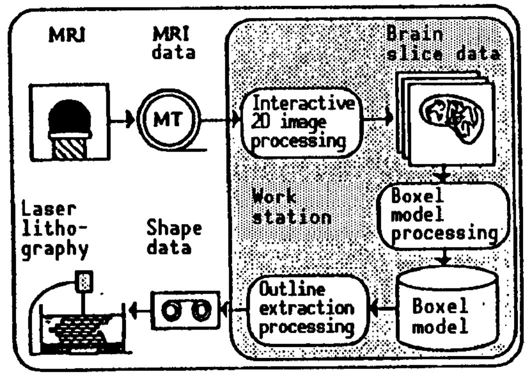


Figure 1. System Configuration

In Figure 1 the overall configuration of the system is diagrammed. The input to the system is two-dimensional MRI slice data provided by an MRI unit made by Siemens. Brain images are extracted and converted to outline data by the photoforming system SOUP 530RH made by C-MET. Inside the system, the brain slice data are extracted by means of interactive two-dimensional image processing performed on the two-dimensional MRI slice data. Then a boxel model is made from the brain slice data. In order to enhance the precision of the shape data at this time, CT data interpolation is performed. The shape data is finally subjected to outline extraction processing.

Photoforming is a technology which fabricates solid models by making horizontal slices of object shapes, using a UV laser to harden one layer of a liquid UV-curing resin at a time along the outlines, and building up these layers. With photoforming it is possible to model hollow shapes, shapes in which the internal shape is important, and shapes which have overhangs and the like. Hence the technology is suitable for modeling complex shapes such as physiological subjects.

We next consider the boxel model and the various subsystems.

4. Physiological Shape Representing Model

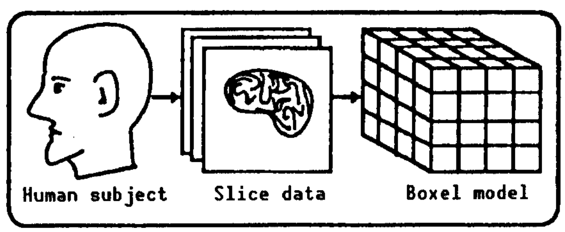


Figure 2. Conversion to Boxel Model

A physiological shape model must represent boundary shapes and internal structures, and be able to represent shapes which have internal voids.

The boxel model is believed to satisfy this definition. MRI data consists of data on multiple slices. By combining these slice data three-dimensionally as diagrammed in Figure 2, they can readily be handled as boxel models.

In view of this, the boxel model was adopted as the physiological shape model in this system.

5. Interactive 2D Image Processing

The extraction of slice data on the brain only from the MRI data is accomplished by interactive two-dimensional image processing. The way this operates is diagrammed in Figure 3. In this processing, the brain slice data are extracted using trial-and-error combinations of the following three functions.

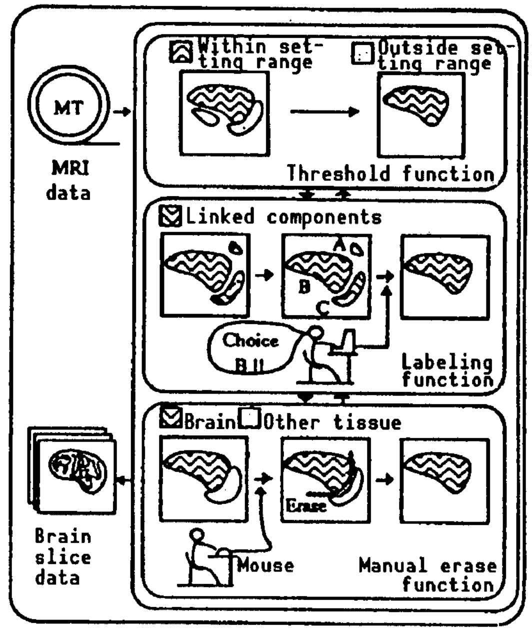


Figure 3. Interactive Two-Dimensional Image Processing

1) Threshold Function

The range of necessary pixel values is set, and picture cells having pixel values outside this range are handled as picture cells of pixel value 0. If the range is made narrow, however, there is a danger that data really needed will be lost. For this reason, the range is set so that data on the cranial region are not cut out, and the functions described below are used in combination.

2) Labeling Function

Picture elements having pixel values other than 0 are linked together and those which form one lump are defined as linked components. A unique label number is assigned to each linked component, so that the linked components can be selected merely by designating this number.

3) Manual Erase Function

By using a mouse to trace over areas to be erased, the pixel values along the mouse track are set at 0. By having a human decide on which areas to erase, it is possible to reflect the experience and knowledge of physicians.

6. Linear Interpolation

The slice data obtained from the processes described above are converted to a boxel model by boxel modeling procedures.

If the slice intervals (1.4mm) are set as the intervals along the Z axis of the boxel model, however, the allowable interlayer interval for the photo-forming system (0.01~1.0mm) will be exceeded. Linear interpolation is also necessary in order to produce a physiological model having a smooth shape similar to that of the actual thing.

When converting to the boxel model, therefore, the MRI values are subjected to linear interpolation using Formula (1).

$$V'(i,j,h) = (1-\alpha)V(i,j,k)+\alpha V(i,j,k+1)$$

$$\text{where } \alpha = \left(\alpha = k - \frac{b}{a}h\right) \quad (1)$$

In this formula, V(i,j,k) is the MRI value for pixel (i,j) in slice k, V'(i,j,h) is the interpolated MRI value at the (i,j,h) coordinates in the boxel model, a is the slice interval, and b is the interpolation interval in the Z dimension in the boxel model.

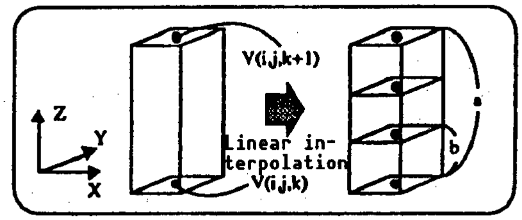


Figure 4. Linear Interpolation

For each of these interpolated layers, an outline shape is extracted and shape data are produced.

7. Outline Extraction Processing

The photoforming system hardens the outlines of the object sections and piles these up to make a solid form. Thus an outline shape must be extracted for each layer in the boxel model.

