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OPTIMUM BUILD ORIENTATION OF3D PRINTED PARTS FOR A ROBOT GRIPPER

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ABSTRACT

Build orientation is one of chief factors which could affect the build time and support material requirement in fused deposition modelling (FDM)3D printing (3DP) process. Intelligent building orientation is inevitable for prototyping of parts, corresponding to least build time and support material. Decision of build orientation could be simple for standard and uniform parts; nevertheless, same practices could not be applied for prototyping of tailored parts. Prototyping of intricate, non-standard and customized parts usually demand pre-processing, prior to go for FDM printing to identify optimum build orientation, such that build time and material requirement could be mitigated. The present study investigates the best possible build orientation to attenuate build time and support material, while prototyping an intricate and complex robot arm. The standard practices for build orientation of couture parts of the robot arm assembly under study do not exist. Therefore effort has been made to devise build orientation to develop the parts rapidly and economically.

Keywords: rapid prototyping, fused deposition modelling, 3D printing, rapid tooling, build orientation.

INTRODUCTION

3D Printing (3DP) or technically known as Additive Manufacturing (AM) is a group of technologies that is growing rapidly in manufacturing field. For the current study, Fused Deposition Modelling (FDM) 3D Printing technique was used. FDM technology is a method of printing 3D objects using various materials like Acrylonitrile-Butadiene-Styrene (ABS), Poly-lactic acid (PLA) and Nylon by extruding heated filaments from a heated extruder and depositing material layer by layer on the print bed to make a part.

The study analysed the build orientation of 3D product to minimize the build time and support structure. Build orientation is determined by the orientation angle of the product built on the print bed. Build orientation effects many properties such as build time, support structure and surface finish. For this study, only two parameters will be assessed which is build time and support structure. Lastly, support structure is defined by the material produced to support overhang structure of the product that needs to be build. With advancement of AM technology, finding best orientation to print or built a product will give a faster build time and lesser support structure.

The solid modelling CAD software was used for designing parts and proprietary 3D printing software was used for parts fabrication which is needed to place the parts for 3D printing and to plan the build orientation.

Build orientation determines a lots of parameters in FDM process such as surface finish, build time, cost of the materials, shrinkage, curling, trapped volume, filling paths and patterns [1], [2], [9]. Support structure gives support to the overhanging features of the part [3]. Build time is dependent of part volume and support structure.

Byun and Lee [1] described that the build time consists of data preparation time, part build time and post-processing time though it is fully estimated based on part geometry and machine parameters. Their works were based on multi-attributes decision making using Simple Additive Weighting (SAW) method on part cost surface roughness and build time for SLS, SLA, FDM and LOM. A similar approach was taken by Ahn *et al.* [2] on multi-objective approach which considers part accuracy apart of build time. Alexander *et al*. [3] described that orientation can be determined with automation where an automatic computing support structure for part in layer manufacturing and will decide on best orientation. If two orientations required support structure with equal surface areas, lower centre of mass is chosen. Nevertheless, build orientation was found to affect strongly on build time and support structure. Frank and Fadel [4] developed an expert system that considered the quality of surface finish as the rules of determining a preferred orientation based on user input and decision matrix of various parameters affect the prototype implemented in the system. Two important geometric features were chosen from list of hole, surface of revolution, round surface, thin structure, plane, and overhang. Yan and Gu [5] did a study on the fatigue behaviour from 3 proposed build orientations (X, Y and 45º). The result showed that 45º orientation shows the highest capacity to store strain energy and highest fatigue life while X position recorded the highest Ultimate Tensile Strength (UTS). Conner *et al*. [6] did an experimental investigation in which 4 shapes were tested and deduced that cube and cylinder are recommended to build in 0º and 90º orientation to achieve the least volumetric error while pyramid best built in 64º orientation and sphere is constant at any orientation. When combined cylinder and cube, the volumetric error is least according to the orientation of the origin shape. The highest recorded volumetric error is at 45º orientation. Sreeram and Dutta [7] performed a study in which build time is estimated by roughly slicing the part while same method is used for a polyhedral object. The build orientation of the part with respect to the build platform is described in the ASTM F2921-11 standard [8]. The same standard will be used for the project to find the build orientation.

