Design and manufacture of life size human model using material extrusion and vat photopolymerization additive processes

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Abstract. Nowadays, Additive Manufacturing (AM) is increasingly being used in various fields of medicine. Using Material Extrusion additive process - Fused Filament Fabrication (FFF) method are produced 3D models of organs or body parts designed for preoperative planning, individual prosthetic and orthopaedic appliances and others. The Vat Photopolymerization additive process – Stereolithography (SLA) method is used to produce precision hearing aids, wearable assist devices, prosthetics, orthotics and so on. The content of the article describes the process of designing and manufacturing the life size human model to show the possibilities and advantages of using selected additive methods in the field of medicine and thus pointing out the versatility of using the AM technology on a concrete example. The aim of this article is to provide an up-to-date practical application of FFF and SLA additive methods in the fast-growing field of AM and to present to the reader a specific example of the use of AM with the idea of raising a better general understanding and supporting research into the use of AM technology in medicine.

1 Introduction

Medical applications for AM are expanding and are expected to revolutionize the field of medicine. Medical uses for AM can be organized into several broad categories, including: creation of customized prosthetics, implants, and anatomical models; tissue and organ fabrication and pharmaceutical research regarding drug dosage forms, delivery, and discovery [1].

There are many benefits in using AM in the field of medicine such as a customization and personalization, increasing cost efficiency, enhanced productivity and other. The great advantage that AM provides in medical applications is the freedom to produce custom-made medical products and equipment. The custom-made implants, fixtures, medical models and surgical tools have a positive impact in terms of the time required for surgery, patient recovery time, and the success of the surgery or implant [1-6].

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Another important benefit is the ability of manufacturing medical aids and equipment at low prices. The AM is becoming more competitive and cheaper compared to conventional manufacturing methods for small production of models. This is particularly true in the medical field, where implants and other medical aids and equipment are required to be design and manufacture to fit an individual patient [1-3].

The article deals with the design and manufacture of a life size human model using the Material Extrusion (FFF method) and Vat Photopolymerization (SLA method) additive processes serving to visualize the human body shape and skeleton for medical purposes. In this case, the AM technology also seems to be the optimal solution for the production of a human medical model that can serve both the needs of doctors and patients themselves.

2 Design of life size human model

The Cinema 4D computer software was chosen for the design of life size human model. This software is using for 3D modelling, polygonal modelling, animating, motion graphic and rendering applications and is developed by MAXON Computer GmbH.

The life size model of a human body consists of the skeleton and the contour of the body, i.e. it is a model without muscles and internal organs. This model serves as a visual demonstration of a human skeleton placed inside the body, which is transparent for skeletal visibility. The process for designing and modifying a 3D model to the desired state will be described below.

The 3D model of the body and skeleton in Standard Tessellation Language (STL) format was obtained from a web library and served as a default model (Fig.1a). The 3D model was adjusted according to desired function of the medical model. At first, the interconnected models were separated into a separate skeleton 3D model and a separate body shape 3D model. This was necessary due to modifications of the individual parts on the skeleton and also on the body (Fig.1c).

Fig. 1. Modifications of 3D models: a) default interconnected 3D models, b) 3D models with modified hand position and c) two separated 3D models of body shape and skeleton.

The default 3D model made it possible to adjust the position of the body (Fig.1b). The knowledge from the experiments mentioned in the articles [7, 8] were beneficial to appropriate adjustment of the necessary modifications of the digital model as well as the production process parameters of the individual parts of the skeleton model. In the process of designing and manufacturing a human body model, the following problems had to be addressed: low number of digital model polygons in STL format, open parts of the model, need of splitting the models into parts according to the size of the production machine platform and necessity of modifying of individual parts of the skeleton model necessary for their subsequent joining. Increasing the number of polygons in polygonal model (Fig. 2) caused various model defects due to the fact

that the model was a complex shape object, but it was necessary in order to increase the resulting surface quality of the produced model. Digital model defects such as holes or missing triangles caused by the software optimization algorithm, had to be modified manually. The bones of the skeleton model were joined together. There were gaps between the bones because in the human body, this space is filled with cartilage. These gaps were filled and thus the individual bones were joined (Fig. 2 b, c, e).

Fig. 2. Modifications of 3D models of bones: a) default polygonal mesh, b) increased the number of polygons and filled gaps, c) zoom into the modifications of bone model, and d), e) default and increased number of polygons and filled gaps.

The joints of the individual models had to be adjusted so that the individual parts of the model stabilized with each other in the desired position and at the same time form a sufficiently strong joint. In this case, a solution using pin-hole joining was proposed. Here it was necessary to design the optimum pin-hole dimensions with regard to the shrinkage of ABS material during and after the production of bone models. Since the shrinkage of the material depends on the infill (internal structures of models), the shape, the size of the model, and many other parameters, some experimentally verified information had to be used. Based on the publications [7, 8] the dimensions of the individual parts of the bone models have been adjusted for production by the additive FFF method.

