Fabrication of stereolithography models – A summery of case studies on the field of mouth, jaw and face surgery

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ABSTRACT

Dresden University of Technology has been using a stereolithography system since January 1993. Besides the special engineering application fields like product development and design visualisation, the fabrication of medical models is a very important field of work (10 ... 20 models each year).

The latter mentioned models are based on computertomography and MRI data. Especially models of skull, lower and upper jaw are produced. In this kinds of bone the inside structure of the part (i.e. the nerve canal) is particulary required. This is the big advantage of the stereolithography procedure because the material used allows to illustrate and to see it.

Experiences in the transformation and manipulation of the raw data, the quality and accuracy of the models and the influence of the surgery technique in connection with the results will be shown in this paper jointly submitted by engineers and doctors using selected examples.

Keywords: Rapid Prototyping, Stereolithography, Medical Models, CT, MRI

1 INTRODUCTION

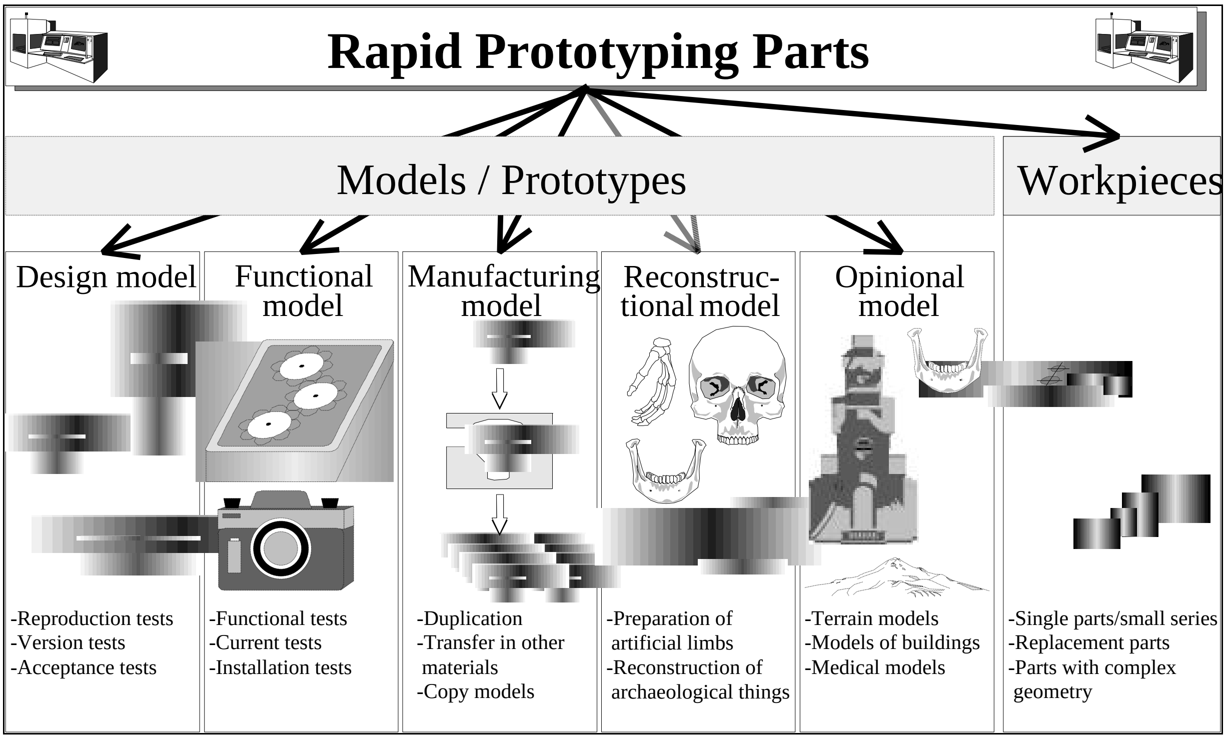

Figure 1: Stereolithographic products - ranges of application

Since the early eighties, advanced modelmaking methods (see Figure 1) known as rapid prototyping techniques have been implemented in industry. RP techniques enable to manufacture patterns and prototypes of also complicated part geometries within short time and at low costs.

RP technology includes methods such as:

- Stereolithography being the eldest and mostly widespread RP technique now;
- Laser Sintering enabling maximum material variety (bonding of plastics, metals, moulding sand, ceramics);
- Laminated Object Manufacturing

All methods summarized under rapid prototyping are based on generative modelmaking and manufacturing of workpieces. Hereby, the parts are formed from amorph material (powder, monomers, filaments, threads and others) by means of chemical or physical effects. The materials are laminated to a fixed joint by adding energy such as laserlight or heat. For additional information see references 1 to 4.

