Preißler, Marc; Broghammer, Jana; Rosenberger, Maik; Notni, Gunther

Inline process monitoring method for geometrical characteristics in additive manufacturing

Original published in:	2018 Joint IMEKO TC1-TC7-TC13 Symposium: Measurement science challenges in natural and social sciences. - [Bristol] : IOP Publishing, 18 June 2018. - (2018), art. 12035, 6 pp. ISBN 978-1-5108-6494-8 (Journal of physics. Conference Series ; 1044)
Conference:	IMEKO TC1-TC7-TC13 Joint Symposium : (Rio de Janeiro) ; 2017.07.31-08.07
Original published:	2018-06-18
ISSN:	1742-6596
DOI:	10.1088/1742-6596/1044/1/012035
[*Visited:*	2024-01-25]

Inline process monitoring method for geometrical characteristics in additive manufacturing

M Preissler, J Broghammer, M Rosenberger, G Notni

Technische Universität Ilmenau, Faculty of Mechanical Engineering, Group of Quality Assurance and Industrial Image Processing

E-mail: marc.preissler@tu-ilmenau.de

Abstract. This method provides a suitable solution for monitoring an additive manufacturing process. The implementation is evaluated in a manufacturing machine of fused filament fabrication. The main parts of the work are the developing and integration of an adaptable 3D hardware platform, the pre-processing of captured layer point clouds and the developing of object point cloud stack. The result is sufficient to estimate the manufacture quality and complies requirements for an inline process control method.

1. Introduction

The area of additive manufacturing (AM) is increasing in almost every sector of industry and is getting more and more important as an alternative for traditional factoring methods like milling. The advantages begins with the process of developing in Computer Aided Design (CAD). The user can create more and more complex geometrical structures without to generate a blueprint. The transformation in machine readable code follows after mechanical developing in CAD. The so-called *slicing process* is usually preceded and manufacturing parameter are to be set. The parameter setting allows an advantage for AM at once. The knowledge of the requirements for the developed part and adjusting of the right parameters for the AM process might be a cost effective manufacturing process in comparison to traditional manufactured parts. The manufacturing time is certainly one of the most important factors in costing, particularly for single pieces. The initial costs are a very high and getting lower with a higher number of manufactured parts. [1]

New and more effective AM technologies are still in developing and might be able to reduce the manufacturing time. But to reduce manufacturing time is just one way for increasing the cost effectivity in AM. The increasing of the manufacturing quality is simultaneously desirable. These include higher geometric accuracy, convenient surface and the conformance for mechanical requirements of the manufactured pieces. An approach for controlling the manufacturing process could be a possibility for monitoring the AM process, what is called inline process monitoring.

Inline process monitoring and also control are one of the evolving areas in AM. It could be the next evolution for this manufacturing technologies. Monitoring in manufacturing processes is useable for visibility of the manufacturing quality and responsible for traceability at once.

Process parameters can be monitoring, but also the manufacturing results can be compared with expected values. These values can describe geometrical and mechanical specifications for the manufactured part. Inline process monitoring is only capturing the manufacturing process. Inline process control has the claim to manipulate instantly process parameters for constant quality of the manufacturing results in a quality control loop (Figure 1). Inline process metrology describes the measurement of the workpiece inside the manufacturing machine and defines the process control loop within the time of the manufacturing process [2].

