Surface Analysis in Additive Manufacturing Using Image Processing.

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Abstract - Fused Deposition Modeling (FDM) is a type of additive manufacturing process where prototypes are developed by depositing layers on previously deposited layer of material. Surface roughness is an important factor in determining quality of produced parts. This work proposes a methodology to calculate the surface roughness of part manufactured using FDM process. The surface roughness values to be measured using conventional stylus instrument and Digital image processing technique. Stylus comes in direct contact with surface so it destroys the surface topography. Image processing is a non-contact method hence it overcomes this problem. A camera and directional lightings will be used to capture images of surface of specimens. These images will be analyzed and processed using various image processing techniques available in MATLAB image processing toolbox. Experimental results will be validated by comparing the results obtained by using image processing technique with conventional stylus system. The system is also proposed to inspect surface irregularities.

*Key Words***:** Surface roughness, image processing, MATLAB, FDM.

1.INTRODUCTION

Surface roughness is an important factor which impacts on assembly of various parts resulting in higher friction that causes heat formation and may lead to failure. So the desired functioning of machined components is hugely affected by surface roughness. Conventionally stylus instrument is used to measure the surface roughness. Since this measurement process is of contact type, it is not suitable for online measurements. As the stylus is in direct contact with the surface it can affect the surface properties of the material. So, there is a growing need for a reliable, online and non-contact method for surface measurements. Over the last few years, advances in image processing techniques have provided a basis for developing image-based surface roughness measuring techniques.

Conventionally, surface roughness is measured using stylus instrument. Stylus profilometer creates scratches on surfaces during the measurement process; it results in degradation of surface quality. Also this method is slow and hence not suitable for high-speed applications. Non-contact methods are highly recommended, as these methods are non-destructive, fast and reliable. These methods generally involve vision system and image processing techniques. So there is need of a Digital method to find surface roughness which will be faster

and can give real time results in cheap rates comparatively existing non-contact type techniques. Image processing technology is useful to get required data from images.

Additive manufacturing (or 3D printing) technology is classified according to its material type or process. Material type is classified as solid, liquid and powder. One of the most widely used additive manufacturing process is Fused Deposition Modelling (FDM). FDM is a process of developing prototypes by depositing layers of material according to predetermined cross sectional geometry. Quality of the produced part is highly dependent on surface finish. The material used in FDM is generally thermoplastic. FDM involves layered deposition with fixed thickness of each layer, hence produced part suffers from staircase effect. Staircase effect is significant factor which affects surface finish. Staircase effect is a phenomenon where the layer marks can be seen clearly on the surface of manufactured parts.

Image Processing is nothing but a method to extract or obtain useful information from an image. It is simply a signal processing technique where various operations are performed on an image. Nowadays image processing is among the most rapidly growing technologies. There are two types of image processing such as analogue and digital. In this paper we will focus on digital image processing. Digital image processing techniques helps in the manipulation of the digital images. Steps in digital image processing are as follow as,

1. Image Acquisition.
2. Image Enhancement.
3. Image Restoration.
4. Image compression.
5. Morphological Processing.
6. Segmentation.
7. Representation and description.
8. Character recognition.

Related work:

The researchers carried a research regarding surface roughness using image processing. The conventional surface roughness measurement technique uses stylus hence it is of contact type and because of that the surface gets damaged sometimes. This work attempts to evolve a vision system based image processing technique for non-contact evaluation of surface roughness [1]. Mathworks provide essential knowledge to process the captured images using image processing toolbox [2]. Researchers carried experiments regarding various techniques to measure surface roughness in Selective laser sintering method. Tactile measuring methods allow a quick and reproducible characterization of the surface roughness. Based on the measuring method and the optical material properties fault measurements most comparable to

the tactile measurements are the results from Focus Variation [3].

