Different Strategies for Rapid Prototyping of Digital Bas-Reliefs

Applied Mechanics and Materials Vol. 510 (2014) pp 163-167
Online available since 2014/Feb/06 at www.scientific.net
© (2014) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMM.510.163

Different Strategies for Rapid Prototyping of Digital Bas-Reliefs

Monica Carfagni[a], Luca Puggelli[b]

Department of Industrial Engineering, University of Florence, Italy

[a]monica.carfagni@unifi.it, [b]luca.puggelli@unfi.it

Keywords: Bas-Relief; Rapid Prototyping Techniques; Artistic Surfaces.

Abstract. In the last decades several computer-based procedures have been devised with the aim of speeding up the 3D reconstruction from a single image in the form of bas-relief. At the same time, the use of rapid prototyping (RP) technology considerably spread enabling quick manufacture of 3D products directly from 3D modelling systems.

The present paper presents a few consideration about different possible strategies for bas-reliefs manufacturing by using the main RP techniques (stereolithography (SLA), selective laser sintering (SLS), fused deposition modeling (FDM) and Polyjet/Multi-jet technology). A practical example is used for discussing pros and cons of the different alternatives.

Introduction

For many products characterized by a strong stylistic content (such as jewels, fashion accessories, ceramics, house-ware, plaques and coins), the design process often produces as a final results a digital 3D model representing sculpted-like, natural or, in general, artistic surfaces in form of bas-relief.

This kind of representation can be obtained directly working from scratch in a 3D modeling software environment (e.g. Rhinoceros, 3D Studio, Maya) or by translating 2D handmade drawings.

With respect to this, in the last decades several computer-based procedures have been proposed in literature with the aim of speeding up the process that allows the 3D reconstruction (in the form of bas-relief) starting from a single image [1-10]. Commercial software [11] has also been developed making available functions for 3D bas-relief reconstruction.

A particular application of bas-relief-like surface generation regards the "translation" of paintings into tactile media for blind people [12-14].

As previously mentioned, the final result consists of a "digital relief" to be used as input for CAM and/or RP systems.

Although a lot of improvements have been done in the past for CAD-CAM integration the gap between CAD and CAM remains partly unfilled in rapid creation of 3D prototypes and in cost-effective production of complex and highly detailed surfaces (as natural or artistic ones) provided in the form of triangulated models (e.g. STL files). This is even more emphasized in case only a single prototype needs to be produced, as for tactile bas-reliefs or, more in general, when a pre-prototype is needed for assessing the outcome of the digital 3D modeling process.

The use of RP technology allowed, in the last 15 years, to overcome many limitations characterizing CAM-based techniques and to permit the manufacturing of 3D objects directly from the digital geometry database in the form of triangulated model. A variety of RP methods have been developed, including stereolithography (SLA), laminated object manufacturing (LOM), selective laser sintering (SLS), fused deposition modelling (FDM), and three dimensional printing [15-17].

Although many RP techniques have become popular and widespread, not all of them are particularly suitable for the specific application, i.e. for the prototyping of bas-reliefs. Moving from these considerations, this paper is meant to provide a brief analysis of the main factors to be taken into account when selecting the most appropriate technology.

Comparison of RP Techniques

As already stated, sculpted-like, natural or, in general, artistic surfaces in form of bas-relief are characterized by fine details and significant depth variability. As shown in Fig. 1 the thickness of the final shape may vary from few millimeters to some centimeters.

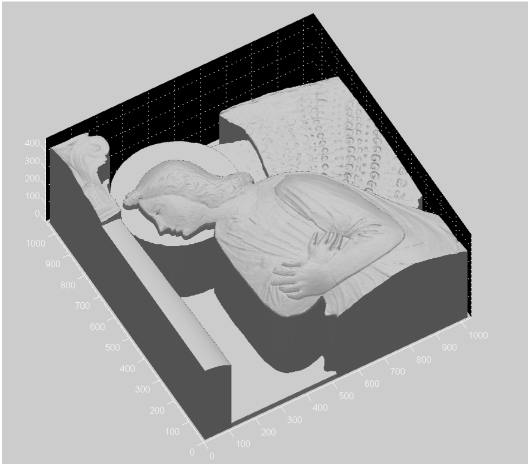


Fig. 1 Thicknesses of bas-reliefs

Since it is assumed that this kind of prototypes are used for a limited time and/or they are produced for aesthetic assessment, the geometry could be reduced to its hull with uniform thickness so that the prototype results robust to the touch.