The requirements for manufacturing parts are getting more and more complex. Lightweight, composite materials and effective stiffness are fields with high research potential for manufact urer. New potential is available through the width accessibility of additive manufacturing methods. These methods

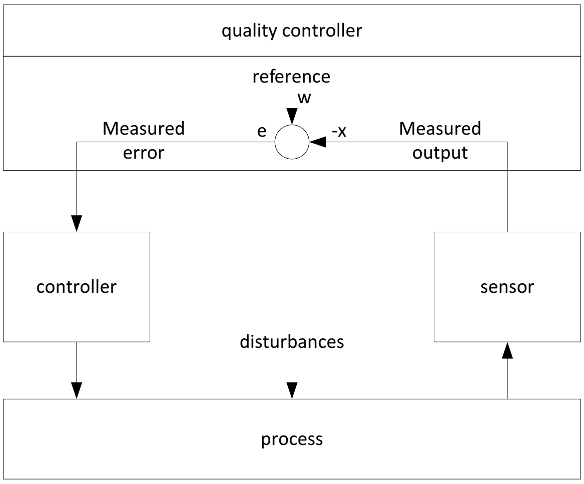


Figure 1. Quality control loop

scan be differentiate in two major summarized groups based on their usage. Firstly the classical additive manufacturing processes, which includes Stereolithography (STL) and Selective Laser Sintering (SLS). These systems are well-established in development departments of large companies and service companies. But the purchasing and using of these machines is still relatively expensive in comparing to other AM technologies. The second group of generative manufacturing processes is constituted by fused filament fabricationModelling, Multi Jet Modelling and Binder Jetting. The primary use of the second group converts more and more to engineering and design companies for manufacturing objects directly from CAD. Meanwhile additive manufacturing systems on the market are slightly more expensive than laser printers a few years ago. These are usually based on the fused filament fabrication (FFF) method. Meltable synthetic materials are liquefied in a heating nozzle and coated in layer constru ction equivalent of CAD Data. [3] The low costs results of the cheap raw material and the simple mechanical structure of the overall system. Furthermore the large variety in material of available filaments for an FFF manufacturing system requires adapted machine parameters for an acceptable manufacturing result. The parameters are normally only adjustable with the help of iterative manufacturing process steps or the machine operator has high expertise in handling with different filament. The number of possible process failures is very diverse and can be reasonable in different causes. A great support is the knowledge of all relevant process parameters for better understanding of the AM process and should content of this work.

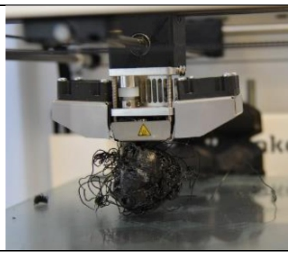
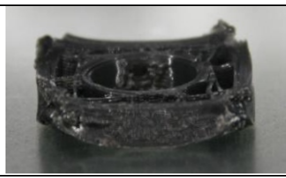
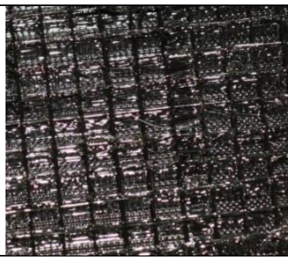
An inline process monitoring method could be implemented in each of these additive manufacturing groups. This paper presents an inline process monitoring method for a fused filament fabrication manufacturing machine.

2. Potential process failures in fused filament fabrication

The fused filament fabrication process is one of the cheapest AM method for initial costs and thus currently most popular for consumers. The manufacturing process works additive, what means the objects structure is manufactured in layers. The raw material for manufacturing is mostly plastic wire on a coil (Filament) or granulate and is melting in a nozzle, which builds the separate layers. The subsequent cool down process of the melted material is very sensitive and is influencing through a lots of parameters of the surrounding [4] [5]. Also changing of filament from another supplier can cause in some process failures, because different chemical additives are being used. The additives are necessary to influence the filament color and should make it easier to handle the material for the manufacturing process.

Example effects for process failures in fused filament fabrication are showing Table 1, if the manufacturing process isn't under stable conditions or the machine parameters settings is wrong.