A machine learning model based on bi-stream Deep Convolutional Neural Network (DCNN) was developed to characterize layer-wise images of the SLM process for on-line identification of defects induced by process non-conformities. A machine learning approach for on-line fault recognition via automatic image processing is developed to timely identify material defect [4]. Researchers proposed a system containing one camera and two polychromatic light sources in a real time Additive manufacturing process for detecting two types of defects. The system was proposed to find surface defects in Binder jetting process. Areas where too little and too much powder has been applied and areas with different porosity [5]. Line fabrication experiments were conducted using FDM head to examine whether the fabrication parameters have an effect on the surface roughness of the fabricated structure. From the experimental research, it was found that the thickness of the line tends to even over the cross-section as the gap between nozzle and substrate is small [6].

A short introduction to image processing techniques used in machining is presented here. A detailed review of image processing applications in machining for over the past decade is discussed in this chapter. Advantages and disadvantages of machine vision techniques applied for tool condition monitoring and surface finish studies over the other techniques have also been presented in this chapter [7]. It is observed that the right choice of layer thickness and orientation always remain as a most significant parameter for surface roughness. While other parameters like road width, air gap and speed of deposition may also play an important role in enhancing the surface roughness. Also, a theoretical model is developed to understand the effect of different parameters on surface [8]. conducted experiments where the surface roughness of FDM produced parts is calculated using stylus profilometer and light sectioning method. Light sectioning method is more efficient for measurement of FDM produced parts, as it is non-contact and reliable method. It can be concluded as light sectioning method has middle-level accuracy and provides results with acceptable tolerance [9].

2. Methodology

Figure 1 shows the steps involved in surface roughness measurement of FDM generated parts using stylus instrument and light sectioning vision system. At initial stage, the specimen is modeled by using CAD tools, in next step same CAD file is converted in STL file which will be used as input for actual FDM process. Later the STL file is provided as an input to a Slicing software. Slicing Software divides the image in layers. Every layer is stored separate PNG image. Slicing software creates G-codes. This code is given to 3D printer. Finally, the printer prints the specimen. Once specimen is manufactured, Surface roughness is measured. There are two ways of measure the surface roughness i.e. conventional method and non-conventional method. In case of conventional method surface roughness is calculated using stylus Profilometer instrument.
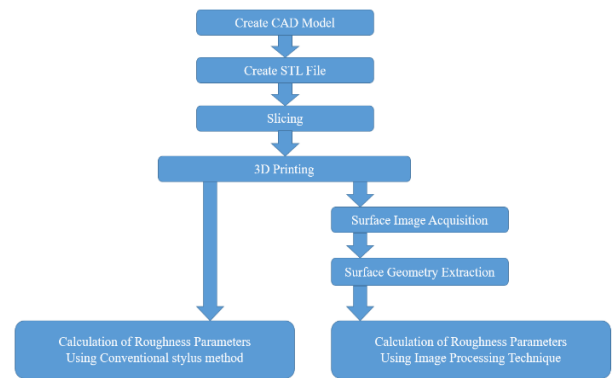

Fig -1: Flow chart of methodology

2.1 Deciding Parameters:

Figure 2 shows the different parameters that affects the part quality and mechanical properties of 3D printed parts using FDM method. As we discussed earlier the parameter which affects the surface quality heavily is layer thickness [8]. Temperature and humidity also plays a vital role in the surface quality of the specimen. Air gap, raster angle, raster width, infill density, shrinkage factor are also important to obtain better surface quality.
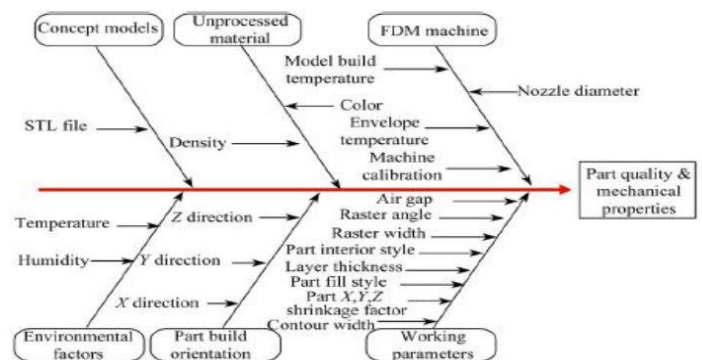

