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Original published in:	Journal of physics. Conference Series / Institute of Physics - Bristol : IOP Publ.. - 1065 (2018), art. 32005, 4 pp.
Original published:	2018-08-01
ISSN:	1742-6596
DOI:	10.1088/1742-6596/1065/3/032005
[*Visited:*	2020-06-09]

IOP Conf. Series: Journal of Physics: Conf. Series **1065** (2018) 032005 doi:10.1088/1742-6596/1065/3/032005

Approach for optical innervolumetric 3-dimensional data acquisition

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Abstract. This work presents a suitable solution to get innervolumetric 3-dimensional data of an Additive Manufacturing (AM) process. The necessary image capturing and generating of singlelayer pointclouds is presented. The subsequent pointcloud composition to an objectpointcloud is also explained. The sensor system is implemented and evaluated in a Fused Filament Fabrication (FFF) manufacturing machine. The captured innervolumetric data represents informations about internal structures of the manufactured object and might be a possibility to qualify the manufacturing process. Potential quality features could be geometry dimensions, surface roughness or other manufacturing defects. These informations could control a quality control loop and subsequently improve the manufacturing process.

1. Introduction

Metrology and methods for 3-dimensional measurement have found a place in many parts in our life. Consumer electronics are equipped with 3-dimensional technique [1] and similarly modern quality assurance processes in production and manufacturing fields. The global automated optical metrology market is expected to reach US$1.5 bn by the end of 2021 [2]. That means an increasing of 66 percent sales in comparing to 2014. Reasons can be found in necessity for a high grade of automation in manufacturing and production processes. This development is inevitable to get high innovation and quality for competitive staying in the market [3]. The claimed high grade of innovation is only possible with research and development in these optical fields. This includes the availability of new sensor technologies and the capability for evaluation of new processing approaches.

Furthermore new production and manufacturing methods challenges quality assurance and process control systems. Complexity of manufacturing processes are getting higher, just-in-time production is more important than ever and flexibility can be crucial for success.

New technologies have also changed development workflows in past and will also do it in future. Mentioned by way of example is the development of Computer Aided Design (CAD) workflow, which has enormously accelerate the product development. Users can design complex geometrical structures and put them in virtual assembly group. Furthermore are the possibility for finite element methods (FEM) or other simulations. The blueprint creating is also getting easier and saves time effectively.

Another step for new ways in product development was possible since the first additive manufacturing processes were presented in the idea for stereolithography (STL) of Alain Le Méhauté, Olivier de Witte and Jean Claude André [4] in 1984. The transformation from CAD in machine readable code opens new ways for rapid prototyping and manufacturing.

Furthermore new and more effective additive manufacturing technologies are permanent under developing and might be able to change the manufacturing workflows in future too. Currently the process time for additive manufacturing has disadvantages in many cases in comparing to traditional manufacturing methods like milling. The increasing of the manufacturing quality is simultaneously desirable. Higher geometric accuracy, convenient surface and the conformance for mechanical requirements of manufacturing parts are criterions for improving quality in additive manufacturing. New approaches for manufacturing process control are necessary and actually have to be integrated in process. These methods are called inline process monitoring and an approach is explained in this paper.

2. Methodology and experimental setup for innervolumetric 3-dimensional data acquisition

Additive manufacturing uses another kind of way to create the form of a workpiece. Traditional manufacturing methods, like milling or cutting, are tooling a workpiece in a subtractive way. Process control in former of geometry tolerance or surface checks are just possible after finished manufacturing process.
The workflow for additive manufacturing offers some kind of advantages in this case. The workflow starts with a designed model in CAD and is followed by a transferred STL file for the slicing process [Figure 1]. The model gets sliced in horizontal layers and a path planning for laser, extruders or other moving parts, depends on which additive manufacturing technology is used, get created. Different adjustable parameters, for example layer heights, temperatures, speeds and even more, can be defined for influencing the manufacturing process.

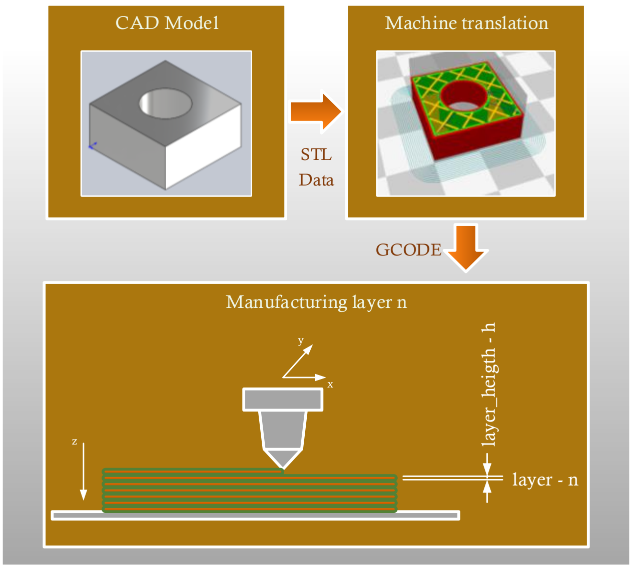

Figure 1: Workflow for additive manufacturing

The high grade of parameter variety for process controlling implicates a risk for unstable manufacturing processes.
Additive layer manufacturing offers the possibility to take a look inside the manufactured workpiece. These view from inside offers informations about potential manufacturing failures, structures and geometrical dimensions. Unstable manufacturing processes can be recognized and existing manufacturing processes can be optimized.