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The current study will use robotic gripper as model and new orientation need to be found as the model is a combination of many shapes or features.

METHODOLOGY

The robot arm under study is a gripper assembly with three parts, to be assembled together. The 3D CAD models of these parts can be seen in Figure-1. The connector arm is used to fix claw arm on the claw base so that it can work in the allowed degrees of motion. The FDM machine used in the study was CubePro Duo 3D printer by 3DSystems and polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS) were used as support and build materials respectively. The CAD files were converted to standard tessellation language (STL) format and were imported to the3d printer software to virtually place and orient the 3D CAD model on build platform. Figure-1 is showing the CAD models for the robot arm.

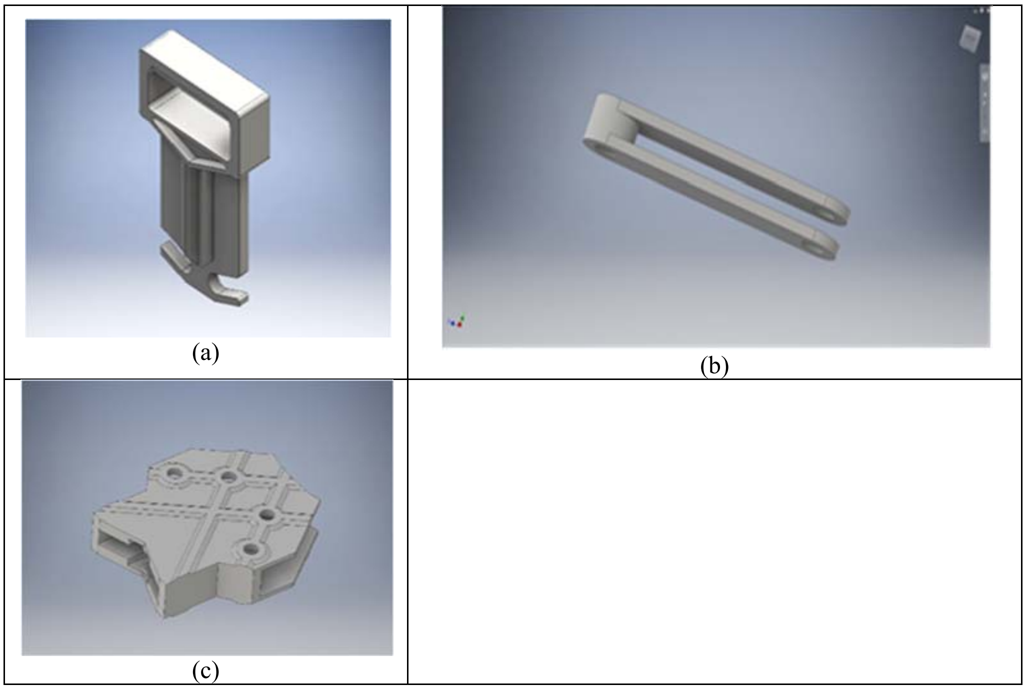

Figure-1. Parts of robot gripper assembly; (a) Claw arm, (b) connector arm and (c) claw base.

As pre-processing is to devise optimum build orientation for these components, initially the parts were oriented along principal axes and the corresponding values of build time and support material requirement were noted. The build or slicer software was used for virtual placement of the 3D CAD model on the build platform and the build time and material requirement, as calculated by the software were recorded for analysis. Each part of the robot arm was placed along each principal and auxiliary axis to record corresponding values of build time and support material as per calculated by the standard software. The principal planes for FDM printing of parts have been defined in ASTM F2921-11 standard (Figure-2). The auxiliary planes are however, not defined in any standard, but are determined by the study according to the features of the part under investigation.