As a consequence, the main aspects that need to be taken into account to evaluate RP technologies can be summarized as follows:

1. attainable level of detail;
2. surface finishing;
3. material consumption;
4. possible necessity of post-finishing phases (e.g. support removal, hardening treatments).

Due to the huge variety of additive-technologies, the four best known and most widespread ones have been selected for the subsequent analysis: 1. stereolithography (SLA); 2. selective laser sintering (SLS); 3. fused deposition modeling (FDM); 4. Polyjet/Multi-jet technology.

SLA is one of the first and one of the most diffused rapid-prototyping technologies on the market; developed across the latest 80's, it employs a computer controlled-laser to draw the layer cross-section of the part on a blade of liquid polymer that hardens where struck. At the end of this process, the tray on which the part lays lowers to a depth corresponding to the section's thickness, a fresh blade of liquid polymer covers it and the manufacturing proceeds with the following slice, until the whole object is completed. It has to be noticed that, since the model is built in liquid, "the overhanging regions of the part (unsupported below) sag or float away during the building process. The prototypes thus needs some predesigned support until it is cured or solidified" [15]. Post-finishing is required to ultimate surface's quality and the supports need to be removed manually.

Among the best machines available on the market, the one selected for the proposed analysis is iPro™ 8000 produced by 3D System Inc.

Differently from the previous ones, the SLS systems use a laser beam to sinter successive deposited layers of powder instead of liquid. The material is preheated in order to facilitate the sintering process; the unfused powder serves to support the possible overhanging parts, so that no additional supports are required. For this kind of systems, two different machines are selected: EOSINT P 800 and FORMIGA P 110 both produced by EOS GmbH.

The FDM is a diffused RP technology in which a temperature controlled head extrudes a thermoplastic material and draws, slice by slice, each cross-section of the shape, analogously to SLA. Support structures (soluble or not) are needed in case of overhanging parts that have to be removed manually at the end of the process. As sample, it has been selected FORTUS 900mc™, produced by Stratasys Ltd.©.

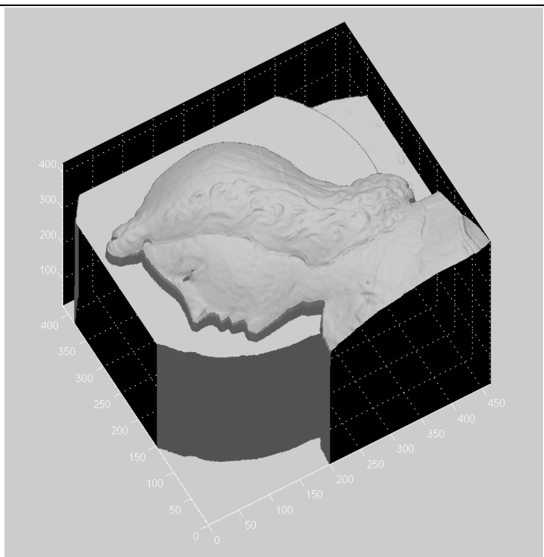
Polyjet and Multi-jet technologies work by jetting a latest-generation photopolymer ultra-thin layers onto a building tray. Each layer is cured by UV light immediately after its deposition. A gel-like material is used to support overhanging parts and has to be removed at the end of the process, with the help of a high pressure water jet cleaner. The selected machine is Objet Eden260V, produced by Stratasys Ltd.©.

