Title:
Geometrical Fidelity of Consumer Grade 3D Printers

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Introduction:
Fused Deposition Modeling (FDM, reg. Trademark by Stratasys Inc.) or Fused Filament Fabrication (FFF) is a layer oriented Additive Manufacturing (AM) technique where semi-molten thermoplastics like Acrylonitrile Butadiene Styrene (ABS) are extruded in strands through a heated nozzle of a printhead that is mobile in two directions (X-Y plane). FFF printers can be classified by precision or cost where professional 3D printers are expected to be more precise and faster than low cost or consumer grade 3D printers. This research is to evaluate the geometric fidelity of 3D printed parts on consumer grade 3D printers in regard of the printing orientation. With this research we present a low cost and unobtrusive method to perform geometrical analysis for flat printed additively manufactured objects. By providing a software component that is able to extract geometrical information from existing models (as STL or STEP files) and matching them to digitally acquired images from printed objects we are able to ascertain the geometric fidelity of 3D printed objects under the influence of varying filling patterns and object orientation.
Prior approaches to assess the quality of 3D printed objects include tensile strength tests [1], [3] following standards (ISO 527-2). Research is also performed on different AM methods like powder-based 3D printing [4] with respect to object layout [2], [5].
Main Idea. This research evaluates the geometric fidelity of 3D printed objects by utilizing digital image analysis techniques. ISO 527-2 Type B specimen are modeled using Houdini Software then positioned on the virtual printbed and sliced in 0.3 mm thick layers utilizing MiracleGrue slicer. The specimen are printed on a Makerbot Replicator2X 3D printer with an X-Y resolution of 0.011 mm. The test set is divided into two where the first object set (Test set A) is printed with their longest side parallel to the X axis and the second object set (Test set B) with their longest side oriented at an angle to the X axis (See fig. 1). The test includes objects with parallel patterns of 0, 5, 10, 30, 45, 60 and 90 degree resulting in toolpaths along the parallel lines. For the second test set the orientation angle is chosen to match the parallel pattern degree. A minimum of 3 objects per pattern angle and orientation is printed for a total of 81 specimen. The objects thickness is one layer or 0.3 mm in order to eliminate effects of multi-layer printing. Evaluation of specimen is performed by scanning the objects in a Konica Minolta BizHub42 with an optical resolution of 600x600 pixel per inch (PPI) into lossless high-quality TIFF files. The resulting image files are analyzed by measuring distances digitally against a reference grid. For further improvement the edge and corner detection algorithms for automated object geometry reconstruction for calibrated (resolution and size) images are utilized. The hypothesis is that objects printed at an angle to the axis yield higher geometrical fidelity due to the resulting toolpath with smaller distances and more direction changes. Toolpath lines not parallel to an axis are interpolated by the slicing software into step like structures as the printer geometry is not capable of

true diagonal or circular movement. Smaller toolpath segments are executed with lower speed compared to longer segments thus resulting in higher precision. Measurements are taken for three specific dimensions a) length, b) width at left end and c) inner width at the middle of specimen (see fig. 2). ISO 527-2 prescribes these dimensions as Overall length ≥150mm (l_3), Width at ends (b_2) 20.0±0.2mm and Width of narrow portion (b_1) 10.0±0.2mm. Further dimensions as Radius (r), Distance between broad parallel-sided portions (l_2), Gauge length (L_0) are not measured as they are not clearly distinguishable in the resulted specimen. Preferred thickness (h) deviates in our research from the standard (4.0±0.2mm) as the focus of this work is on single layer structures.

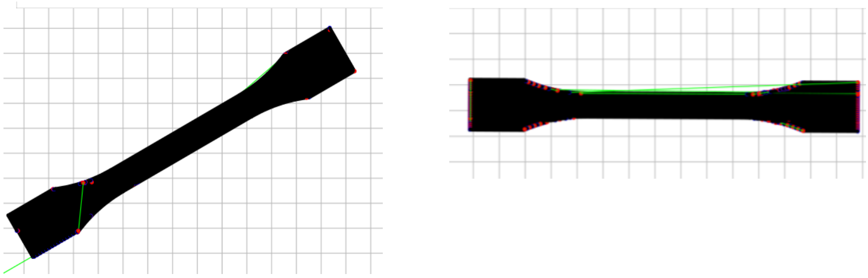

Fig. 1: View of toolpath for object from Test set A (horizontally aligned) on the left (a) and object from Test set B (aligned at angle to X-axis) on the right (b)