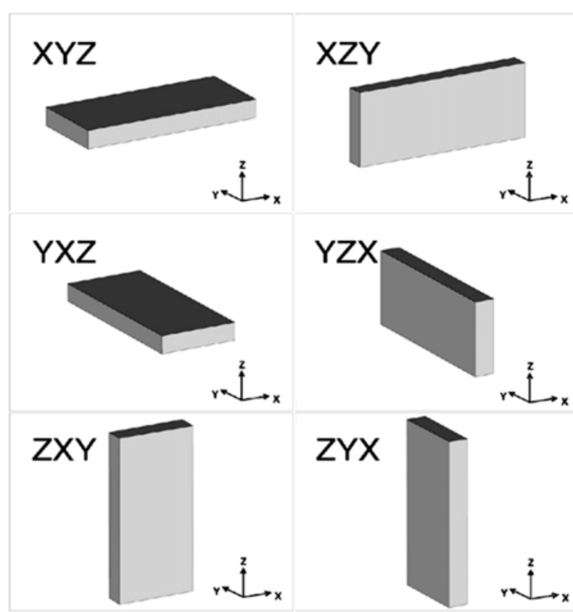

Figure-2. Standard build orientations as per defined by ASTM F2921-11.

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The parts of robot assembly were oriented on the build platform in the software according to the ASTM F2921-11 standard. The support material requirement was simulated and build time was calculated by the software and recorded for analysis. For hidden overhangs, like in the claw base, while oriented in YXZ principal plane (Figure-3b) the support material was not explicitly visible. In such case top surface was removed by incomplete simulation of printing to visualize support material requirement. For other orientations of the other parts, any major modification was not needed and build time and material requirement were recorded as usual.