Fig -2: Parameters affecting part quality and mechanical properties
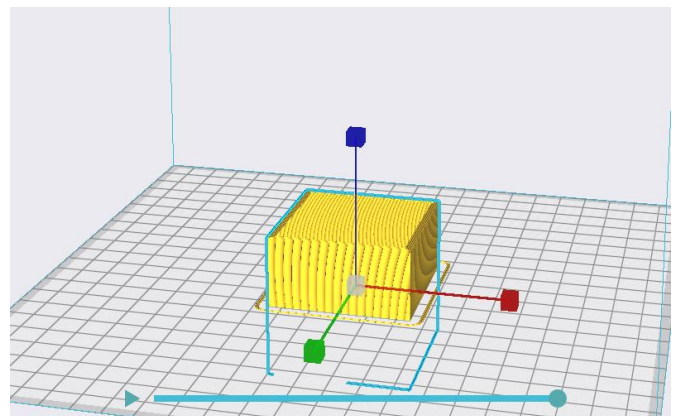
2.2 Slicing:

Fig -3: Slicing of CAD file.

Figure 3 gives schematic representation of a specimen in slicing software. We have to define different parameters then the slicing software divides the CAD file in different layers according to defined parameters. Every layer is saved as separate image and create G-codes. Finally, G-code is given to printer.
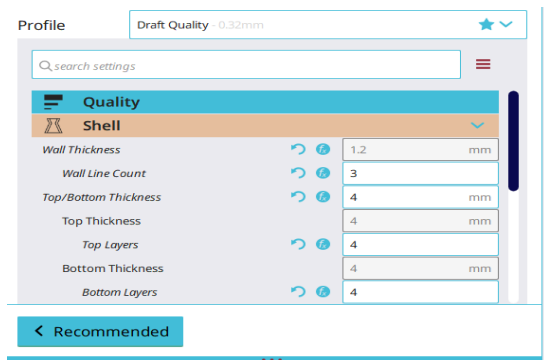

Fig -4 (a): Defining Parameters.

Figure 4(a), 4(b) and 4(c) gives us idea about the process of defining various parameters which affects the quality of surface of the specimens.
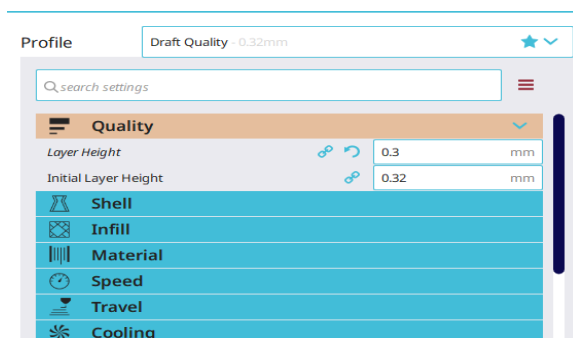

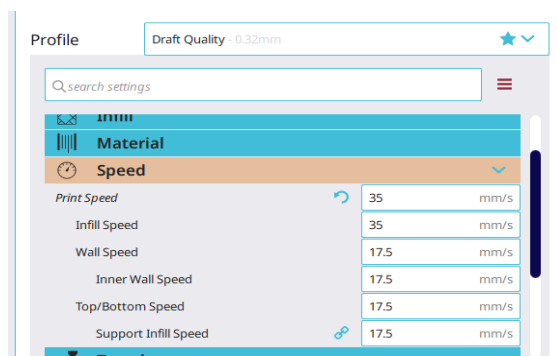**Fig -4 (b):** Defining Parameters.

Fig -4 (c): Defining Parameters.

2.3 Material:

Selecting the right material for 3D printing is one of the most important part of the experiment. However, ABS is stronger than polylactic acid but due to its availability and printing ability PLA is most widely used for FDM printing.

Properties	Values
Technical Name	Polylactic acid (PLA)
Material Type	Thermoplastic
Mechanical Properties	• Rigid • Stiff • Good Strength
Melt Temperature	157-170 °C
Specific Gravity	1.24
Tensile Strength	61-66 MPa
Availability	Easily Available
Printing Ability	Easy to print
Applications	Decorative parts.

