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Determination of Material Density by Means of Computerized Tomography

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Abstract: When evaluating dimensions, the crucial thing is the closest possible determination of a surface. Industrial computerized tomography works with relative material densities, therefore, unlike in medical fields, there is no need to assign particular density to individual shades of grey. In some cases, however, determination of material density or a variation of its density in a selected area is required. To establish the percentage of variation in density of a material, any surface determination is sufficient, as a ratio of two relative values is calculated therefrom.

Keywords: computed tomography, density, isosurface

1. Introduction

Treatment of morphological disorders of mandibular structure is intended to improve appearance and function, achieve proper occlusion, correct proportions, facial length and mandibular rami, as well as good shape of the chin [1, 2]. The facial region is a particularly difficult one to treat, since many delicate anatomical structures are found here. Less extensive disorders can be treated orthopedically, however the majority of disorders require surgical treatment.

Several factors influence determination of density by means of computerized tomography:

1. ***Material*** *– the denser the material, the less precise determination of its density. With denser materials, the number of artifacts rises (beam hardening, scattering, ...).*
2. ***Form*** *– the more complex the form of the scanned object, the more the radiation scatters on its surface, thus the scattering possibility increases. The denser the object, the more pronounced the phenomenon.*
3. ***Cumulative material thickness*** *– the greater the cumulated thickness and density, the greater the material "non-homogeneity" due to non-homogeneity and X-ray radiation absorption. This effect is present in simple forms, too (a block, a cylinder...). Surfaces of metallic materials are subject to emergent beam hardening.*

2. Methodology of the Experiment

Samples with known density were selected for the experiment. To avoid as many effects on measurement as possible, plastic samples were chosen. Tab. 1 presents particular types of material and their densities as per the respective material lists.

Individual samples used are of rectangular and cylindrical form of different sizes. The plastic objects were put into a space-efficient arrangement, with the plastic objects separated from one another by polystyrene.

The effect of scanned parameters and the effect of the use of a copper filter on

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Tab. 1: *Material types and their densities.*

Material	Density [kg.m^{-3}]
Polypropylene (PP)	910
Polyamide (PA)	1140
Polyvinyl chloride (PVC)	1420
Polytetrafluorethylene (PTFE)	2160

scanning results was observed in course of scanning.

Four scanning steps were observed. All samples were scanned simultaneously in course of the first two scanning procedures, while scanning parameters were modified depending on a filter used. The sample arrangement is shown in Fig. 1. below.

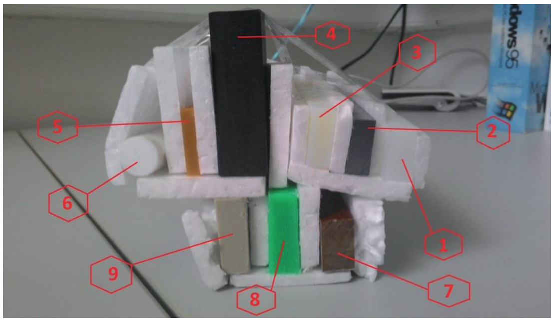

Fig. 1: *Scanning sample arrangement.*

1 - Polyethylene, 2 – Polyvinylchloride, 3 - Polyamide, 4 - Rubber, 5 - Polyurethane, 6 - Polytetrafluorethylene, 7 - Textolite, 8 - Polyethylene, 9 - Polypropylene

Reconstructed samples were analyzed in an analyzing software VGStudio MAX v.2.2 (Fig. 2) from Volume Graphics (Germany). This software helped analyze CT values and the measured objects' surfaces. An exact edge was determined by the ISO-50% method.

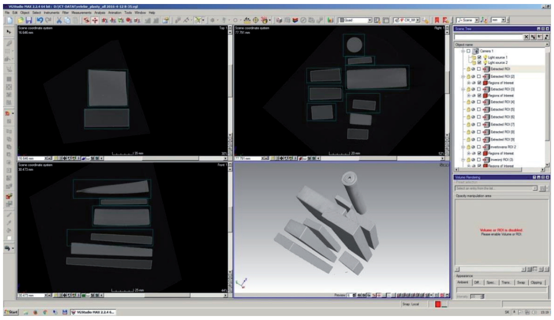

Fig. 2: *Sample imaging and their reconstruction in VGStudioMAX.*

To obtain relevant information from the given segments, the set thus generated had to be further separated into individual samples measured. The reason for segmentation is correct surface determination. Had the segmentation been skipped, the surface of a portion of materials would not have been determined correctly. An automatic material detection function was applied to material separated into individual portions. Because material homogeneity was assumed, as was the relative low density of the evaluated materials, manual selection of material was not necessary. Fig. 3 shows a histogram and an isosurface value (yellow frame) of a selected sample. In the upper part of the figure, surface and material values are highlighted.

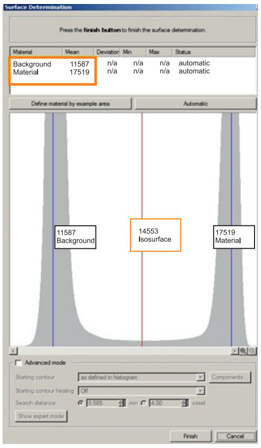

Fig. 3: *Histogram and isosurface, air and material value presentation.*

As precise as possible material surface determination is necessary to obtain the volume of an evaluated object, which can be further used for calculating the material density. The sample's volume value is highlighted in Fig. 4.