In this process, as diagrammed in Figure 5, slice data is extracted for each boxel layer, and outline extraction (an image processing technique) is performed on these slices.

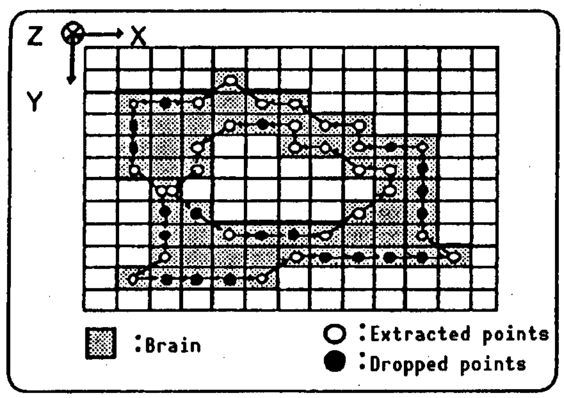


Figure 5. Outline Extraction

However, when this is done, as can be seen in Figure 5, all points on a straight line which is a part of the outline are extracted and the outline is configured. More specifically, not only are the white dots in the diagram extracted as outline configuring elements, but the black dots are extracted as well. This being so, when part of the outline constitutes a straight line, only the beginning and ending points of that line segment are extracted, and the intervening points are dropped. In other words, the black dots in Figure 5 are eliminated. By so doing, the number of outline points is sharply reduced without altering the shape, thereby saving memory space. This also enables processing times to be reduced.

8. System Application Examples

The MRI data used consisted of 128 pages of slice data with 256 × 256 pixels per slice. The slice interval was 1.4mm and the pixel interval was 1.0mm.

[The paragraph describing Photographs 1–6 (not shown) is omitted.]

9. Problems in Modeling Physiological Shapes

With the present system it is not possible to differentiate multiple-layered structures. There are two viewpoints on such multilayered structures. There is, firstly, the problem of simultaneously displaying both skin and brain tissue. With the present system both are handled with surface processing, with only the skin visible from the outside. However, as a surgery support system, it is necessary to see the brain from the outside, even if only as an outline. We are now studying ways of making this possible. And then there is the problem of simultaneously displaying both brain and blood vessel tissue, another multilayered structure. In handling this, it is possible to distinguish the two types of tissue by processing one as a solid. We are currently developing the software needed for this process.

10. Concluding Remarks

We constructed an organ modeling system which extracts organ data, and brain shape model data in particular, and fabricates models by means of photoforming. The system has the following features and functions.

1) Functions to extract brain slice data from two-dimensional images by means of interactive editing involving a physician

2) Brain boxel-modeling and linear-interpolating functions

3) Functions for extracting outlines and compressing outline data

4) Physiological model fabricating functions

In conclusion we wish to express our appreciation to all those who cooperated with or aided in this project, including Y. Uchiyama and S. Kaneda of Hokkaido University.

References

1. Kimoto, *et al.*, *1990-Nendo Seimitsu Kogakkai Shuki Taikai Gakujutsu Koenkai Koen-Ronbunshu*, 1990, pp 507–508.

2. Takamori, *et al.*, *Seimitsu Kogakkai 1992-Nendo Shunki Taikai Gakujutsu Koenkai Koen-Ronbunshu*, 1992.

Brain Structure Model Strategy Using MRI Data

93FE0169 Tokyo MODELING TECHNOLOGY ASSOCIATION, PHOTOFORMING SYSTEMS RESEARCH COMMITTEE in Japanese May 92 pp 46-51

[Article by Noboru Niki, Hiroshi Nishitani, and Yoji Marutani, Engineering Department, Tokushima University

1. Introduction

In this research project our objective was to develop a three-dimensional recognition and support system for the human head, that part of the body which demands the highest level of accuracy for medical diagnostics and surgery planning. More specifically, the system would be able to recreate three-dimensional information from medical images and make this information available to medical specialists for diagnostic and surgery-planning support.

For this purpose we need to develop high-precision imaging techniques for brain data and recognition and support methods for capturing these image data. A number of imaging techniques have been developed, including blood-vessel imaging equipment, X-ray CT, magnetic resonance imaging (MRI), PET, and superconducting quantum interference device (SQUID), and have been of monumental significance in providing better information for diagnoses and surgery planning. Two- and three-dimensional graphics displayed by recognition and support tools for image data. In this context, three-dimensional graphics is a tool for recognizing and supporting a virtual three-dimensional environment on a display screen. This technology is clearly inadequate when the subject is the cerebral cortex or subthalamus in the middle of the brain, where it is difficult to capture the shapes of cerebral blood-vessel networks which contain complex branching structures.

In this report we discuss techniques for extracting brain structure data with high precision from MRI data, reconfiguring the shapes of cerebral organs, and fabricating full-size models using laser lithography.[1-3,5-7] Using these techniques, we configure a three-dimensional recognition and support system which is able to capture complex brain structure data in an actual three-dimensional environment. The system is made even more effective in diagnostics and surgery planning when used in conjunction with three-dimensional graphics.

2. Brain Structure Model Fabrication

The procedure by which brain structure models are fabricated is as follows. The system is roughly diagrammed in Figure 1.

1) Shape configuration of brain structures from multichannel MR images

2) Fabrication of brain structure models by laser lithography

3) three-dimensional display of brain structures and clinical evaluation using actual-size models

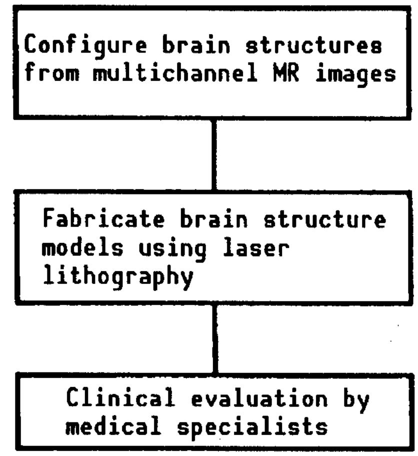


Figure 1. Brain Structure Model Fabrication

We use multichannel MR images to extract brain structures. MRI permits various types of photographic method to be used, and images having the various characteristics of T1 emphasizing images, T2 emphasizing images, PD emphasizing images, and MRA images can be captured in the same section. In this system we use channel image data suitable to each cerebral structure. Brain structures which are difficult to extract with single-channel image data are extracted by integrating three-channel image data from T1, T2, and PD emphasizing images, respectively. Multichannel MR image capture requires a long time, so this photography or capture is done efficiently by careful site selection and by using the various attributes of brain structures.