Table -1 Properties of PLA.

Figure 5 Shows PLA filament which is used for 3D printing. PLA filament has gained wide acceptance within 3D printing partly because it is made from renewable products and also because of its mechanical properties. As the melting temperature is low there is no need to heat the bed while printing the part using PLA. PLA has greater heat resistance so it is widely used in food industry.
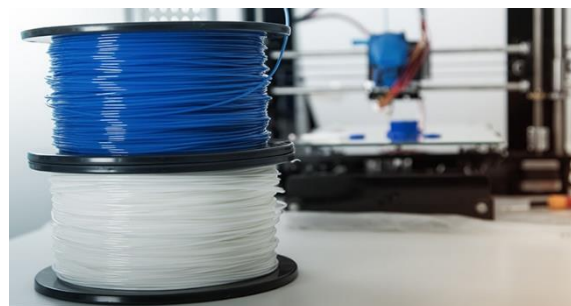

Fig -5: PLA Filament

2.4 Printing:

Figure 6 shows the 3D printer used to manufacture the specimens. Spool of PLA filament is mounted around a spool holder. The filament is passed through an extruder and provided to nozzle. The filament is heated upto certain temperature, melts and extruded through nozzle, layer upon layer onto a build tray to form the 3D object. The thickness of each layer is provided while slicing the CAD file in slicing software.
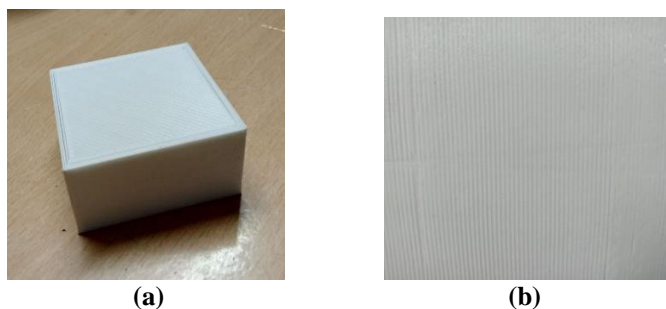

Fig -6: FDM 3D Printer

(a) **(b)**

Fig -7: Printed specimen.

Figure 7(a) represents one of the printed specimen and 7(b) shows the image of top surface of the same. Similarly, few other specimens are to be manufactured following the earlier discussed steps with changing some input parameters. The top surface of perfectly printed specimen can be taken as a reference image to compare with surfaces of other specimens. Before that the surface roughness parameters are measured using conventional stylus profilometer.
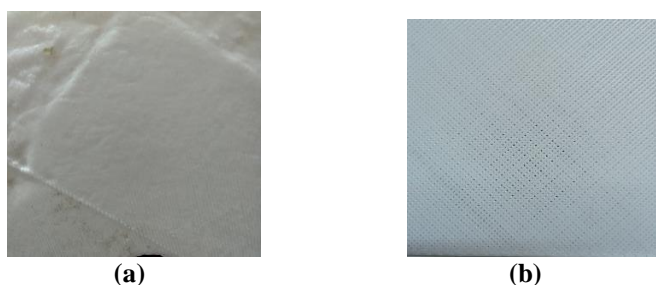

(a) **(b)**

Fig -8: Surface of specimens with defect.

2.5 Measuring Surface Roughness:

Figure 9 shows the stylus profilometer instrument which is used to measure surface roughness. Profilometer contains a stylus probe. The stylus probe is adjusted in such a way that it just touches the surface of specimen. Then the probe is moved on the surface. Profilometer measures the different surface parameters and display the value on screen.

Measuring surface roughness using conventional stylus profilometer comes under contact type method because the stylus probe is directly in contact with the surface of the specimen. Due to this sometimes the probe can damage the surface of specimen leading to irregular surface finish.

Fig -9: Stylus profilometer.