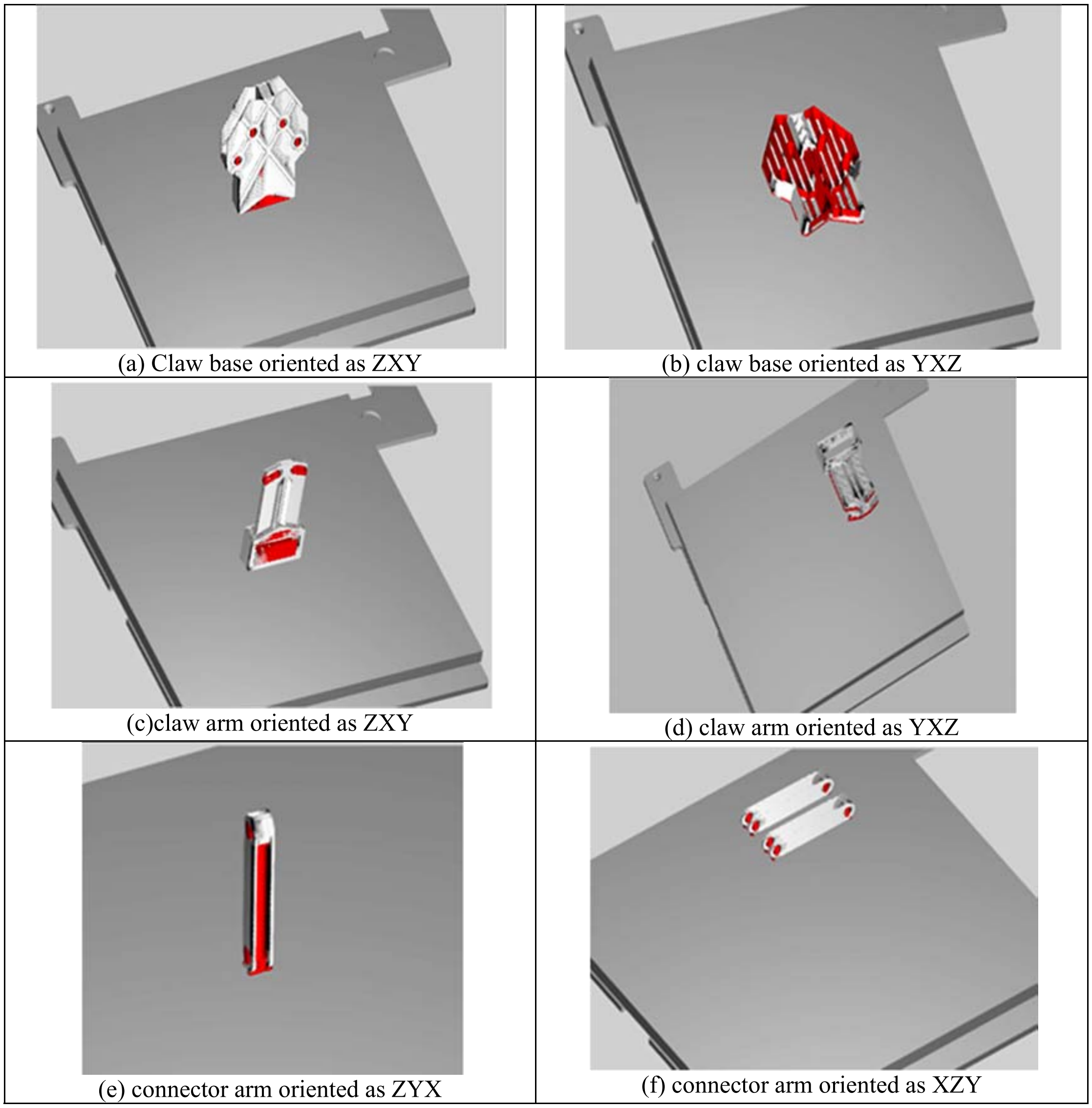

Figure-3. Build orientation of components of robot assembly in principal planes.

RESULTS AND DISCUSSIONS

Optimums build orientation for claw arm

In different orientations the material consumption and build time displayed diversified behaviour in claw arm. The descending of print platform is gradual and time consuming, therefore placing longest dimension in vertical position would be tedious. Moreover the part printed would be fragile in transverse direction. The performance of XYZ and YXZ orientations were comparable, however the movement of nozzle in Y-direction is quicker, therefore X-direction impedes slightly. In revision 1 of YXZ orientation (Figure-3d), the print time was increased because the part was placed in the centre of the print platform, however, placing the part at the top-right corner, nearest to the nozzles provides least build time. Similar to claw base, claw arm also best suites with YXZ orientation. Figure-4 is showing the parameter information for claw arm.