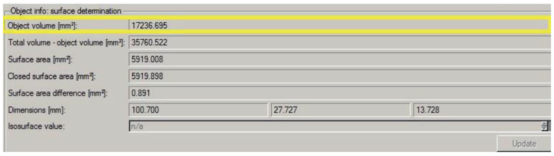

Fig. 4: *Selected material sample volume.*

To calculate their density, individual samples need to be weighed. The weighing was carried out by the use of laboratory scale Nagata FATH 06S with the weighing range of 300g and a ±0,1g deviation.

2. Material Density Evaluation

Sample scanning with a copper filter

A 0.25mm-thick copper filter was used in scanning to remove soft radiation and contingent beam hardening. Filter deployment is not conventional with plastics, but in some directions, the material features great cumulative thickness with a potential to translate into non-homogeneities.

Scanning results concerning all samples, with the use of the filter, are presented in Tab. 2, with particular materials listed as per their catalog density.

Sample scanning in the absence of a copper filter

Filterless scanning was performed with a lesser current, as no filter loss needed to be compensated for.Tab. 3 presented results of measurements without the filter. Particular materials are listed as per their catalog density.

3. Result summary

This subchapter contains an analysis and an overall summary of the obtained results. Out of the latter, the isosurface value, the sample's volume obtained from the analysis, and the calculated density value merit further processing. The value of grey in the background and that of the material is unimportant due to dependence of the former on scanning, and the value of a sample's weight is constant for each material type.

Thanks to data from scanning all material types with the use of the filter as well as without its use, a summarizing Tab. 4 could have been produced.

The summarizing table (Tab. 5) makes it possible to determine differences between scanning with a filter and without one, where the difference between the parameters compared is expressed in an absolute value.

Tab. 2: *Values obtained in filter measurements.*

	Value of grey			Sample properties		
Material	**Background**	**Material**	**ISO surface**	**Volume [$10^{-6}m^3$]**	**Weight [$10^{-3}kg$]**	**Density [$10^{3}kgm^3$]**
Polypropylene	11587	16924	14553	21.925	20.10	0.9167
Polyamide	11677	18474	15076	12.159	13.84	1.1382
Polyvinylchloride	11745	25378	18561	19.760	27.08	1.3703
Polytetrafluorethylene	11640	24518	18709	13.696	29.52	2.1552

Tab. 3: *Values obtained in filterless measurements.*

	Value of grey			Sample properties		
Material	**Background**	**Material**	**ISO surface**	**Volume [$10^{-6}m^3$]**	**Weight [$10^{-3}kg$]**	**Density [$10^{3}kgm^3$]**
Polypropylene	8942	13762	11352	22.029	20.10	0.9124
Polyamide	8992	15109	12050	12.056	13.84	1.1479
Polyvinylchloride	9144	16174	12815	6.109	7.61	1.2455
Polytetrafluorethylene	8902	21548	15225	13.343	29.52	2.2122

Tab. 4: *Summarizing table including all samples*

	Filter scanning			Filterless scanning		
Material	**Background**	**Material**	**ISO surface**	**Volume [$10^{-6}m^3$]**	**Weight [$10^{-3}kg$]**	**Density [$10^{3}kgm^3$]**
Polypropylene	14553	21.925	0.9167	11352	22.029	0.9124
Polyamide	15076	12.159	1.1382	12050	12.056	1.1479
Polyvinylchloride	15500	6.250	1.2174	12815	6.109	1.2455
Polytetrafluorethylene	18709	13.696	2.1552	15225	13.343	2.2122

Tab. 5: *Difference in scanning with a filter and without one*

	Difference			Difference in percentage value		
Material	**Background**	**Material**	**ISO surface**	**Volume [$10^{-6}m^3$]**	**Weight [10^{-3}kg]**	**Density [$10^{-3}kgm^3$]**
Polypropylene	3201	0.104	0.0043	21.9955	0.4743	0.4691
Polyamide	3026	0.103	0.0097	17.3226	0.8471	0.8522
Polyvinylchloride	2685	0.141	0.0281	17.2613	2.2560	2.3082
Polytetrafluorethylene	3484	0.353	0.057	18.6221	2.5774	2.6448

4.Conclusion

The analysis of the obtained data leads to a conclusion that notwithstanding a relatively great percentage variation in the isosurface value (15-22%), the percentage difference in density deviates from the value listed in catalog by less than 3%, with the deviation being greater in materials displaying greater density.

Real density of individual samples subject to experiment has not been determined by any other, more precise methodology, therefore the percentage difference from a sample's real density cannot be determined.

Considering the fact that we do not know real densities of the materials in question (it is our assumption they are similar to the values listed in the respective catalogs) and in the light of the obtained results, the computerized tomography is a suitable method for obtaining densities of plastic materials.

5. Acknowlegment

The work was supported by research grant „Metrological processing of biomedical data obtained by 3D scanners for educational purpose" (KEGA 063TUKE-4/2016) and „Researche of .contact and contactless strategies for coordinate measurement of freeform objects" (VEGA 1/0182/15).

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