Traverse Speed	1mm/s.
Battery	Alkaline; minimum 600 measurements of 4mm measurement length.
Measurement	Metric or inch units.
Cut of Values	0.25mm,0.8mm and 2.5mm.
Traverse Length	0.25-25mm.
Display	LCD- matrix, 8 lines*20 characters, alphanumeric.
Keyboard	Membrane switch panel tactile.
Language	English, German, Italian, French.
Filter	Digital gauss filter or 2CR filter (ISO).
Calculation Time	Less than or equal to 2 sec.
Parameters	Ra, Rz, Rt,Rp, Rmr, etc.

Table -2: Information about stylus Profilometer.

2.6 Image Processing:

For capturing the images, a setup is created. The schematic representation of system is shown in figure 10. The system consists of a camera and two lights. One light source (top light) is mounted exactly at the top where the camera is mounted so that the light source will does not create any shadows and the camera will capture most uniform illumination possible. The second light source shines on the powder bed at a very flat angle (sidelight). The side-light creates shadows when there are differences in height in the powder bed, which the camera captures from above. These shadows are not created when using the top-light (Figure 1). After the creation of each powder layer, two images are acquired, one using the top-light, and one using the side-light. By subtracting the two images from each other, the shadows are extracted and evaluated. The top-light ensures that color differences on the surfaces are not misinterpreted as shadows.
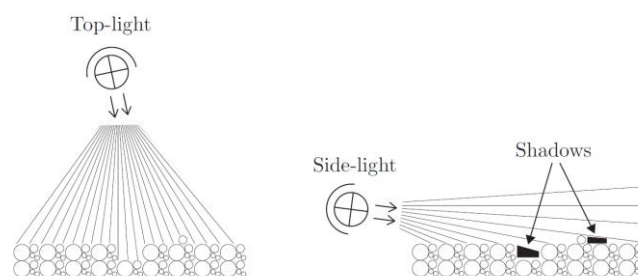

Fig -10: Schematic Representation of Proposed system.

After capturing the images of surfaces, those images are to be sent to image processing toolbox. Image processing toolbox provides a comprehensive set of reference standard algorithms and workflow apps for image processing, analysis, visualization and algorithm development. Image segmentation, image enhancement, noise reduction, geometric transformation, image registration and 3D image processing can be easily carried using MATLAB image processing toolbox. Visualization functions and apps let us explore images, 3D volumes, and videos. Adjust contrast, create histograms, and manipulate regions of interest (ROIs). Edge detection, image region analysis, Hough transform and Gray

level co-occurrence matrix (GLCM) are important features regarding this work.

Texture statistics like correlation, contrast and homogeneity are calculated using GLCM. GLCM considers the spatial relation among pixels in the image. Workflow to obtain texture statistics using GLCM is as follow as,

1. Import an image and convert ir into grayscale.
2. Define offset.
3. Construct GLCM.
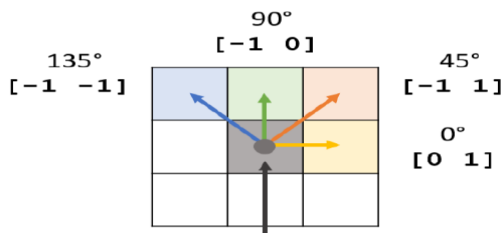4. Calculate texture statistics.

Fig -11: Spatial relation between pixel of interests

The offset is defined in terms of how many rows and columns it is away from the pixel of interest. The defect on surface is illustrated using overlapping the image of irregular surface on the reference image.

The statistics of texture obtained with the help of GLCM is used to find Ra and Rz values of surface roughness and then can be compared with the values measured using conventional stylus profilometer.

3. CONCLUSIONS

The surface roughness of FDM produced parts is calculated using stylus profilometer and digital image processing method. Digital image processing method is more efficient for measurement of FDM produced parts, as it is non-contact and reliable method. It can be concluded as digital image processing method has middle-level accuracy and provides results with acceptable tolerance. The proposed system gives the results in less time compared to conventional stylus method so it can be widely used to measure the surface roughness of the specimen.

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