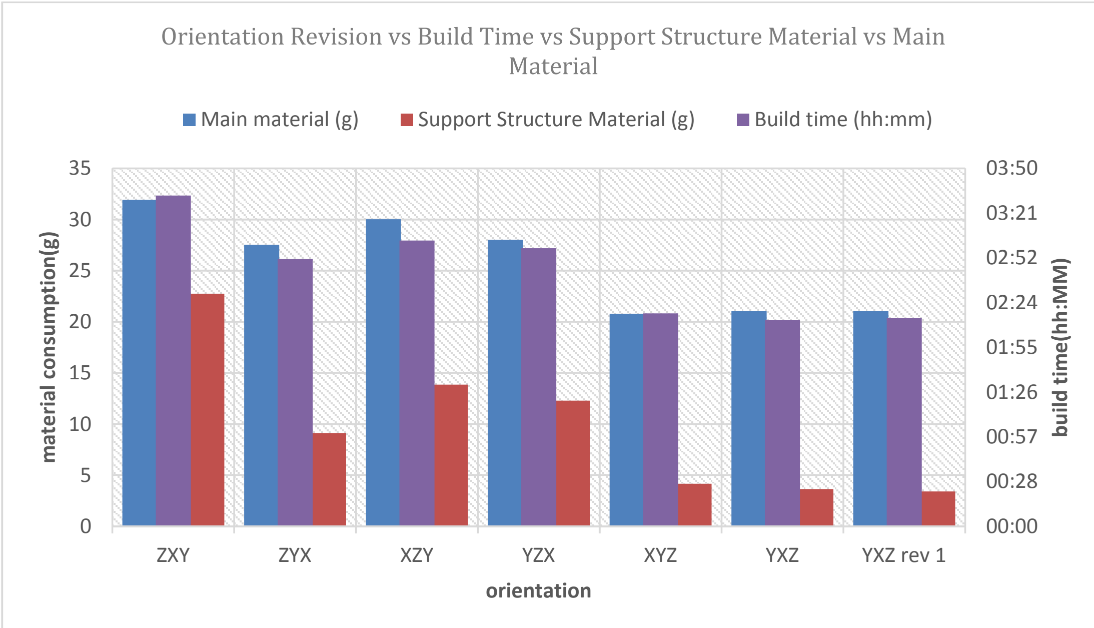

Figure-4. Data graph for claw arm.

Optimums build orientation for front connector arm

The front connector arm is composed to two slender type elongated components, which are hollow sandwiched with each other. Both the plates are connected by a short shaft like joining element, near to each end. In ZYX orientation (Figure-3e), the support for the main plates of connector may be negligible; however, the joining element may consume more support. Moreover, since the longest dimension is in vertical position, therefore printing time would be high. In YXZ and YZX orientations, the support structures are required because the dual plate acts as complete overhang structure. The best suited orientation is XZY (Figure-3f), requiring least support material under the joining shafts only. Build time would also be less since the longest dimension is parallel to the extruder of printer. Print time is further reduced by placing the part at top right corner of print platform. Figure-5 is showing the parameter information for connector arm.

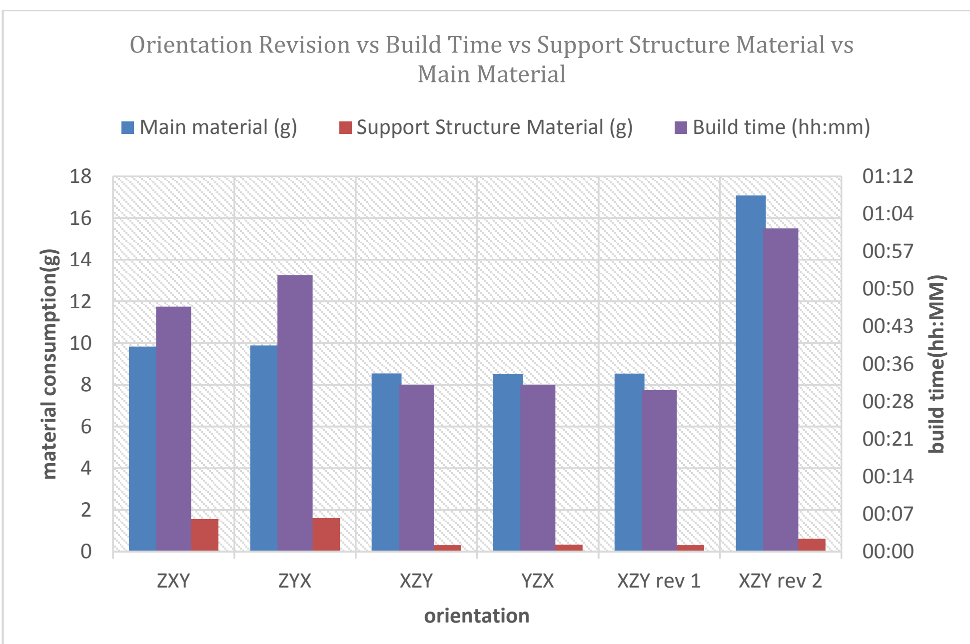

Figure-5. Data graph for connector arm.

