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(54) Title: METHOD FOR AUTOMATED 3D PRINT QUALITY ASSESSMENT AND REDESIGN

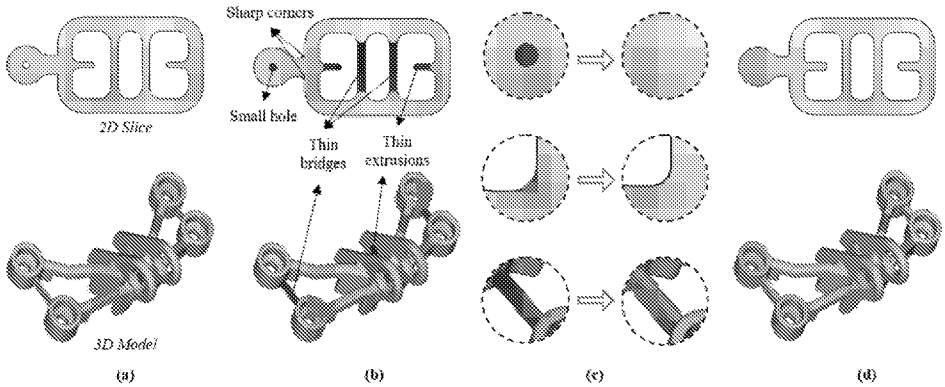

Fig. 1

(57) Abstract: Shape diameter-based approaches to identifying and correcting 2D slices of 3D models (or the 3D models themselves) are provided for improved manufacturability. Using the present approaches, critical error-prone regions in 2D slices or 3D models can be identified, including thin extrusions and bridges, sharp corners, small holes, and narrow intrusions. The areas of these regions can be computed and used to quantify the printability of the slices or models. The boundaries of slices or models can be modeled as mass-spring-damper systems for performing local deformations to correct error-prone regions. External forces, that are a function of shape diameters and interior angles, can be imposed on the modeled systems for this purpose.

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[Continued on next page]

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INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER

IPC - G06F 17/50, G06T 19/20 (2019.01)

CPC - G06T 2219/008, G06F 17/50, Y02P 90/265 20151101; G06T 19/00, G06F 17/5086, B33Y 50/00, G06F 2217/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y --- A	Tedia et al. "MANUFACTURABILITY ANALYSIS TOOL FOR ADDITIVE MANUFACTURING USING VOXEL-BASED GEOMETRIC MODELING." In: Proceedings of the 27th Annual International Solid Freeform Fabrication Symposium ? An Additive Manufacturing Conference, August 2016, [online] [retrieved on 02 January 2020 (02.01.2020)] Retrieved from the Internet < URL: https://sffsymposium.engr.utexas.edu/sites/default/files/2016/001-Tedia.pdf >, entire document, especially Abstract; page 2-5, 12-15	1-2, 7-9, 13 ---------- 3-6, 10-12
Y -- A	Chen et al. "Fast and robust shape diameter function." In: Fast and robust shape diameter function. PLoS ONE 13(1): e0190666., 26 January 2018, [online] [retrieved on 02 January 2020 (02.01.2020)] Retrieved from the Internet < URL: https://doi.org/10.1371/journal.pone.0190666 >, entire document, especially Abstract; page 1-6, 1-12	1-2, 7-9, 13 ---------- 3-6, 10-12
A	US 2015/0269282 A1 (Palo Alto Research Center Incorporated), 24 September 2015 (24.09.2015), entire document	1-13
A	US 2013/0297059 A1 (AUTODESK, Inc.), 07 November 2013 (07.11.2013), entire document	1-13

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03 January 2020	17 JAN 2020
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Lee Young Telephone No. PCT Helpdesk: 571-272-4300

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 19/46068

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

--- (See Continuation in Supplemental Box) ---

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
Claims 1-13

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 19/46068

Continuation of:
Box III. Observations where unity of invention is lacking

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I - Claims 1-13 are directed to a method for automatically determining thin features of a slice of a 3D model.

Group II - Claims 14-18 are directed to a method of determining sharp corners of a 3D model.

Group III - Claims 19-20 are directed to a method of determining small holes of a slice of a 3D model.

Group IV - Claims 21-25 are directed to a method of determining a printability of a 3D model comprising a plurality of slices.

The inventions listed as Groups I-IV do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Special Technical Features:

The invention of Group I included the features of calculating a vertex normal, calculating an inward vertex normal; tracing a pre-determined number of rays from each vertex; calculating a distance of travel for each ray before a first intersection with the at least one boundary of the slice; calculating a shape diameter function for each vertex as the average of distances of travel for the rays of such vertex, not required by any other group.

The invention of Group II included the features of calculating an interior angle formed at each vertex by adjacent vertices; determining the vertices having interior angles less than a pre-determined lower threshold as a convex sharp corner; determine each vertex having an interior angle greater than a predetermined upper threshold as a concave sharp corner, not required by any other group.

The invention of Group III included the features of calculating a dilation of the slice using a circular structuring element having diameter r; calculating an erosion of the slice using a circular structuring element having diameter r; identifying any boundaries or portion of the at least one boundary of the slice closed as a result of the dilation and erosion as small holes and/or narrow intrusions; and generating an output showing the identified small holes and/or narrow intrusions, not required by any other group.

The invention of Group IV included the features of calculating an area of each slice; calculating an area of thin regions of each slice; calculating an area of convex sharp corners of each slice; calculating an area of small holes, narrow intrusions, and concave corners of each slice; and determining a printability index using the claimed equation, not required by any other group.

Common Technical Features

Groups I-III share the features of obtaining a slice of a 3D model to be printed on a printer having a printer resolution, wherein the slice has at least one boundary defined by boundary edges and vertices.

Groups II and IV shares the feature of convex sharp corners and concave sharp corners.

However, the shared technical features do not represent a contribution over prior art as being anticipated by US 2015/0269282 A1 (Palo Alto Research Center Incorporated), 24 September 2015 (24.09.2015).

Palo Alto Research Center Incorporated teaches obtaining a slice of a 3D model to be printed on a printer having a printer resolution (r), wherein the slice has at least one boundary defined by boundary edges and vertices v (Fig. 5B; para [0014], [0077]-[0078], - Slices of the 3D model are received; slices represent 2D solids of the 3D model to be printed in corresponding print layers; polygons that define the boundary of a slice; printer resolution); convex sharp corners and concave sharp corners (Fig. 5B; para [0077]- inward and outward polygon offset that will automatically capture rounded corners, and the white-hat transform, which is the set difference between the polygon and its opening, which will capture the low resolution regions of the model).

As the common features were known in the art at the time of the invention, this cannot be considered a common technical feature that would otherwise unify the groups. Therefore, Groups I-IV lack unity under PCT Rule 13.