However, it was not enough to use information from published experiments alone to determine the optimum pin-hole size, but it was necessary to perform the experiment in our particular case. The pin was designed with a diameter of 20 mm and a length of 60 mm. This was subsequently produced in the required number as a separate model, thus, while maintaining the same production parameters, the shrinkage had the same value for all produced pin models. The determination of the hole dimensions was the aim of an experiment in which several samples of pin-hole joints were produced and tested with different hole enlargement values.

Table 1. Table containing selected values of tested samples.

Sample number	Hole diameter 20 mm	Value of increasing (mm)	Value of increasing (%)	Diameter with the increased value (mm)
n. 1	20	0,05	0,25	20,05
n. 2	20	0,10	0,50	20,10
n. 3	20	0,15	0,75	20,15
n. 4	20	0,20	1,00	20,20
n. 5	20	0,25	1,25	20,25
n. 6	20	0,30	1,50	20,30
n. 7	20	0,35	1,75	20,35

Considering the information available from the above-mentioned publications and the experiment performed, value of 1.50% increasing was used in the design of skeleton models, representing a hole diameter of 20.30 mm. It is also important to note that a 90%

infill setting was used around the hole. Infill setting of the model around the hole also has a significant effect on the shrinkage of the hole itself. In order to determine the exact numerical values of shrinkage of the models, it would be necessary to obtain a digital model of the produced models by e.g. 3D digitization technology and then compare them with nominal models, but this was not the idea of the article. Since it was necessary to place the light-emitting diodes in certain places on the skeleton, especially in hip and knee joints or spine, the several holes were created in these places for the purpose of placement these diodes. The platform was also designed. The role of this platform was to stabilize the entire model (skeleton and body) as well as to locate electronic components (Fig. 3 b, c).

Fig. 3. Modifications of skeleton models : a) zoom view on the pin-hole joint, b) models of bones joined to platform and c) view at the separate models ready for AM

After the skeleton was completely modified, then the body shape 3D model was modified. There was also important to increase a number of polygons (Fig. 4 a), dividing the body model into multiple parts (Fig. 4 b) as well as to create a 4 mm body wall thickness (Fig. 4 c). The manufacturing of models with a 4 mm wall thickness significantly reduces productions time, material consumption and the weight of the model itself compared to a full body model. To ensure the accurate positioning and stiffness of body shape 3D model, prismatic connections between individual body parts have been proposed. Body transparency was another important factor that influenced the choice of creating a certain wall thickness.

Fig. 4. Modifications of body shape model: a) increased the number of polygons, b) divided model into multiple parts and c) prismatic joint of hand models with a thickness of 4 mm.

3 Manufacture of life size human model

The Material Extrusion additive process, specifically, the FFF additive method was chosen for manufacturing of 3D skeleton model. This method is one of the most common and also the most used AM method in practice. Fused thermoplastic fibres are extruded

from the tip of a heated nozzle that moves in the X and Y axes. Thin fibres are deposited on a platform that has a significantly lower temperature, which ensures fast cooling of the melted thermoplastic. After the platform has been reduced to a precisely defined thickness of one layer, another layer is deposited. The Omni Factory 2.0 (Omni3D) and Sigmax R19 (BCN3D Technologies) production machines were used for the production of skeleton from Acrylonitrile Butadiene Styrene (ABS) plastic material [9-14].

The Vat Photopolymerization additive process, specifically, the SLA additive method was chosen for manufacturing of 3D model of body shape. Using this method, models are made of liquid photopolymer that is cured by ultraviolet (UV) light. The formed parts are made of plastic material layer by layer by precise movement of the laser beam after liquid photopolymer. This type of material instantly solidifies under the UV light action. After the production process is completed and finished, the model is lifted out of the container, placed in a UV oven, which is not only dried but also additionally hardened and cured. The ProX 800 3D printer (3D Systems) production machine was used for production of body shape model from VisiJet Clear plastic material [15-18].

Fig. 5. The final additive manufactured 3D model of life size human body.

4 Conclusions

The AM technology was chosen to produce a life size human model consisting of the skeleton and the body shape. This technology has been chosen mainly because of the production of complex shapes from which the 3D model was created. In particular, the skeleton is composed of many complex shapes, the complexity of which has been enhanced by the necessity of adjusting the internal structure due to the location of the light-emitting diodes and joining elements. The FFF additive method was chosen due to the fact that the method can be used to produce models with different percentages of infill, thereby achieving a significant reduction in final model weight, material savings, time and thus cost of production. In the manufacturing of the body shape model, it was necessary to choose a transparent material that would allow to clearly see the skeleton and the places illuminated by the diodes. The choice of SLA additive method was due to its high accuracy, speed, transparency of the material and smooth surface of the models produced. The main advantages of using the FFF and SLA

additive methods in this case was: automated production, speed of introduction of possible changes into the production process, possibility of producing complex shapes and internal structures, saving material consumption, time and cost. The main aim of this article was present to the reader a specific example of exploitation of AM with main advantages and the idea of raising a better understanding and importance of this technology and supporting research into the use of AM in medicine.

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