Optimums build orientation for claw base

For the claw base, ZXY orientation (Figure-3a) may appear to be most appropriate orientation however, despite the least support material required, yet the build time and overall material requirements are high in this orientation compared to YXZ (Figure-3b). The orientation in YXZ was observed to be most optimum since it required minimum support material and print time. The limitation associated with this orientation is that the support material is enclosed within the part cavity and therefore is difficult to remove however. The other orientation, despite consuming moderate support material, is ruled out because of prolong manufacturing times. Figure-6 is showing the parameter information for claw base.

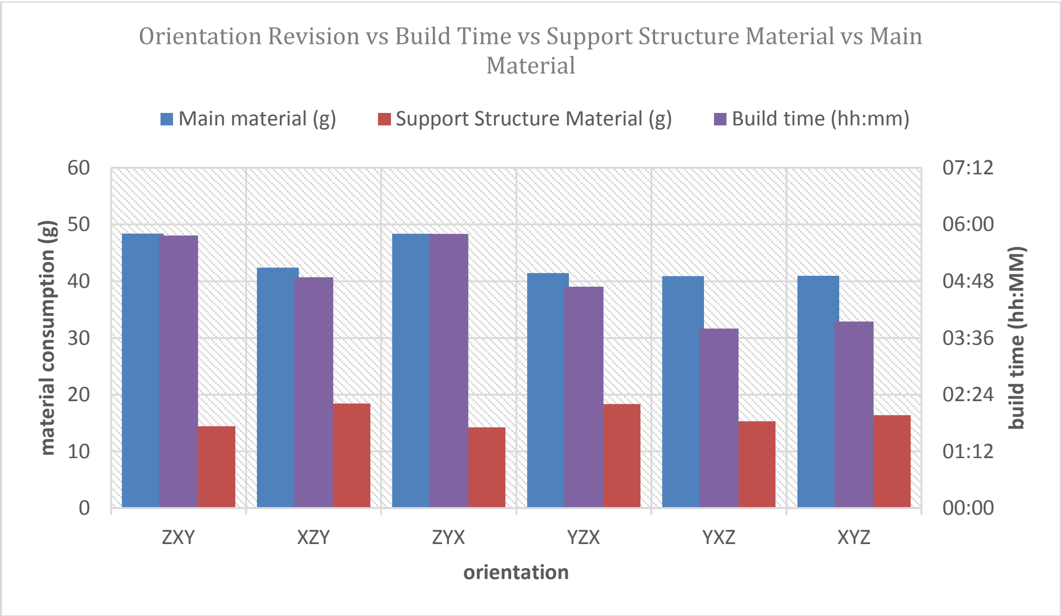

Figure-6. Data graph for claw base.

CONCLUSIONS

In different orientations the material consumption and build time displayed varied behavior. The part feature placed parallel to the direction of side-ways movement of nozzle consumes least time. It is therefore preferred to keep longest feature so as it is aligned to the side-ways (y-axis) movement of nozzle. The vertical dimension (z-axis) is the most time consuming, therefore least feature is placed vertically. The printed parts exhibit strong anisotropy, especially in mechanical strength. In the stacking layers, compressive strength would be high but transverse and shear stress would be quite low. Loading perpendicular to layers can easily be borne by the part, whereas parallel loading can easily cause failure. It may be kept in mind while choosing optimal orientation that priority should be given to mechanical strength and as long as maximum strength is achieved, the build orientation can may be modified so as to render the overall process economical. Table-1 shows the summary of orientations, material usage and build times.

Table-1. Summary of best suited orientations with corresponding build time and material.

Part	Orientation	Main material (grams)	Support structure material (grams)	Total material (grams)	Build time (minutes)
Claw Arm	YXZ	21.04	3.39	24.43	134
Connector Arm	YZX	8.42	3.34	11.76	61
Claw Base	ZYX	48.38	14.25	62.63	348
TOTAL		77.84	20.98	98.82	543

It is recommended that future studies may be conducted to investigate build orientation and manufacturing time using other commercially available 3DP techniques. Open source software and printers can be used for tailored design of support structures so as to further decline the support material and time of print.

ACKNOWLEDGEMENT

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