The three-dimensional images of the brain structures extracted from the multichannel MR images are made into full-size models by laser lithography. In the past, efforts were made to fabricate full-size models by sculpting or cutting away material from a solid form.[4] With such a method one can make relatively simple organ models of things like bones, but this is not suitable for fabricating models of brain structures having blood vessels and other complex substructures. This being so, we employ a technique which uses light energy to selectively harden a fluid material to fabricate any desired shape.[1-3] With this technique, a laser beam is moved under computer control over the surface of a photosensitive resin to fabricate brain structure models.

We used multichannel MR images taken from volunteers to evaluate three-dimensional displays and full-size models of brain structures, and had a medical specialist make clinical evaluations of multichannel MR images in real cases.

3. Configuring Brain Structures From Multichannel MR Images

3.1 Extracting Brain Structures From Multichannel MR Images

The procedures for brain structure configuration consist of extracting the brain structure images from the multichannel MR images and configuring organ shapes from the brain structure images.[5-7] We used the time-of-flight technique in capturing MRA images. We made actual images in which presaturation was used to emphasize either arteries or veins.

We also made clear images of the cerebral cortex and CSF (which are difficult to extract from single-channel image data) by integrating images which emphasize T1, T2, and PD, respectively. The integrated image shows the images which emphasize T2, T1, and PD, in that order, from left to right. In calculating the image values for this integrated image, we selected and designated the CSF region in the site of interest, and used distance functions to calculate the interval between coordinate points in each sample from the coordinate points in the multichannel MR image values. We thus made it easy to extract brain structures from this image.

For extracting bone areas from CT images we use a simple threshold-value processing technique. This method is unsuitable for extracting brain structures from MR images, however, because the dynamic range of the image values is large and the boundaries are indistinct.

In the method of extracting brain structures used, we first isolate an area of image values from the MR image in which the organ of interest exists. Then we compute edge images for this area using Marr-Hildreth operators. Finally, using pixel linkage characteristics, we begin to perform three-dimensional searches from the center of the image of the organ of interest extracted with the threshold-value technique. In this operation we expand the area and finish when we reach the edge of the image of the organ of interest. That is how we extract the organ of interest. This process is diagrammed in Figure 4.

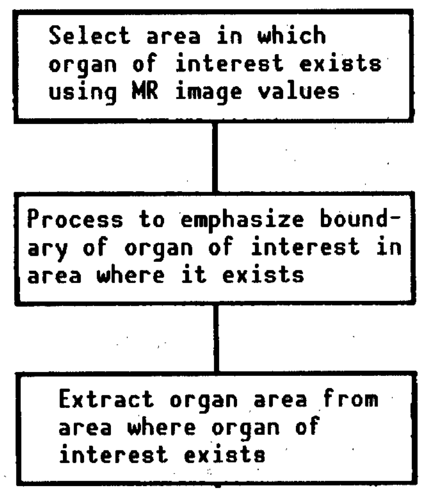


Figure 4. Extraction of Organ of Interest

The Marr-Hildreth operator is defined by the formula

$$C(x,y,z) = \nabla^2 (I(x,y,z) * G(x,y,z,\sigma))$$

where $I(x,y,z)$ represents an MRA image, $G(x,y,z,\sigma)$ a Gaussian function, $*$ a convolution operation, and ∇^2 a Laplace operator. $C(x,y,z)$ represents the edge image. In this operation, the MRA image is smoothed with a Gaussian function and the edges of this smoothed image are emphasized with the Laplace operator.

3.2 Reconfiguring Organ Shapes From Brain Structure Images

The slice interval of the unit that makes the full-scale model is a 0.1-mm spatial resolution. The MR image resolution is a 1-mm spatial resolution. It is necessary to match the spatial resolution between the units. The resolution in the slice direction of the MR image is enhanced by interpolation.

There are different methods of interpolation. One is to extract the targeted organ images after interpolating the MR images in the slice direction and then configure the organ shapes. Another is to first extract the targeted organ images from the MR images, then add correspondences between the organ outline data and configure the shapes. The former method involves tremendous computation volume because of the interpolation computations and number of images. We therefore adopted the latter method. There are boxel representations and triangular patch representations to represent this shape. We represent shapes with the idea of reconfiguring smooth organ shapes. When boxel representation is used, the organ shape is configured with boxel sets, and it is possible to reconfigure smooth shapes by beveling the shape surface boxels.[8] For the configuration of the organ shape here we employ triangular patch expressions which impart correspondences between outline data with triangular patches.[9-12] This enables smooth shapes to be reconfigured with relative ease.[9-11] For the organ shapes, the outline data of the organ images are smoothed with a spline function, thereby removing the quantumizing noise which develops because of image resolution roughness. The intervals between the smoothed outline data are given correspondences with triangular patches by an improved version of the Christiansen technique.[9-12]

There are two types of organ shape models which can be fabricated, namely pipe shapes and filled shapes. The filled shapes are stronger than the pipe shapes because they are not hollow. When blood vessels are the subject, the filled shape can capture variation in vessel diameter and network relationships. The pipe shape resembles the actual blood-vessel shape even more, and it is hoped that this will have applications in designing artificial blood vessels and planning balloon surgery. We here fabricate full-size models, selecting either the filled shape or pipe shape after considering the questions of targeted organ model strength and model fabrication time.

3.3 Three-dimensional Representation of Brain Structures

We make three-dimensional displays of the organ shapes configured by extracting organ images and employing triangular patch representation. For this shadowing we use a volume rendering method.[13] When the resulting MRA image is displayed in three dimensions, we can discern the three-dimensional relationship between brain tumors and blood vessels. We found from this that it is difficult to capture three-dimensional data on sites in blood-vessel networks having complex branching structures. We also made three-dimensional representations of the gray matter of at the brain surface, as well as of the cerebral cortex and blood-vessel network. We found that it is possible to make three-dimensional representations of three-dimensional structures in the gray matter, but that it is difficult to capture the actual shape of the cerebral cortex. By implementing this technique the shapes can be embodied, but it is difficult to capture the structures because the shapes are complex.