Applications in product development naturally include medical instruments and devices. Using these modelmaking techniques, development times and costs can be reduced by 30 to 70 %, particularly in cases of housings and other complicated part geometries.

2 A NETWORK FOR MEDICAL RAPID PROTOTYPING IN EUROPE

In the summer 1998 a european network called PHIDIAS started. Sponsored by European Commission the network contains 40 partners (14 are industrial partners) from 11 countries.

The complete title of the network gives an information about the main focus of the project. It is: „Technology for manfacturing of medical models based on rapid prototyping and medical imaging technique: quality assessment and application development".

In detail the network supported the following activities:

- Travel/Subsistence
- Specific topic workshop organisation
- Case reports, Presentation
- Internal papers and Scientific papers

With the help of the network the partners hope to increase the number of applications in the medical field and in the same time to elevate the quality of the models based on medical imaging.

The Institute of production engineering uses the stereolithography system of the Dresden University of Technology in cooperation with the medical department. Especailly the clinic of craniofacial surgery has a great interest in using this models in operation and implant planning.

In the following part of the paper a summary of the experiences will be presented.

3 FABRICATION OF MEDICAL MODELS

3.1 Basic principle

We abstracted our experience obtained in layer manufacturing of technical models to the production of medical ones. Complicated geometries related to human bone structures are typical in craniofacial surgery. Since the beginning of the 80ies, it has been possible to generate physical models according to data obtained by Computer Assisted Tomography (CT) or Magnetic Resonance Imaging (MRI). As a disadvantage, this methodology has some limitations in manufacturing of models in the jaw and skull regions. For instance, these methods are not able to visualize structures inside the bone such as nervous channels or tumours as well as very filigree bone regions.

Rapid Prototyping, particularly stereolithography is capable to bridge the gap mentioned above. The parts are manufactured in a generative way. Thereby, voids may be integrated into the models. These voids may be recognized due to the transparency of used materials.