With reference to the previously listed requirements, particularly needed in bas-reliefs manufacturing, the characteristics of each selected machine (that represent in brief the most relevant models available on the market) are summarized in the Table 1.

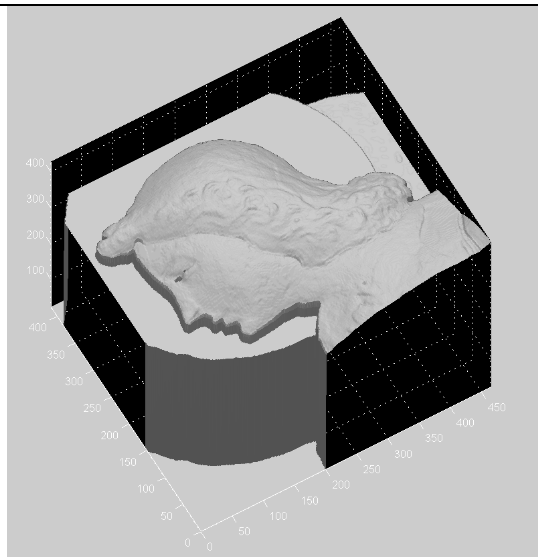
Table 1 Essential characteristics of the selected machines.

Machine	Precision (minimum layer thickness)	Auxiliary support
iPro™ 8000 (SLA)	0.05 [mm]	Y
EOSINT P 800 (SLS)	0.12 [mm]	N
FORMIGA P 110 (SLS)	0.06 [mm]	N
FORTUS 900mc™ (FDM)	0.127 [mm]	Y
Objet Eden260V (Polyjet)	0,016 [mm]	Y

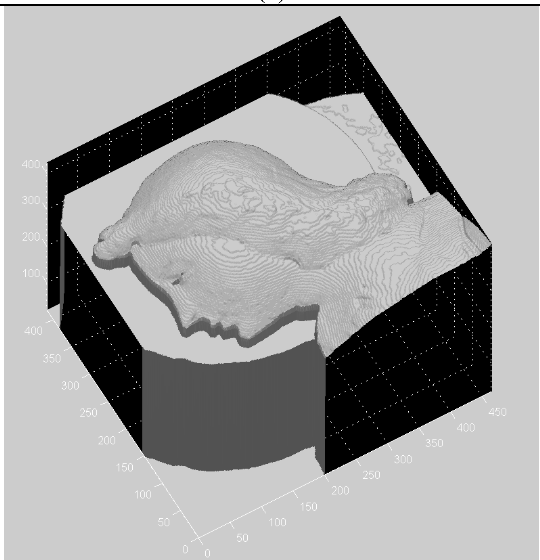
The minimum layer thickness represents a crucial aspect for detail reproduction and surface quality. Figure 2 shows the obtainable quality with reference to the above mentioned maximum precision reachable by each machine. As already mentioned all the considerations are drawn with reference to the exemplificative case study, i.e. the one depicted in fig. 1. whose dimensions are 100 x 100 x 40 mm^3.



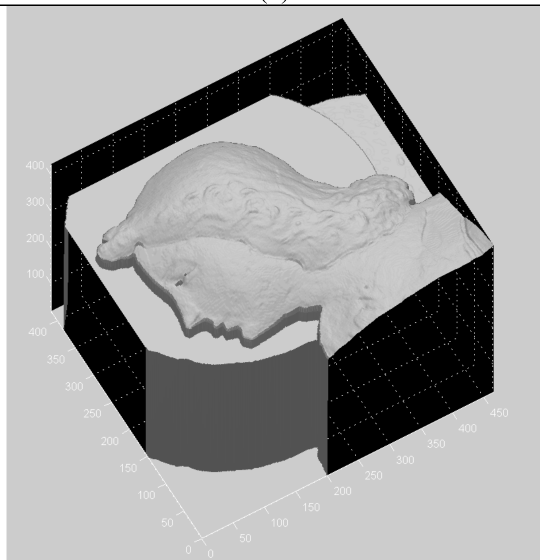
(a)