Three-dimensional graphics of a blood-vessel network or cerebral cortex is a three-dimensional data presentation in a virtual three-dimensional environment, and it becomes clear that the capture of three-dimensional data is inadequate.

4. Brain Structure Model Fabrication by Laser Lithography

4.1 Full-Size Model Fabrication Unit[1-3]

When a photosensitive resin is irradiated with light, the irradiated portion exhibits a polycondensation reaction and hardens. That is the principle on which this unit is based. If exposures are made by scanning with a narrowly focused light beam, one obtains a hardened layer in the scanned shape. If we sequentially build up these hardened layers, we can fabricate an organ shape in any desired shape.

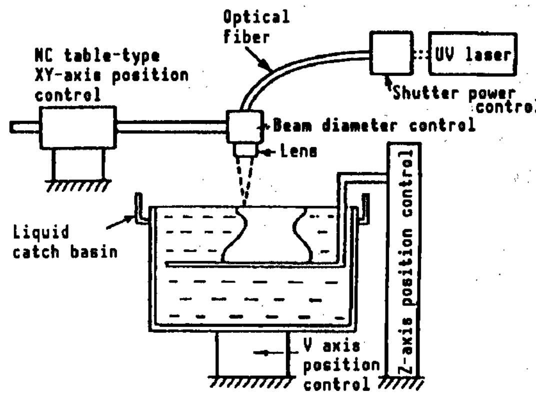


Figure 7. Model Fabrication Apparatus

Slice data for a shape model stored on the computer are taken out from the bottom end, the light beam is made to scan based on this shape, and hardened layers are formed. After forming a hardened layer, an unhardened resin layer of some given thickness is superimposed on top thereof, and the exposure and hardening of the next slice begins. This is repeated until the upper end of the shape model is reached. During the curing reaction, the upper and lower layers are mutually hardened and joined so that an integrated plastic shape model is fabricated. The configuration of the device developed by Marutani and his associates is diagrammed in Figure 7. The light source is an He–Cd laser. This is transmitted through optical fiber and the scribing is done by means of an NC servo mechanism. The photo–curing resin is a cation polymerization type with very low viscosity and little shrinkage during curing.

4.2 Targeted Organ Model With Supports

When the targeted organ has complex branching structures, shape data appears anew not only from the lowermost layer but also during model fabrication. If model fabrication is done in this state, these shape data will be free-floating in the photo-curing resin liquid and model fabrication will become impossible. The model must be fabricated for these data also from the lowermost layer. To do this, supports are added from the lowermost layer for these shape data so that the targeted organ model is supported. The way these supports are added is as follows. The connectivity of slice data is searched for from the lowermost layer, and supports are added, from the lowermost layer, to the slice data that newly appear.

4.3 Targeted Organ Model Fabrication

In an example in which we fabricated a shape model of a blood–vessel network of a volunteer, we were able easily to capture the three–dimensional structure of the complex blood–vessel. Blood vessels are indicated in red so that the supports can be readily distinguished. Model fabrication required 10 hours.

In another instance we fabricated shape models which look from the top of the head and from the upper right back of the head. The red pipe model shows the arteries, the blue pipe model shows the veins, and the red lump model shows a tumor. It is not natural that no vein model is fabricated in the right region, but this is due to the fact that the veins had not been imaged for this region at the time of photographic capture. We are readily able to understand the intertwining relationship between brain tumor and blood vessels. Model fabrication in this case also required 10 hours. In another set of shape models we show the outer appearance from the top of the head and from the upper right front of the head. The red pipe model shows the arteries and the red lump model shows arterial blockage. We can see that the way the blood vessels travel has been altered by the arterial blockage. Model fabrication in this case required two hours.

By fabricating full-size models, it becomes possible to observe in real time, from any direction, actual cranial blood vessels in a real three-dimensional environment. Compared to three-dimensional graphics techniques, it is possible to capture three-dimensional information on blood-vessel networks having complex branching structures and the way blood vessels and tumors are intertwined with far more clarity. We were able to demonstrate the effectiveness of full-scale models as three-dimensional recognition and support tools for diagnostics and surgery planning.

5. Concluding Remarks

We have used two- and three-dimensional graphics as recognition and support tools involving image data from medical imaging equipment. Three-dimensional graphics are used in this context to capture organ shapes, but this only provides information in a virtual three-dimensional environment and does not satisfy all our needs. In particular this technology in inadequate for capturing the convoluted brain structures of interest to brain surgeons.

In this research project, we have proposed a solution to this problem by fabricating full-size models. We actually extracted blood-vessel images from MRA images, configured blood-vessel shapes from these extracted images, and used laser lithography to fabricate full-scale models. By so doing, we made it possible to capture three-dimensional information on brain blood-vessel networks in a real three-dimensional environment, and facilitated the real-time observation of actual brain blood-vessel networks from any desired direction.

Full-size models are recognition and support tools which present a real three-dimensional environment which is not possible with three-dimensional graphics. By employing this technology together with three-dimensional graphics, it is possible to configure an even more sophisticated three-dimensional recognition and support system. We now plan to work together with brain surgeons to perfect a highly sophisticated recognition and support system, applying the system to many clinical cases and producing full-size models at the clinical sites. This will make it necessary to shorten the time required to fabricate the models.

References

1. H. Kodama, "Automatic method for fabricating a three-dimensional plastic model with photohardening polymer," *Rev. Sci. Instrum.*, Vol 52, No 11, 1981, pp 1770-1773.

2. K. Nakai and Y. Marutani, "Rezarisogurafi niyoru rittai moderu sosei," *Denshi Joho Tsushin Gakkai Ronbunshi*, Vol J71-D, No 2, 1988, pp 416-423.

3. K. Nakai, *et al.*, "CT gazo ni motozuku 3-jigen hikari zokei moderu no sakusei," *Iyo Denshi to Seitai Kogaku*, Vol 27, No 2, 1989, pp 86-91.

4. Hisano, *et al.*, "CT gazo deta wo riyoshita hone keijo kako no kokoromi," *Denshi Tsushin Gakkai Gijutsu Hokoku Gazo Kogaku*, February 1988.

5. A. Iwasa, *et al.*, "MRI to rezarisogurafi niyoru kekkan 3-jigen moderu sakusei," *1991-Nen Denshi Joho Tsushin Gakkai Shunki Zenkoku Taikai*, 1991, pp 7-193.