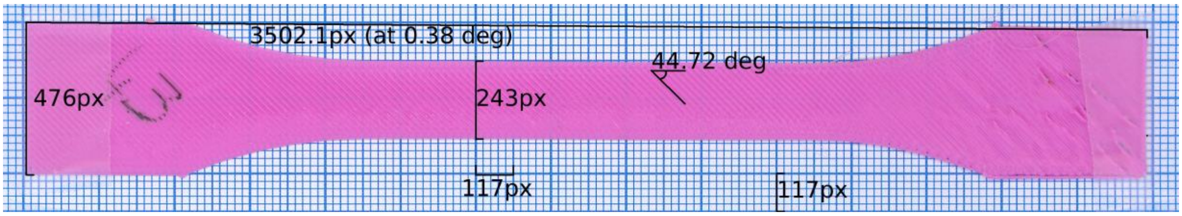

Fig. 2: Visual analytics of printed object number 43

<u>Conclusions</u>:

The hypothesis cannot be verified as differences in length, width and inner width of the specimen between the different test sets is not significant. The general fidelity is low and ranges from -1.54 percent in length (mean length = 14.77 cm) to 3.8 percent in inner width (mean inner width = 1.038 cm). In fig. 3 to 5 the results per dimension are shown with the abbreviation of (*hor*) indicating horizontally aligned objects (Test set A) and results indicated by (*oriented*) referring to objects from Test set B.

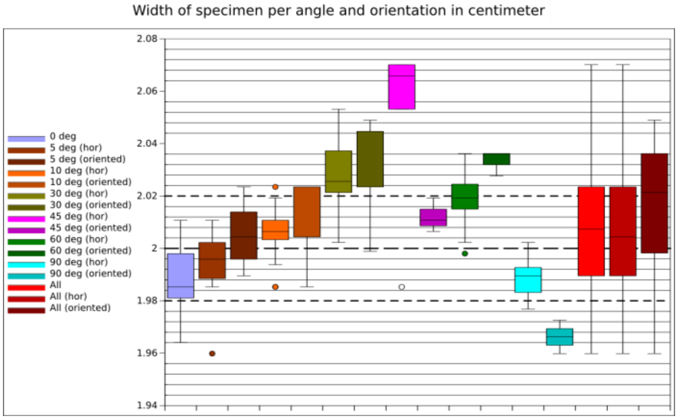

Fig. 3: Width of specimen per angle and orientation in centimeter.

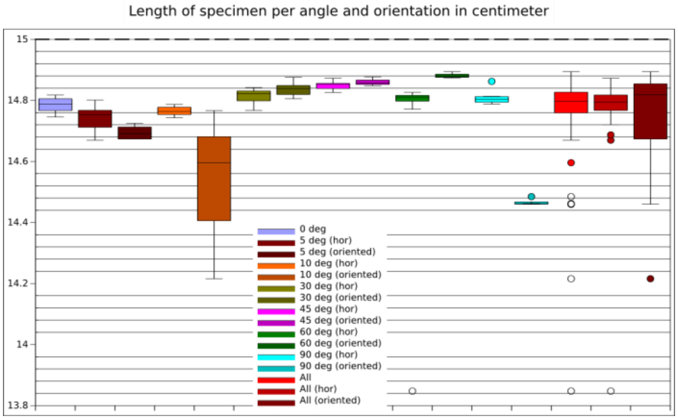

Fig. 4: Length of specimen per angle and orientation in centimeter.

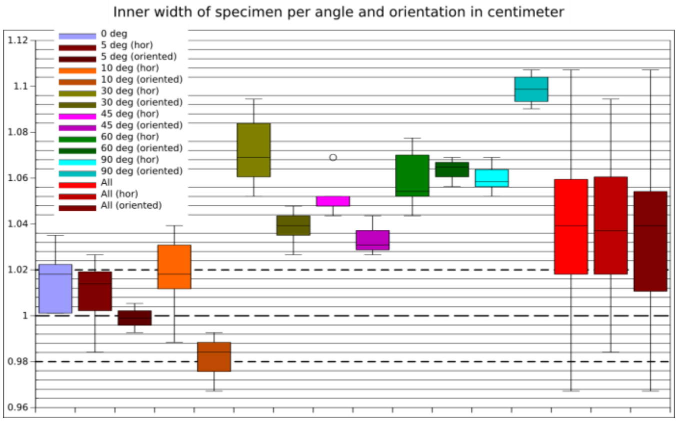

Fig. 5: Inner width of specimen per angle and orientation in centimeter

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