For this purpose a hardware platform for additive manufacturing processes is developed and assembled in a Fused Filament Fabrication machine [5]. The self-made and adaptable hardware platform for the inline process monitoring is able to output 3 - dimensional information about the manufactured layer during process time. The assembly position is chosen over the additive

manufacturing machine in bird view to capture the information from layer to layer. Other assembly position are not acceptable, because a modification of the additive manufacturing machine would be necessary and might decrease the efficiency of the manufacturing process. Furthermore the hardware platform should also usable for other additive manufacturing processes and inline process monitoring tasks.
The hardware platform has a stereoscopic camera system and the necessary projector for fringe projection is placed between both cameras. The GigE Vision cameras and C-mount lenses are replaceable to diversify the field of view. At once the field of view defines the accuracy of the measurement system and furthermore the point cloud resolution depends on it. 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 a 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.
The monitoring workflow starts after the first layer is manufactured (Figure 2). The nozzle head moves out of way to give a free for view for data acquisition. A necessary calibration process was performed before [6]. The projector generates different fringe pattern and projects to the layer. The stereoscopic image sensors captures the necessary 2-dimensional images of the first manufactured layer and calculates a pointcloud of the layer [7][8], which is called singlelayer pointcloud in this work. The image data controlling for pointcloud generating and the controlling of the additive manufacturing machine is performed on a Linux-based x86 PC-architecture. The applied software libraries for 2-dimensional image acquisition are QT5, OpenCV and the Sony Camera SDK.

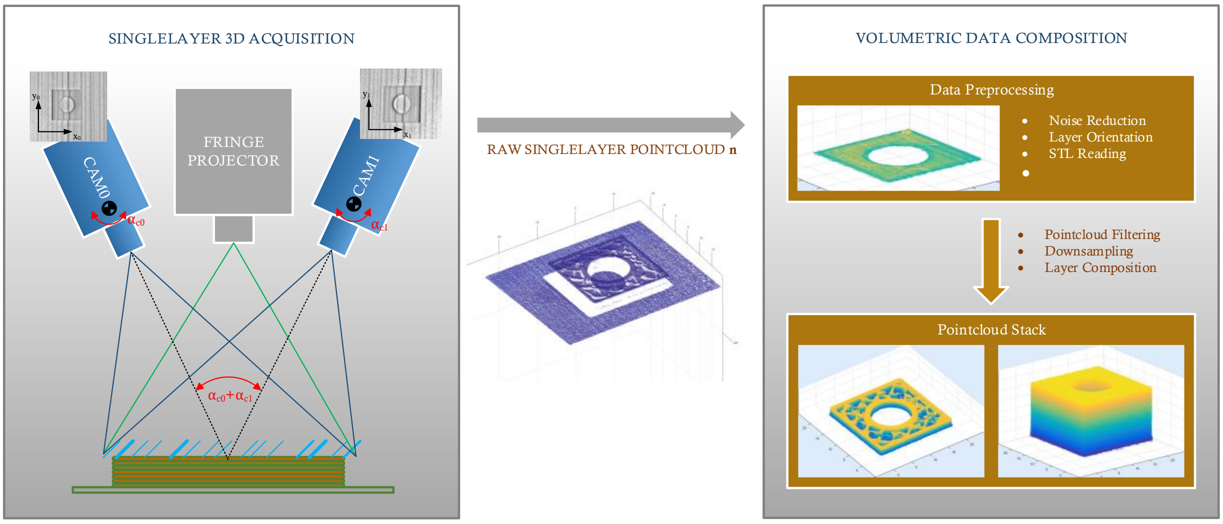

Figure 2: Workflow for Volumetric Data capturing

The captured singlelayer pointcloud has to pass some preprocessing steps to be optimized for next processing steps. These preprocessing steps are noise reduction in pointcloud, fitting the pointcloud in correct orientation, removing pseudopoints and the platform ground. During time the next layer is additve manufactured and the next singlelayer pointcloud of the second layer is captured. The preprocessing steps are starting from the beginning and a circle of manufacturing and capturing starts. At the end of the finished additive manufacturing process the same number of singlelayer pointclouds and manufactured numbers of layer are available. Additionally the informations of the CAD is saved in the STL file. Furthermore the height of each layer is known and is used for the composition of the singlelayer pointcloud to the objectpointcloud, which represents the complete manufactured workpiece. The informations of the STL file and the known layer height is used to define a region of interest (ROI). The ROI is necessary and defines the number of points, which are relevant for orientation calculation within pointcloud. The composition of all singlelayer pointcloud is the subsequent processing step. Overload points are getting removed to don't get double informations and reducing data storage. A subsequently reducing of pointcloud resolution is also possible.

3. Results

The result of this work is a 3-dimensional innervolumetric pointcloud, which describes a complete additive manufactured object. The maximum object size for the monitoring process are 200 x 220 mm in x and y direction. The z dimension is just limited through working space of manufacturing machine. Pointcloud structures with less µm resolution are possible to identify. This potential informations could be the knowledge base for subsequent process control steps or just to evaluate the manufacturing process. The hardware platform is also deployable for further additive manufacturing machines and methods.

4. Conclusion

The aim of this work is to create a possibility to capture informations about an additive manufacturing process. Challenges are to get these informations during the manufacturing process and the system should be adaptable for further additive manufacturing methods.

This work presents a stereoscopic camera system and a fringe pattern projector to get 3-dimensional geometry informations after every manufactured layer – a singlelayer pointcloud. This case and the apriori knowledge about the layer height permits a construction of a complete object pointcloud.

The singlelayer and object pointcloud can be used to evaluate the additive manufacturing process and a control loop can increase the manufacturing quality.

5. Acknowledgment

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

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