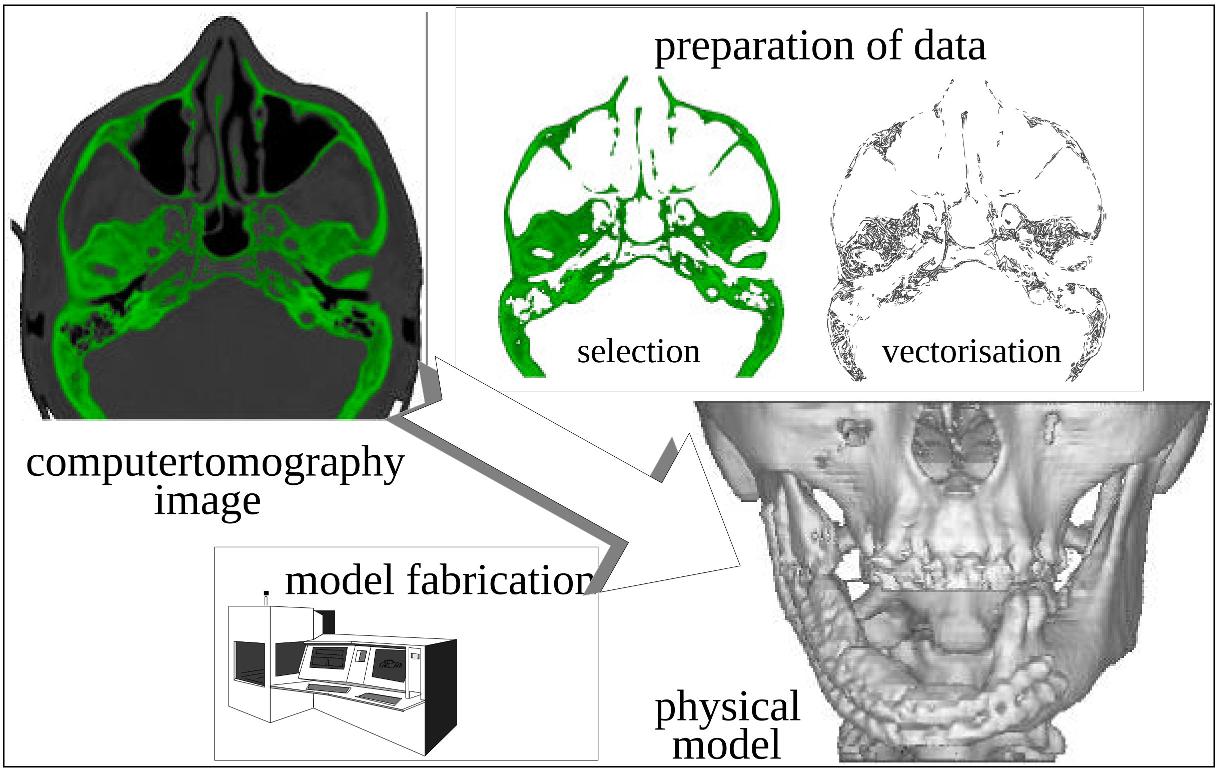

Figure 2: the way from CT images to a physical model

In contrast to most technical applications, medical models are manufactured according to data available in gray scale images (see Figure 2). These CT- or MR images are available in the pixel format. Each pixel of the image is allocated one determined gray scale whereas the gray scale includes information on the kind of the corresponding tissue.

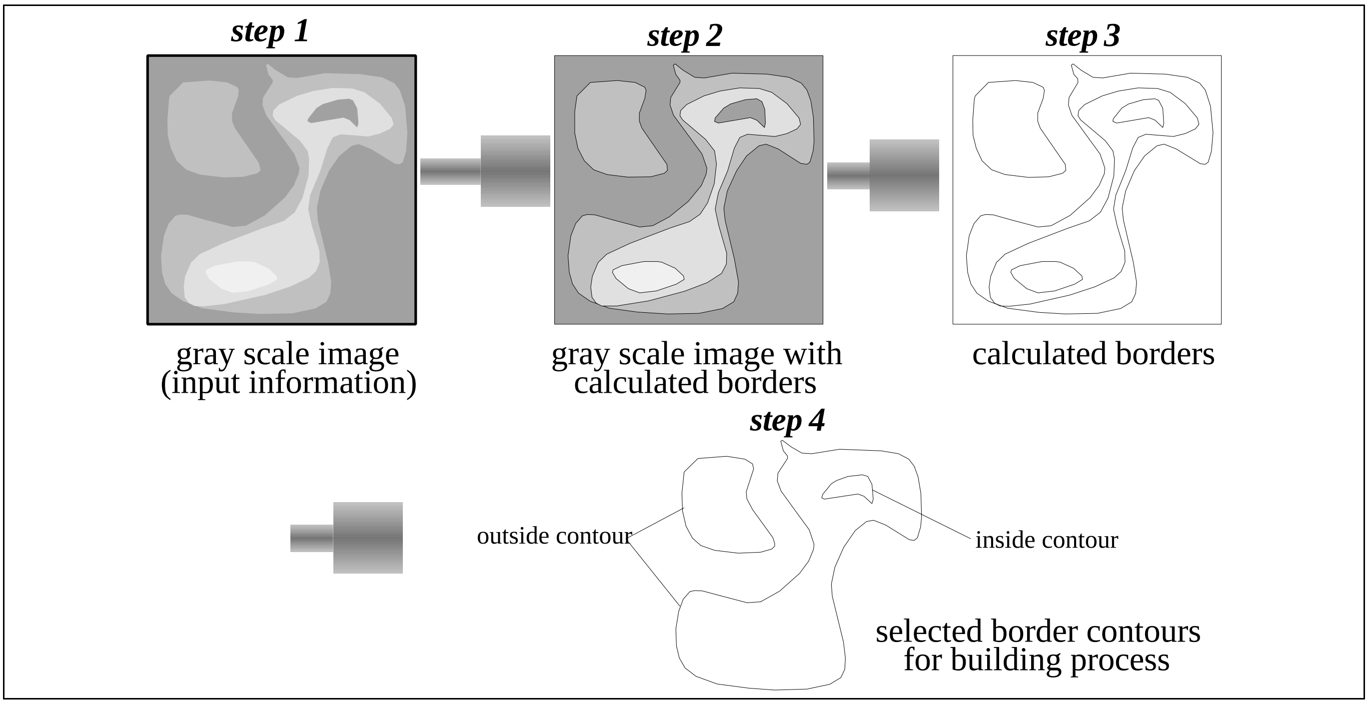

Figure 3: Sequence of data preparation using gray scale images

For model manufacturing, the pixel data must be translated into a vector-oriented notation (see Figure 3). The following interfaces are used for data transfer:

- The STL interface (StereoLithography Interface) enabling a continuous 3D surface representation by triangular facets;

- The CLI interface (Common Layer Interface) handing over boundary contours in the individual laminated structures of generative manufacturing techniques;

Either quality of recorded data as well as manufacturability of individual organs and structures depend on the physical and technical principles the scanning methods are based on.