Table 1. Examples for Process Failures in fused filament fabrication

Failure description		**Potential reasons**
Not sticking to platform		• manufacturing speed too fast • wrong platform- or nozzle temperature • trouble with platform surface • build platform is not level or wrong distance to noozle
Warping		• wrong platform temperature • fan cooling • trouble with platform surface
Blobs and Zits		• nozzle temperature too high • wrong retraction parameter • too many extrusion of filament
Weak Infill		• manufacturing speed too high • wrong infill extrusion

The manufacturing process in FFF starts with the first layer and is very important for the following layers. The parallel and correct platform levelling to the nozzle is a basic requirement for stable process conditions and has immense affect for layer sticking. If these conditions aren't achieve, the first layer doesn't stick to the platform and some warping effects can follow. In worse case the object starts to lift completely and damages the manufacturing machine.

The correct adjustment of the machine parameters is also important for mechanical properties to get correct surfaces of the manufactured object. Also the variable filament diameter has influence for the material extrusion and consequently more or less material extrudes for layer building. The affects can be blobs and zits on the surface, which impairs the next layer and more manufacturing failures can follow. The fluctuating material extrusion has also influence the infill, which is most responsibly for mechanical properties and stiffness.

The variety of potential process failures in Additive Manufacturing is wide and is almost impossible to give a complete overview in this paper.

3. Experimental design

The aim for this inline process monitoring method is to get dimensional information of the manufactured object on the platform within the process time. A capturing directly after process finishing is possible with conformable sensor hardware equipment. But therefor the construction of the manufacturing machine needs a rebuilding process and that isn't claim of this work.

For this purpose an adaptable 3D - inline process platform for evaluating additive manufacturing processes in fused filament fabrication has been developed. The self-made and adaptable hardware platform for the inline process monitoring [Figure 2] is able to output 3 - dimensional information about the manufactured object during process time. It is positioned over the additive manufacturing machine in bird view to capture the information from layer to layer. Other places for positioning are not acceptable, because a modification of the additive manufacturing machine is necessary and that could decrease the efficiency of the manufacturing process. Furthermore the self-made hardware platform should also usable for other AM machines and inline process monitoring tasks.

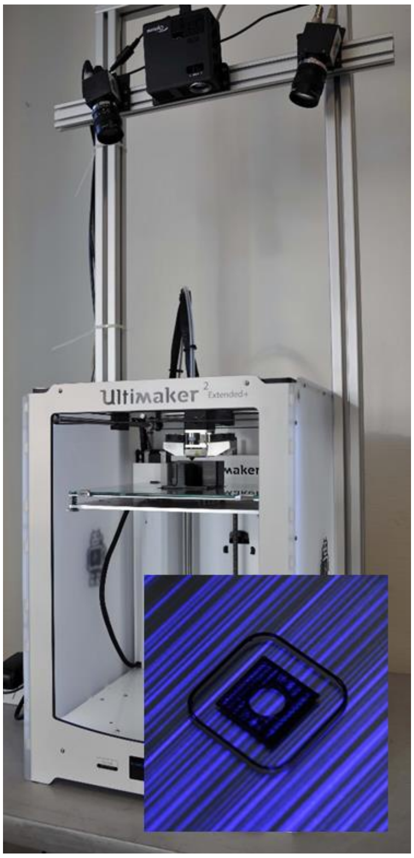


Figure 2. Experimental design

The hardware platform has the structure of stereoscopic camera systems and the necessary projector for fringe projection is placed between both. The GigE Vision cameras and C-mount lenses are replaceable to vary the field of view. At once the field of view defines the accuracy of the measurement system and furthermore the point cloud resolution is being affected. The experimental design for this paper composes of a Sony IMX249 2.4 MP image sensor and lens with a focal length of 25 mm. This setup offers to capture the maximum available workspace in the manufacturing machine of 220 x 220mm. The maximum depth in focus depends on the selected lens and the selected aperture. But the depth of focus has to be a minimum of the chosen layer thickness. Common fused filament fabrication machines are able to manufacture a layer thickness of 50 - 400 µm.