6. N. Niki, *et al.*, "3-D Fabrication of Blood Vessels Using MRI and Laser Lithography," *World Congress on Med. Phys. & Biomed. Eng.*, Kyoto, 7-12 July 1991, p 958.

7. K. Matsuzaki, *et al.*, "3-D Solid Model Reconstruction from MR Images for Surgical Approach," *Symposium for Comput. Assisted Radiology*, Baltimore, to appear 14-17 June 14-17 1992.

8. W. E. Lorensen and H. E. Cline, "Marching cubes: a high resolution three-dimensional surface construction algorithm," *Proc. ACM, SIGGRAPH '87*, Vol 21, No 4, 1987, pp 163-169.

9. N. Niki, *et al.*, "Tobu CT gazo karano no keijo no koseido kosei to sono noen 3-jigen hyoji," *Denshi Tsushin Gakkai Ronbunshi*, Vol J69, No 10, 1986, pp 1518-1527.

10. N. Niki, *et al.*, "Tobu CT gazogun karano zoki no koseido keijo kosei to sono noen 3-jigen hyoji," *Nippon Iyo Gazo Kogakkaishi*, Vol 5, No 4, 1987, pp 369-375.

11. N. Niki, *et al.*, "Tobu x-sen CT • kekkan zokei gazo karano koseido fukugo 3-jigen hyoji," *Denshi Joho Tsushin Gakkai Ronbunshi*, Vol J70-D, No 12, 1987, pp 2525-2534.

12. H. N. Christiansen and T. W. Sederberg, "Conversion of complex contour line definition into polygonal element mosaics," *Proc. ACM, SIGGRAPH '78*, 1978, pp 187-192.

13. N. Niki, *et al.*, "Iyo gazo no aimai keijo no 3-jigen hyojiho," *Denshi Joho Tsushin Gakkai Ronbunshi*, Vol J73-D-II, No 10, 1990, pp 1707-1715.

Oral Surgery Simulation Using Three-Dimensional Model

93FE0169 Tokyo MODELING TECHNOLOGY ASSOCIATION, PHOTOFORMING SYSTEMS RESEARCH COMMITTEE in Japanese May 92 pp 52-57

[Article by Masaaki Goto and Takeshi Katsuki, Dental and Oral Surgery Laboratory, Saga Medical School; and Nagaaki Oyama, Satoru Oishi, Masahiro Mimura, Image Data Engineering Research Facility, Tokyo Institute of Technology

1. Introduction

X-ray CT photographs represent sectional images of the body at some specific interval. Each X-ray CT photograph contains only two-dimensional information. However, when X-ray CT images photographed at small intervals are superimposed by computer processing and displayed, three-dimensional images of considerable precision can be obtained. Accordingly, two-dimensional X-ray CT image data is also very frequently computer-processed to make three-dimensional images in the field of oral surgery. However, even though the solid images displayed on the screen contain three-dimensional information, they are nevertheless two-dimensional images processed to appear three-dimensional, and are not real solid objects.

In the field of computer aided design (CAD), cutting tools are controlled based on the data prepared, and three-dimensional solid models are carved out. There are also reports of solid models prepared by cutting tools in this way being used in jaw and face reconstruction and in trauma surgery.[1,2] More recently, moreover, systems have been developed which fabricate three-dimensional models based on three-dimensional shape data prepared by CAD. The models are fabricated by scanning liquid resins with laser beams to produce localized curing.[3,4]

In the study reported on here we used X-ray CT photographs taken of oral surgery patients, obtained three-dimensional data from these photographs on the bones in the head and face, and produced three-dimensional solid models from UV-curing resin.

2. Method

We first performed CT scans on the jaw and face regions of a patient (male, aged 58 years) suffering from odontogenic keratinized cysts in the right mandible. The CT scanning system used was a Somatom DR-H made by Siemens. The testee was made to lie face up on the CT scanning table, with his head fixed by a headband to prevent head movement. The CT scanning was done with a tube voltage of 125kv, tube current of 350mAS, and section interval of 2mm.

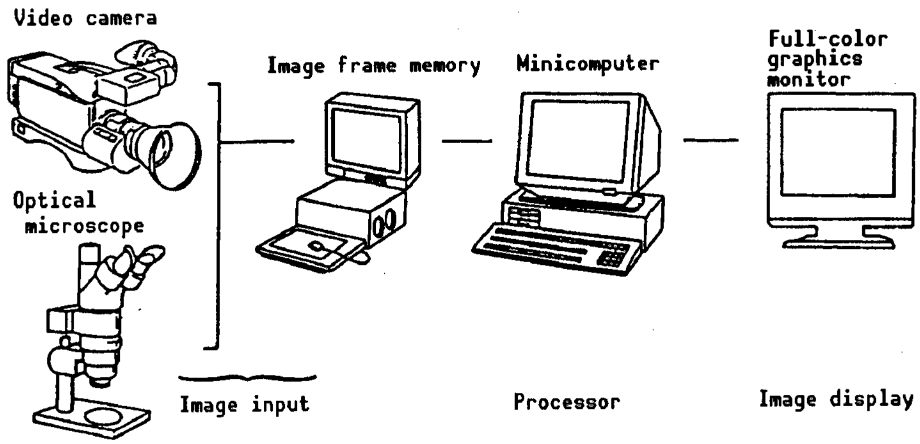


Figure 2. Three-Dimensional Image Reconfiguring System Hardware

We used a three-dimensional image reproducing system belonging to our department to prepare three-dimensional shape data of the facial bones from X-ray CT photographs made continually at 2-mm intervals (Figure 1 [not reproduced]). The three-dimensional image reproducing system is made up of an image input unit, a processing unit, and an image display unit. At the image input unit, the X-ray CT photographs were traced to make line drawings, and these were input into an image frame memory using a CCD video camera (Figure 2). The images in the frame memory were then subjected to binary, fine-line, and other image processing. The images were then manually edited, and the outlines required for the three-dimensional image formation were extracted. After inputting all of the X-ray CT photograph tracings, we checked to see how the outlines at each section were connected to the section before and after it, and joined these using the cursor. The wire frame images prepared in this way were colored and shaded, and then displayed on a full-color graphic display on the image display unit.

