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Information technology — 3D printing and scanning — Assessment methods of 3D scanned data use in 3D printing

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Foreword

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Introduction

This document was developed in response to the need for quality management of 3D printing and scanning technology through the use of information and communication technology (ICT).

3D scanning is the process of scanning a real-world object or environment to collect data on its shape and possibly its style attributes. The main purpose of 3D scanning is for generating high-precision digital 3D models.

A 3D scanner can be based on many different technologies, each with its own purposes and targets, limitations, and advantages. There could be many limitations in each type of target object that will be digitized. For example, optical technology often encounters many difficulties with dark, shiny, reflective, or transparent objects. Another example, as for computed tomography scanning, structured-light 3D scanners, and LiDAR technology, the generation of digital 3D models requires the use of non-destructive internal scanning technology.

Despite the rapid growth of 3D scanning applications, the accuracy, precision and reproducibility of generated 3D models from 3D scanned data have not been thoroughly investigated. Especially if 3D scanned data are used for 3D printing, their accuracy and precision are critical. Inaccuracies can arise due to errors that occur during the imaging, segmentation, postprocessing, and 3D printing steps. The total accuracy, precision, and reproducibility of 3D printed models are affected by the sum of errors introduced in each step involved in the creation of the 3D models.

For the spreading of 3D printing applications, it is necessary to review and evaluate the various factors in each step of the 3D model printing process that contribute to 3D model inaccuracy, including the intrinsic limitations of each printing technology.

In this context, it is important to evaluate the overall process of data processing. In order to minimize cumulative errors throughout the 3D printing life cycle using 3D scanned data, it is important to evaluate and correct initial errors. By identifying and addressing these initial inaccuracies, the impact of errors occurring during the 3D printing process can be greatly reduced. In addition, the method used to evaluate 3D scan data for 3D printing is also essential.

There are many algorithms for 3D scanned data such as semi-automatic segmentation, deformable model-based segmentation, and Convolutional Neural Network based segmentation. There are several well-known errors during image-based modelling of Region of Interest (ROI), which are over segmentation, under segmentation, outlier, inaccurate contour, and malalignment. Even though there are more than twenty metrics for evaluating 3D image segmentation, there is no consistent definition of metrics and suitable combination of assessment metrics for 3D printing.

Segmentation assessment is the task of comparing two segmentations by measuring the distance or similarity between them, where one is the segmentation to be assessed and the other is the corresponding ground truth segmentation.

There are three major requirements (accuracy, precision, and efficiency) of assessment for 3D scanned data. Accuracy is the degree to which the segmentation results agree with the ground truth segmentation. Precision is a measure of repeatability. Efficiency is mostly related with time.

This document proposes assessment methods for 3D scanned data to evaluate and enhance the quality of 3D printing models while minimizing errors.

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Information technology — 3D printing and scanning — Assessment methods of 3D scanned data use in 3D printing

1 Scope

This document specifies methods and metrics for assessing the accuracy and precision of 3D scanned data for use in 3D printing, throughout the full 3D printing lifecycle.

This document focuses mainly on 3D scanned data from computed tomography. Computed tomography can acquire information concerning the internal structures, regional density, orientation and/or alignment of scanning objects, as well as their shape and appearance.

This document is applicable to the assessment of image-based modelling, segmentation, and 3D models.

This document is not intended to assess the 3D printed product itself.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1 Terms and definitions

3.1.1
assessment
act of judging or deciding the amount, value, quality, or importance of something, or the judgment or decision that is made

3.1.2
contour
shape of an anatomical structure or part of body, especially its surface or the shape formed by its outer edge

3.1.3
enhancement
process of improving the quality, amount, or strength of something

3.1.4
Euclidean distance
length of a line segment between the two points in Euclidean space

3.1.5
normalization
changing of the values of numeric columns in the dataset to use a common scale, without distorting differences in the ranges of values

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3.1.6
reference image
image that is assumed to have perfect quality

3.1.7
region of interest
ROI
boundary of a specific object defined in the image

[SOURCE: ISO/IEC 3532-2:2024, 3.7]

3.1.8
segmentation
process of separating the objects of interest from their surroundings

Note 1 to entry: segmentation can be applicable to 2D, 3D, raster or vector data.

Note 2 to entry: segmentation method: terms and definition standardized by ISO [ISO 13322-1:2014(en)].

3.1.9
segmented image
separated image extracted from original image with ROI

3.1.10
ground truth
ground truth label
correct answer of the training set for segmentation based on supervised learning

[SOURCE: ISO/IEC 3532-2:2024, 3.6]

Note 1 to entry: “The term for 3.6 of ISO/IEC 3532-2:2024 is “ground-truth label”, the “ground truth” is added in this document.

3.2 Abbreviated terms

ARI	adjusted rand index
AUC	area under ROC curve
AVD	average Hausdorff distance
CT	computed tomography
DICOM	digital imaging and communications in medicine
DSC	Dice similarity coefficient
FMS	F-measure
FN	false negative
FNR	false negative rate
FP	false positive
FPR	false positive rate
GCE	global consistency error
HD	Hausdorff distance
ICC	interclass correlation

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JAC	Jaccard index
KAP	Cohens kappa measure
MHD	Mahalanobis distance
MI	mutual information
PBD	probabilistic distance
RI	Rand index
3D	three dimensional
TN	true negative
TNR	true negative rate
TP	true positive
TPR	true positive rate
2D	two dimensional
VOI	variation of information
VS	volumetric similarity

4 Assessment

4.1 General

4.1.1 Background

Precision, accuracy and efficiency of image processing of 3D scanned data are essential for the application of 3D printing. At the very beginning of image processing, the segmentation methods should be high-precision and accurate. Therefore, assessing the accuracy and quality of the segmentation process and related algorithms is very important.

Image segmentation has different quality aspects.

a) generality for evaluation; the assessment method should be applicable to most of the assessment of image segmentation for 3D scanned data processing.

b) subjective versus objective; currently, mostly subjective assessments exist, conducted by experienced image experts or image processing experts for 3D printing. Even though many objective assessment methods also exist, those are not standardized for 3D scanned data for the 3D printing model.

c) complexity for evaluation; most of the 2D images from computed tomography are pixel or voxel based planar images. In the context of the 3D printing model, image processing reconstructs these images into 3D images which are mostly STL file format or surface mesh format. Most assessment methods for image segmentation are based on overlap, volume, information theory, probabilistic distance, and pair counting. There are more than twenty evaluation metrics for these assessments for image segmentation. In general, practice in automatic segmentation algorithms and manual segmentation are mixed. Additionally, for 3D printing, volume and alignment of 3D scanned data are important. So, current evaluation metrics cannot afford to properly assess the image segmentation of 3D scanned data for 3D printing.

d) evaluation requirements for reference images; current image segmentation algorithms use ‘feature-based or texture-based’ methods. Those algorithms are assessed using 'reference images,' known as

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