A special feature of the hardware platform is the possibility to change and adjust the camera angle and base, which has influence to the output result in form of 3D informations. All necessary translational and rotational degrees of freedom are adjustable. A standard, but high light intensity output, DLP projector is located between both cameras and displays the pattern projection on object. The object distance is reasonable in the minimum projector work distance of 550 mm.

The developed 3D Sensor system is using the fringe projection method [7] [8] and is currently assembled in an Ultimaker 2 extended+, but adaptable in other additive manufacturing systems with requirement to have an free field of view to the manufacturing process on the upper side. A 3D scan in a bird eyes view arrangement is captured after every finished manufactured layer and is the basis for the subsequent image processing. The projector - and camera control, calibration, image acquisition and processing is managed by MathWorks software Matlab. The work is realized by the Image Acquisition Toolbox and the custom stlTools Toolbox.

4. Measurement method

Aim of this work is to get information about the manufactured object structure for a following evaluating purpose. The object information are captured with the hardware platform from the previous chapter. The

CAD file, which is basis for manufacturing process, describes the object in his ideal form and is used for the slicing process. The challenge is the object capturing without losing of geometrical information and afterwards a comparing with the CAD file. Extra time and object handling should be avoided for the capturing. Therefor the idea of inline process monitoring has advantages and should has no influence to the manufacturing process. Another way is to capture the object after finished manufacturing process. Thus it's certainly possible to integrate sensors, but needs mostly rebuilding steps in the AM machine for lossless information capturing. But the aim of this proposal is to get a high system adaptivity for possible subsequent evaluation in other additive manufacturing machines.

The inline process monitoring begins with capturing first layer after manufacturing. The machining head is moving to an outer place to have a clear field of view to the object from bird view. If the calibration process has been performed before [8], the sensor of the hardware platform captures the necessary 2D images of the first manufactured layer and creates a point cloud of the layer, which is called single point cloud in this work. The image data processing for creating the point cloud is performing on a connected PC, which can also control the manufacturing machine. A possible controlling would be a machine stop, if the manufacturing process goes in wrong way. Afterwards the single point cloud is prepared for analysis. The area where the manufactured layer is just placed will be interesting for analysis. The rest of the point cloud around the object is uninteresting and is erased in the single point cloud. Furthermore pseudo points are removed, which constitutes in noise effects. This steps has effect in reducing of the necessary data storage and consequently the subsequent data processing. But the captured platform ground of the AM machine is the virtual reference layer for all subsequent processing steps and is saved in background. The next manufactured layer is following and the layer capturing process starts again. The preprocessed single point clouds might be used for analyses of the manufacturing process, but isn't content of this work. After finishing of the manufacturing process all individuals point clouds are saved on the connected PC and prepared for the compounding of all layers to the final result.

After manufacturing is finished the number of single point clouds are same like the number of layers. The assembly of single point clouds to the object point cloud is necessary and is doing subsequently. One Advantage is the position of the layer to 3D capturing system, because the manufactured layer is always in the same z position. This results in moving of platform in z direction and the fix position of machine head. The compounding of the layers starts at the first and the next layer is orientated to the previous layer. Therefor apriori knowledge is used to position the layers to each other. The z movement of the build platform is constant and very accurate. The predefined layer height in slicing process is also used for point cloud assembly. The overlapping points from one layer to the other is be filtered to reduce data storage.

In summary the object point cloud is created and can be used for analysis. The STL model, what describes the manufactured object, is also be used for result analysis. The STL model is virtually positioned in the object point cloud and geometrical differences are coloured [Figure 3]. For this analysis a user input is required to give a tolerance.