Next the wire frame three-dimensional shape data were output onto a floppy disk and then reinput into the workstation of a three-dimensional model fabricating system from the floppy disk. The three-dimensional model fabricating system, based on photocuring resins, is the COLAMM three-dimensional modeling machine made by Mitsui Engineering and Shipbuilding Co., Ltd. (Figure 3). In fabricating three-dimensional solid models, a laser beam is shown from the bottom of a vessel filled with liquid resin and the resin thus hardened. The laser scanning mechanism follows the outline of each section, and, as each section is completely hardened, an elevator moves up so that the next section can be hardened. The laser scanning mechanism and elevator movements are controlled from the workstation. The laser unit used in this hardening process is an He-Cd laser having a wavelength of 325nm. The resin is an acrylic resin. The conditions under which we fabricated the face and cranial bones are listed in Table 1.

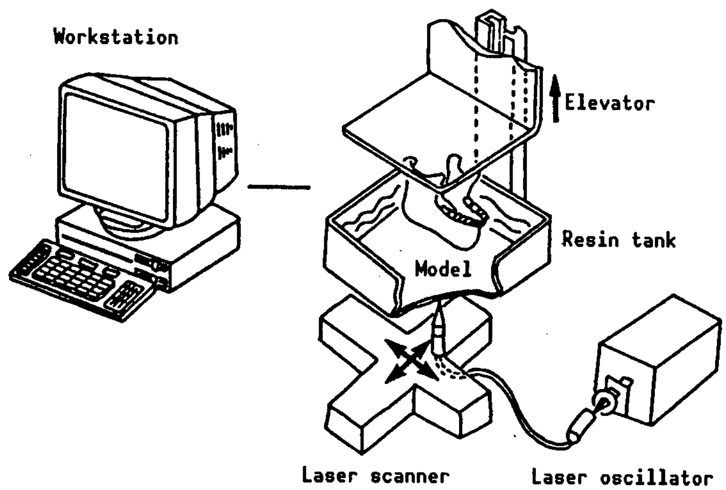


Figure 4. COLAMM Structure Modeler

Table 1. Conditions for Fabrication of Solid Models of Skull and Facial Bones by COLAMM

Conditions	Settings
Laser beam diameter	0.4 mm
Section thickness	0.3 mm
Laser beam scanning speed	17 mm/s
Laser output	120 mW

3. Results

We obtained a panoramic X-ray photograph of the patient's head in which one can discern a transmissive image extending from the bicuspid region of the right mandible to the mandible branch. The degree of mandible swelling and damage, however, is unclear. We also looked at X-ray CT photographs taken at 2-mm intervals. In these we can see the absorption of cortical bone on the cheek and tongue sides, but it is very difficult to discern the spread of the disease vertically.

We also looked at wire frames and colored three-dimensional reconfiguration images prepared from the X-ray CT photographs. The three-dimensional reconfiguration images clearly show that the cortical bone on the cheek side of the mandible has been absorbed.

And finally we examined a three-dimensional solid model made of photocured resin and fabricated from three-dimensional shape data on the cranial and facial bones. This solid model can actually be held in the hands and observed from all directions. This proved useful in determining the scope of excision required and in measuring the size of bone transplants for mandible reconstruction.

4. Opinion

There are many reports on the reconfiguration of three-dimensional images that are based on CT images in the field of oral surgery. The latest X-ray CT scanning equipment now comes with software for three-dimensional reconfiguration supplied as standard equipment, making it relatively easy to observe three-dimensional images displayed on a graphics display from various angles and to view sections. Surgical operation simulation is also being done on monitor screens.[5,6] The images on such displays are of course two-dimensional, however. They cannot be handled directly or viewed from various directions, they cannot be used in simulations in which surgical instruments are used, and they cannot be used to verify the propriety of using prosthetics.

The three-dimensional solid model we fashioned of the cranial and facial bones was a full-scale model. Hence we believe that it extremely useful in surgical treatment planning, operation simulation, and measuring, as well as in educating students and explaining things to patients. The cured resin is not very transparent, however, and we need to develop resins which exhibit improved transparency and can be colored differently according to organ.

Systems which use photocuring resins and fabricate solid models from three-dimensional shape data began to be perfected around 1988.[3,4,7,8] Compared to conventional systems in which machining is performed by cutting tools under computer control, this system is advantageous in that it requires no cutting tools and can fabricate forms of any complexity by the layering process which it employs.

Layering processing is the extraction of contour lines at specific intervals from three-dimensional shape data and building up these contour lines to form a solid model. Since we have outline data for each section in X-ray photographs as noted earlier, with our three-dimensional reconfiguring software we are able to perform layering processing. Layering processing is ideal for making solid structures such as cranial and facial morphology which have complex curves, branches, or voids.

A number of methods are possible for layering processing. In general, most of these methods involve irradiating the surface of a liquid resin with a laser beam, causing localized hardening in the resin, and then lowering the elevator to harden the next layer. However, with this method, deformations readily occur in the resin surface due to surface tension. The apparatus (COLAMM) which we used features shining the laser beam from the bottom of the resin tank so that the influence of surface tension is avoided.[3]

As to the conditions under which we fabricated the solid model of the cranial and facial bones, the laser beam diameter was 0.4mm and the layer thickness 0.3mm. COLAMM is capable of higher layering precision than this, being able to fabricate three-dimensional models with a step differential of approximately 10 μm. However, when the X-ray CT scanning interval of 2mm is considered, the COLAMM setting we used in these tests is believed to have been quite adequate. The positioning of the tracings was done manually, moreover, so there was inevitably some shift error between these tracings. This error results in surface imperfections when the three-dimensional model is made. To eliminate this shortcoming, we would like to convert X-ray CT image digital data directly into three-dimensional shape data and from that fabricate the three-dimensional solid model out of photocuring resin.

The lasers which can be used for resin curing are listed in Table 2. Our system uses an He-Cd laser. He-Cd lasers are air-cooled, so they can be operated with 100V power and used anywhere. Unfortunately quite a bit of time is required to finish a model. With our equipment, it requires 3 hours to fabricate a model to one-third scale, and 24 hours to make a full-scale model. In order to speed up this process, we must study the use of high-powered lasers such as an excimer or Ar laser. This should enable us to shorten the resin polymerization time and laser beam scanning time.