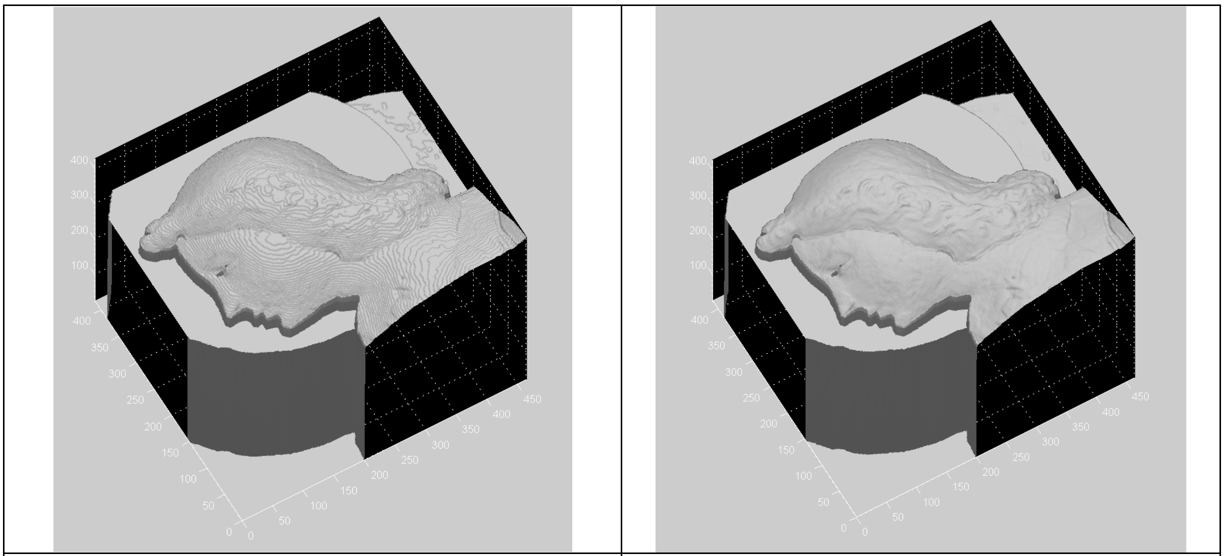
(b)



(c)



(d)



(e) (f)

Fig. 2 (a) Portion of the original 3D model; simulation of surfaces produced by (b) iPro™ 8000, (c) EOSINT P 800; (d) FORMIGA P 110; (e) FORTUS 900mc™ and (f) Objet Eden260V

In case of EOSINT P 800 and FORTUS 900mc™ the stairway effect (noticeable in Fig. 2c e Fig. 2e) is so marked to completely affect the detail level required by the model. Even if the minimum layer thickness produced by these two machines appeared to be small enough, the simulation clearly shows it is not. All the remaining machines have a degree of precision adequate and more than adequate (in case of Object Eden260V) for the purpose for which they have been analyzed.

A second aspect is related to material consumption which, for simplicity, is also assumed to be related to prototype cost and production time.

As already mentioned, due to the particular application, a suitable production strategy could be to realize a uniform thickness hull instead of a massive prototype. Unfortunately, from this point of view many of the analyzed prototyping technologies are not convenient.

FDM needs supports realized in the form of a hatched region, however these supports require a lower amount of material per volume unit of the object and are easily removable since they are soluble; SLA needs to provide the model with appropriate supports in the form of a thin reticulate of the same material used for the prototype which is not soluble; Polyjet technology completely fills all the parts underneath the prototype with support material which approximately has the same cost of the base one and has to be manually removed; SLS does not need any support (so that a considerably lower amount of material is necessary) and only a cleaning phase is required.

All considered, the best option for realizing bas-reliefs appears to be FORMIGA P 110. In fact, in this case, it is possible to realized the hull of the model since no supports are required. Moreover such machines doesn't require particular post-finishing process and a sufficient layer thickness is provided by this machines. However, the fact that, for its own nature, sintering process produces prototypes characterized by quite high roughness should be taken into account in case the products are meant to be touched.