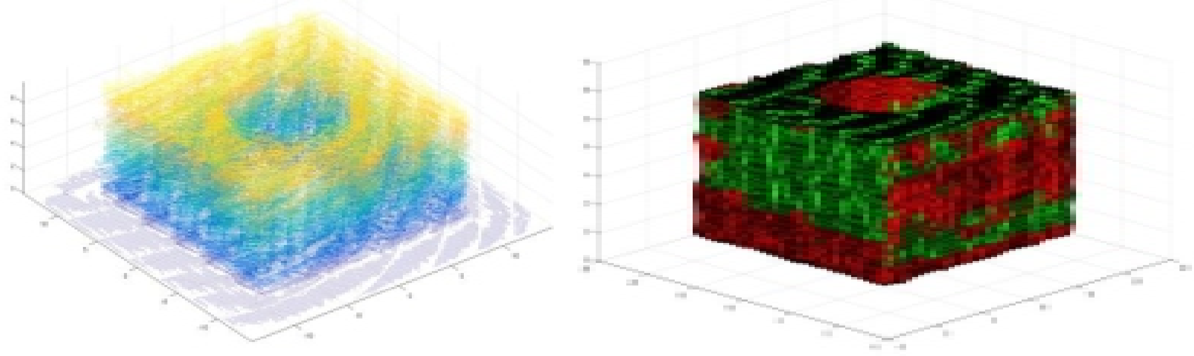


Figure 3. Assembled point cloud and final result

5. Results

The results are achieved with a triangulation angle of 28.7° and a baseline of 271 mm. Camera image size is 1920 x 1200 px and captures in combination with projector an area of 230 x 200 mm. A 20 x 20 x 10 mm cuboid has a density of several million points. The identified measurement stability for 3d reconstruction is 15 µm for white coloured ABS filament and current used algorithm. Admittedly it depends on the measurement field.

6. Conclusion

The investigation of the adaptable 3D sensor system in additive manufacturing system shows the possibility to monitoring the manufacturing process from start to end. The accuracy and number of point clouds are sufficient to give reproductive results for evaluating. A consequent next step is to close the quality control loop and manipulate the machine parameters for increasing manufacturing quality. Furthermore the single points cloud can be used for analysis and can declare more about the manufactured object.

7. Acknowledgment

We thank the federal ministry of education and research for the strong support of this work. The work is related to the project *Qualimess next generation* (03IPT709X).

References

[1] Lindemann C, Jahnke U, Moi M, Koch R 2012 Analyzing product lifecycle costs for a better understanding of cost drivers in additive manufacturing *23th Annual International Solid Freeform Fabrication Symposium–An Additive Manufacturing Conference (Austin Texas USA) 6th-8th August*

[2] Weckenmann A 1999 Koordinatenmesstechnik: Flexible Meßstrategien für Maß, Form und Lage 2nd edition Carl Hanser Verlag GmbH Co KG (München) 224

[3] Crump S S 1992 Apparatus and method for creating three-dimensional objects *U.S. Patent 5121329*

[4] Sun Q, Rizvi G M, Bellehumeur C T, Gu P 2008 Effect of processing conditions on the bonding quality of FDM polymer filaments. *Rapid Prototyping Journal*, *14*(2), 72-80

[5] Rankouhi B, Javadpour S, Delfanian F and Letcher T 2016 Failure analysis and mechanical characterization of 3D printed ABS with respect to layer thickness and orientation. *Journal of Failure Analysis and Prevention*, *16*(3), 467-481

[6] Heist S, Kühmstedt P, Tünnermann A and Notni G 2015 Theoretical considerations on aperiodic sinusoidal fringes in comparison to phase-shifted sinusoidal fringes for high-speed three-dimensional shape measurement. *Applied optics*, *54*(35), 10541-10551

[7] Heist S, Kühmstedt P, Tünnermann A and Notni G 2016 Experimental comparison of aperiodic sinusoidal fringes and phase-shifted sinusoidal fringes for high-speed three-dimensional shape measurement *Optical Engineering.* 55(2), 024105-024105

[8] Zhang Z 2000 A flexible new technique for camera calibration. *IEEE Transactions on pattern analysis and machine intelligence*, *22*(11), 1330-1334