Table 2. Lasers Used for Resin Curing

Laser type	Wavelength	Output power	Output type	Power required	Cooling
Excimer	308 mm	~ 20 W	Pulse ~ 1 kHz	200V AC	Water
Metal vapor (SHG)	314 mm	~ 1 W	Pulse ~ 20 kHz	200V AC	Water
He-Cd	325 mm	~ 80 mW	Continuous	100V AC	Air
Ar (UV)	351~364 mm	~ 5 W	Continuous	200V AC	Water
Ar (visible)	458~515 mm	~ 25 W	Continuous	200V AC	Water
High-pressure mercury lamp	200~700 mm	~ 2 kW	Continuous	100V AC	Air

5. Concluding Remarks

1) We prepared three-dimensional shape data on cranial and facial bones from X-ray CT photographs and used these three-dimensional shape data in the fabrication of three-dimensional solid models made of photocuring resin.

3) Layering processing based on photocuring resins is ideal for the fabrication of three-dimensional models of cranial and facial bones which exhibit complex anatomical morphologies.

3) three-dimensional models of cranial and facial bones are extremely effective in preoperative surgery planning, operation simulation, measurement, student education, and patient education.

References

1. P. M. Lambert, "Three-dimensional computed tomography and anatomic replicas in surgical treatment planning," *Oral Surg*, Vol 68, 1989, pp 782-786.

2. B. A. Toth, *et al.*, "Computer-designed prosthesis for orbitocranial reconstruction," *Plast Reconstr Surg*, Vol 31, 1988, pp 315-322.

3. S. Nagamori, "Shigaisen kokasei jushi wo mochiita kakoho niyoru maikuromashin no sekkei•seisaku," *Kikai Sekkei*, Vol 34, 1990, pp 50-55.

4. H. Saito, "Hikari sorigurafu niyoru 3-jigen keijo moderu no seisaku gijutsu," *Oyo Kikai Kogaku*, Vol 3, 1991, pp 62-69.

5. M. W. Vannier, *et al.*, "Three-dimensional CT reconstruction images for craniofacial surgical planning and evaluation," *Radiology*, Vol 150, 1984, pp 179-184.

6. S. Yokoi, "CG wo riyoshita shujutsu shimyureshon," *NICOGRAPH '91 Tekunikaru Semina Shorokushu*, 1991, pp 162-168.

7. H. Kodama, "Automatic method for fabricating a three-dimensional plastic model with photo-hardening polymer," *Rev Sci Instrum*, Vol 52, 1981, pp 1770-1773.

8. Y. Marutani, "Reza wo mochiita dairesu rittai moderu no soseigata gijutsu," Vol 2, 1987, pp 72-73.

U.S. Trends in Photoforming Systems: Report on 2nd International Conference on Rapid Phototyping

93FE0169 Tokyo MODELING TECHNOLOGY ASSOCIATION, PHOTOFORMING SYSTEMS RESEARCH COMMITTEE in Japanese May 92 pp 58-61

[Article by Hideho Ariyoshi, Matsushita Electric Industrial Co., Ltd.]

1. Introduction

At long last it appears that photoforming systems—capable of making resinous products rapidly and directly from CAD data—will begin to be widely used in Japan. Although work in this field got started in both Japan and the United States at about the same time, the U.S. R&D is now definitely ahead in terms of achieving practicality. The author last year had the opportunity to attend the 2nd International Conference on Rapid Prototyping, which is a major academic gathering in the field. In this article, I wish to introduce the reader to some particular aspects of that conference, particularly those which concern the current trends in the United States.

2. Dayton University and Rapid Prototyping Conference

The 2nd international conference was held 23-26 June 1991, at the Stouffer Center Plaza Hotel in Dayton, Ohio. Dayton is situated along I-75 where there are many automobile factories. Japanese industrialists have built automobile plants and TV tube factories in this area also. The city is famous as the home of the Wright brothers who developed the first practical airplanes.

At Dayton University there is the Center for Advanced Manufacturing, and research is conducted on photoforming technology at the Rapid Prototype Development Laboratory (RPDL). This laboratory was central in the 2nd international conference. The conference was attended by over 400 persons, including participants from Europe and Japan. The schedule included seven sessions plus exhibits and workshops. There are now more than 300 photoforming systems in operation in the United States. The conference was attended by researchers and engineers from all sizes of companies, from large corporations such as automobile and aircraft manufacturers down to small modeling specialty companies.

3. Conference Sessions

There were a total of 41 platform presentations made by representatives from universities, equipment manufacturers, and material producers, etc. The breakdown is indicated in the pie chart below. Many of the equipment vendors and user representatives employed equipment made by three-dimensional Systems, evidence of the market share already enjoyed by U.S. companies. Most of the research done in this field is done by private industry, with relatively few research projects done in universities. In addition to the previously participating Carnegie-Mellon and MIT, this conference was joined by Dayton University, Clemson, Penn State, and three other universities. From Japan there was Saito of Hokkaido University who spoke on the current situation and future trends in Japan.

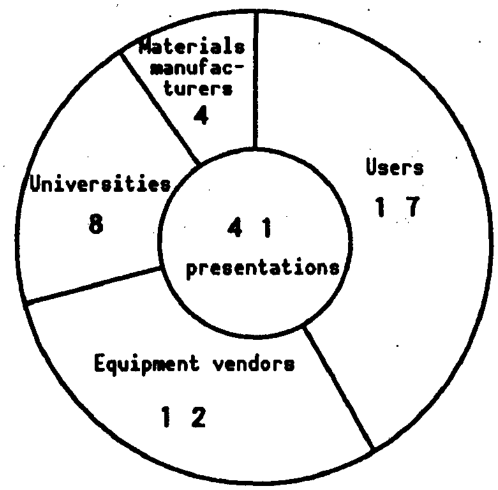


Figure 1. Breakdown of Presentations by Category

We next discuss each session briefly.

Session 1: Latest Technology for High-Speed Modeling

- Analysis of Selective Laser Sintering Technique

    J. Barlow, *et al.*, University of Texas

- Wax Model Fabrication With Particle Modeling Technique

    K. Richardson, Perception Systems, Inc.

- Development, Application of Three-Dimensional Photoforming System for Large Models

    K. Arita and A. Ikeda, Sony Corporation

- Three-Dimensional Printing: Applications to Ceramic Shell and Core Structures, Etc.

    E. Sachs, *et al.*, MIT

This was the session for introducing high-speed modeling systems which had recently come on the market. The Sony system drew much interest. There was a question as to when Sony would enter the U.S. market. Due to patent problems the answer to that question is still unclear.