On the other hand, in case of hull simplification (usable for instance in case of a mere aesthetic assessment) is not considered a valid option, Object Eden260V is the best choice since it allows to represents also finer details with respect to FORMIGA P 110.

Summary

In the present works a number of the best known and most widespread rapid prototyping machines have been analyzed with the aim of assessing which is the most suitable in building sculpted-like, natural or, in general, artistic surfaces in form of bas-relief. The analysis shows that some latest Selective Laser Sintering machines characterized by thin material layers are particularly suitable for the purpose.

References

[1] Remondino, F. and S. El-Hakim, *Image-based 3D Modelling: A Review.* The Photogrammetric Record, 2006. **21**(115): p. 269-291.

[2] Stylianou, G. and A. Lanitis, *Image based 3d face reconstruction: a survey.* International Journal of Image and Graphics, 2009. **9**(02): p. 217-250.

[3] Huang, Z.K., et al., *A New Embossing Method for Gray Images Using Kalman Filter.* Applied Mechanics and Materials, 2011. **39**: p. 488-491.

[4] Weyrich, T., et al., *Digital bas-relief from 3D scenes.* ACM Transactions on Graphics (TOG), 2007. **26**(3): p. 32.

[5] Sun, X., et al., *Bas-relief generation using adaptive histogram equalization.* Visualization and Computer Graphics, IEEE Transactions on, 2009. **15**(4): p. 642-653.

[6] Governi, L., et al., *Digital Bas-Relief Design: a Novel Shape from Shading-Based Method.* Computer-Aided Design and Applications, 2013. **11**(2): p. 153-164.

[7] Kerber, J., et al., *Real-time generation of digital bas-reliefs.* Computer-Aided Des. Appl, 2010. **7**(4): p. 465-478.

[8] Furferi, R., et al., *3D model retrieval from mechanical drawings analysis.* International Journal of Mechanics, 2011. **5**(2): p. 91-99.

[9] Governi, L., et al., *3D geometry reconstruction from orthographic views: A method based on 3D image processing and data fitting.* Computers in Industry, 2013.

[10] Governi, L., et al., *Improving surface reconstruction in Shape from Shading using easy-to-set boundary conditions.* International Journal of Computational Vision and Robotics, forthcoming 2013.

[11] Wang, M., J. Chang, and J.J. Zhang. *A review of digital relief generation techniques*. in *Computer Engineering and Technology (ICCET), 2010 2nd International Conference on*. 2010. IEEE.

[12] Oouchi, S., K. Yamazawa, and L. Secchi, *Reproduction of Tactile Paintings for Visual Impairments Utilized Three-Dimensional Modeling System and the Effect of Difference in the Painting Size on Tactile Perception*, in *Computers Helping People with Special Needs*, K. Miesenberger, et al., Editors. 2010, Springer Berlin Heidelberg. p. 527-533.

[13] Carfagni, M., et al., *Tactile representation of paintings: An early assessment of possible computer based strategies.* Progress in Cultural Heritage Preservation, Lecture Notes in Computer Science 2012. **7616 LNCS**: p. 9.

[14] Volpe, Y., et al., *Computer-based methodologies for semi-automatic 3D model generation from paintings.* Int. J. Computer Aided Engineering and Technology, 2014. **6**(1): p. 25.

[15] Yan, X. and P. Gu, *A review of rapid prototyping technologies and systems.* Computer-Aided Design, 1996. **28**(4): p. 307-318.

[16] Chua, C.K., K.F. Leong, and C.C.S. Lim, *Rapid prototyping: principles and applications*. 2010: World Scientific.

[17] Noorani, R., *Rapid prototyping*. 2006: Wiley.

Materials Engineering for Advanced Technologies (ICMEAT 2013)
10.4028/www.scientific.net/AMM.510

Different Strategies for Rapid Prototyping of Digital Bas-Reliefs
10.4028/www.scientific.net/AMM.510.163