3.2 Models based on computed tomography data (CT data)

Computed tomography (CT) mainly facilitates to represent bones and bony structures in special regions of interest. Within the CT image, the soft tissues can only be identified in a very restricted manner. Consequently, one can only make models for bony structures from these data. At the TU Dresden, CT data are particularly used for modelmaking in craniofacial surgery. Having in mind the relevant structures, the advantages of stereolithography are mostly important.

The CT images commonly used have the following parameters:

- 512 x 512 pixels per image;
- 4096 gray scale levels;
- 2.0 mm minimum distance due to radiation exposure of the patient;

In the formation of physical models according to CT data, a number of errors may occur especially in data handling:

- big distance among the laminated structures in comparison with the follow-up layer thickness (in stereolithography generally from 0.2 to 0.25 mm)

® For that reason, additional layers must be interpolated based on available information;

- Teeth inlays may cause disturbances in the images (so-called artefacts) due to the high absorption of the X rays.

® these defects must be manually removed from the images;

- Inside the different gray scale values, the tissue is reproduced by a number of impacts; for that reason, we cannot conclude that each gray scale value corresponds with one individual kind of tissue.

® The boundaries between the bony and the surrounding tissues are manually chosen by experience;

- Layer data are interpolated already during scanning, especially in the case of helical CT systems whereby patient and scanning system are rotated simultaneously-

® Interpolation errors in individual images;

These errors may cause much manual efforts for data preparation. As a result of radiation exposure of the patient resulting from the used X rays, now we cannot improve the quality of output data by reducing the distance among the layers. This task demands for reduced radiation dose and can only be solved by plant manufacturer himself. Therefore, additional R&D activities will be necessary. Further development in software engineering should be directed to remove data defects and to improve thresholding of the corresponding structures by gray scale values.

Models made from magnetic resonance images

In contrast to computed tomography, magnetic resonance imaging (MRI) facilitates the representation of soft tissues. However, bones or bony structures cannot be identified in the images. In MRI, a lower distance among the image layers can be realised due to the physical background of this method. Thereby, data quality may be correspondingly enhanced.

In contrast to CT, MR images are mostly obtained with 256 x 256 image pixels. In comparison with the CT method, data losses must be registered. This low resolution results in problems for very filigree contours and in worse surface quality of the models.

Despite of these limitations, we may use MR data to make solid models for everyday medical application.

3.3 Use of the models

In the range of medical applications, research is focussed on the following subjects::

Performing operations on the model with enhanced planning of operations in surgery, to define the access for making the operation since anatomic structures may be accurately represented

Improved preoperative selection of implants and transplants

Application of models means reduced operation times and lower stress for the patient, on the one hand. On the other hand, these models are justified by increased implant and transplant accuracy.

4 FABRICATION AND USE OF MEDICAL MODELS AT THE TU DRESDEN

Since the beginning of 1993, a stereolithographic system has been available at the Institute of Production Engineering of the Dresden University of Technology. Technicians, medical doctors and radiologists cooperated to realise a number of applications especially in craniofacial surgery.

These applications range in preoperative surgical planning and the production of special medical instruments and devices. At present, there are most of all used CT images which are generated by the computer tomograph Somatom of SIEMENS.

Data preparation is performed by corresponding software of the firm Materialise. Since 1993, we have manufactured about 25 total or partial skull models and about 30 upper jaw- or lower jaw models. As regards necessary data preparation, the good contact between treating medical doctor and the application engineer operating the RP equipment was very useful. We could choose the boundaries between the structure to be represented and the surrounding tissue immediately on screen. We were also able to integrate error compensations (artefacts) taken from experience of the medical doctors. For that reason, the modelmaking quality have already been optimized on the screen. Additionally, individual models of various other regions of human anatomy were manufactured.
Up to now, MR data have only been used for test purposes in about 5 models. These are only preliminary investigations for series manufacturing.

5 SUMMARY

Manufacturing of medical models by means of rapid prototyping techniques, especially stereolithography, enables entirely new alternatives to plan and perform medical treatments. Regardless of the problems and difficulties that have been explained before there are obvious advantages for treatments which can be used just now. For example, the stress for the patient may be reduced since the necessary operation time can be diminished in conjunction with optimized operation results. Consequently, treatment may be essentially sped up. As another interesting benefit, reduced operation times also mean lower treatment costs which are subjected to public disputes especially in the FRG. Diagnostic security and the quality of the necessary transplants and implants may also be enhanced. Simultaneously, costs may also be reduced in this field.
The next necessary step is to make possible that health insurances finance the model making as a normal part of the medical care of each patient. When this objective is arrived then all partners of the network can open up a new market. More and more doctors and patient can use this opportunities in the medical daily life.

6 REFERENCES

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