Session 2: Development of Three-Dimensional Photoforming Resins

- Photoforming Resin Technology

  R. Chartoff, *et al.*, University of Dayton

- Determining Material Constants in Photocuring Resins by Photoirradiation Reactions

  B. Evans, *et al.*, Three-Dimensional Systems Inc

- Advanced Testing Methods for Photoforming System Resins

  P. Bernhard, *et al.*, Ciba-Geigy Ltd.

- Solid Grinding Prototyping System—Application Analysis

  V. Herskowits, *et al.*, Cubital

- Re Swelling Distortion in Photoforming

  E. J. Murphy, *et al.*, DSM Desotech Inc.

On the subject of photoforming resins, Three-Dimensional Systems gave a presentation on simple testing methods and relational equations for use in determining material constants. Desotech presented predictions and experimental data on resin swelling, one of the causes of product distortion after photocuring.

Session 3: Metal Mold Fabrication and Precision Casting

- Prototype Casting by Photoforming

  W. E. Cromwell, *et al.*, Allied-Signal Aerospace Co.

- Photoforming Applications for Precision Casting

  F. R. Prioleau, Plynetics Corp.

- Model Fabrication by Ceramic Metal Molds Using Chemical Bonding

  S. Mise, CEMCOM Research Associates

- Photoforming and Conventional Metal Mold Fabrication

  W. L. Philips, Chrysler

Allied-Signal has conducted careful studies on materials, apparatus, and techniques involved when photoforming is used in precision casting, and has discovered optimal combinations.

Session 4: Economic and Institutional Problems

- Running Photoforming Equipment: Economic and Organizational Problems

  T. Wohler, Wohlers Associates

- Using High-Speed Prototyping Techniques

  D. Trimmer, DePuy

- Concurrent Product Fabrication Using Photoformed Models

  F. Bell and T. Muldoon, General Manufacturing Systems, Inc, and Parker-Bertea

- Integrating Photoforming in GM's Delco-Ramey Division

  L. Listsey and J. Herbert, General Motors

- Photoforming Technology: Pros, Cons, and Ugliness

  L. Schmidt, Chrysler Motors Corp.

- Economic Problems Concerning High-Speed Prototyping Technology

  D. Tait, Laserform, Inc.

Each company discussed examples of product development using photoforming systems. The GM and Chrysler representatives discussed the results of detailed analyses of the cost and time factors involved in operating photoforming systems for prototyping engine components.

Special Session: Historical Perspectives on Development of High-Speed Prototyping Technology in United States and Japan

- High-Speed Prototyping Technology in 1990's

  C. Hull, Three-Dimensional Systems Inc.

- High-Speed Prototyping Technology in Japan—Present and Future

  K. Saito, Hokkaido University

Session 5: Advances in Software and Interfaces

- CAD Model Definition and Data Transmission for Prototyping

  R. Donahue, *et al.*, Computervision and the University of Dayton

- Re Curved-Surface Triangular Patching for SLA

    X. Sheng, *et al.*, Bremer Institut fur Betriebstechnik und Angewandte Arbeitswissenschaften

- Clemson University Intelligent Shape Editor for Photoforming

    C. Kirschman, *et al*, Clemson University

- What Is the Goal of High-Speed Prototype Modeling?

    T. Heller, Quadrax Laser Technology, Inc.

- Automatic Numerical Control Cutting

    S. McOlash, *et al.*, Eaton Corporation

Clemson University representatives announced their intelligent editor which can add supports to photoformed models, make slice data, and perform simulations. There is still much to be learned, technically speaking, in the area of shape processing, causing consternation among users, and this editor should be very helpful in this regard.

Session 6: Problems Related to Precision

- Three-Dimensional Support Structures for Photoforming

    C. Kirschman, *et al.*, Clemson University

- Photoformed Model Precision

    J. Richter, *et al.*, Three-Dimensional Systems

- Research on Photoforming Consistency and Duplicability

    D. VanPutte, Eastman Kodak Company

- Photoforming Process Precision—A User's View

    E. Gargiulo, *et al.*, E. I. DuPont

Relative to the important issue of photoforming precision, Three-Dimensional Systems introduced the new Weave technique of laser delineation. The benefits of the new technique were emphasized with the presentation of detailed experimental data on product shrinkage, swelling, warping, and creeping. Kodak reported on the results of precision evaluations done on the Three-Dimensional Systems' SLA done at Penn State.

Session 7: Case Studies

- Photoforming Applications for Injection Molding

    T. Mueller, Prototype Express

- Solid Creator System Applications in Designing Engine Parts

    A. Kobayashi, Toyota Motor Corporation

- Getting The Most Out of Your Photoforming System

    D. LaCourse, *et al.*, General Motors

The prototyping of engine parts at Toyota was introduced from Japan, with focuses on applications to air/gas-flow measurement and stress analysis.

Additional Papers

- LOM System Used in Production

    M. Feygin, Helisys Inc.

- Molten Resin Lamination Modeling (FDM): Use of High-Speed Modeling in Prototyping

    S. Crump, Stratasys Inc.

- High-Speed Model Prototyping in Integrated Product Development

    J. Poindexter, Wright-Patterson AFB

- Optical Formation of Three-Dimensional Objects by Simultaneous Layer Bonding Using Photocuring Plastics

    E. Fudim, Light Sculpting Inc.

- Temperature Distribution Time Trends in Photosensitive Monomers

    R. Anderson, *et al.*, University of Dayton

- Single-Unit Prototyping and Small-Lot Molding System

    Prodesign Inc.

- New Integrated System for Model Prototyping

    F. Kurihara, DMEC (KK)

- Evaluation of SLA-Based Small Motor Housings

    E. Lacatus, *et al.*, GM & CADCAM Inc.

4. Exhibits

In addition to the conference activities, some 25 companies set up exhibits concerning various equipment and services. The actual equipment was not shown at all of these exhibits, as is done at the annual Autofact convention, but representative models were presented and the exhibits were instructive.

5. Concluding Remarks

Prior to the conference activities, the U.S. Department of Commerce gave a 30-minute presentation emphasizing the importance of photoforming technology in making U.S. defense and manufacturing industries more competitive.

The 3rd international conference will be held in Dayton also, in June.

References

1. *Proceedings of 2nd International Conference on Rapid Prototyping.*

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