euspen's 23rd International Conference & Exhibition, Copenhagen, DK, June 2023
www.euspen.eu

In-process monitoring of selective thermoplastic electrophotographic process by laser profiling system and digital fingerprint

Shuo Shan[1], Hao-Ping Yeh[1], Marta Rotari[2], Kenneth Ælkær Meinert[1], Jesper Henri Hattel[1], David Bue Pedersen[1], Murat Kulahci[2], Hans Nørgaard Hansen[1], Yang Zhang[1], Matteo Calaon[1]

[1]*Department of Mechanical Engineering, Technical University of Denmark, Building 427A, Produktionstorvet, 2800 Kgs. Lyngby, Denmark*
[2]*Department of Applied Mathematics and Computer Science, Technical University of Denmark, Building 324, Richard Petersens Plads, 2800 Kgs. Lyngby, Denmark*

sshan@dtu.dk

Abstract

In the past decade, the demand for high-volume production of high-precision products with complex shapes has led to the development of new manufacturing processes. Among these processes, the Selective Thermoplastic Electrophotographic Process (STEP) shows potential for meeting these production demands. STEP involves layer-wise construction of a 3D object from a CAD model. However, during process characterization and optimization, defects such as dimensional flaws have been detected in the final products. To address this quality control issue, a laser profiling system has been installed on the STEP machine to detect process stability for every layer added to the 3D bulk. Additionally, finger print test structures have been introduced in the build job to evaluate process performance. Image detection post-processing of the test geometries is carried out to quantify the dynamic dimensional conformance layer by layer of the manufactured component. By using the online data collected through this quality control process, greater control over the manufacturing process can be achieved, and a feedback loop can be established. This feedback loop will allow for the online adjustment of manufacturing parameters, which will be applicable and provide great help for product optimization. The new sensors and algorithms used for this quality control process will also be incorporated into the digital twin, making this technology even more valuable for a wide range of applications.

Process sensing technologies, 3D scanning, Additive manufacturing, Object detection

1. Introduction

Selective Thermoplastic Electrophotographic Process (STEP) is a new technology in the additive manufacturing field. Electrophotographic imaging [1] enables high-volume production by fusing 2D layers into a single 3D bulk structure. It is composed of two essential modules: an electrophotographic engine and a transfusion module. Unlike other conventional additive manufacturing techniques, STEP has been validated as a potential alternative for the massive production of polymer components thanks to its high speed, good precession and fast starting time [2].

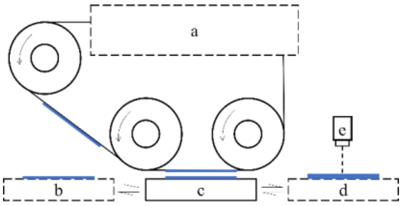

Figure 1. STEP process. a. Electrophotographic Process; b Heating; c. Transfer; d. Cooling; e. Laser scanning

During the STEP printing process, the building plate moves back and forth during the coming layer stacking on it, which makes it difficult to realize precise alignment between successive layers. To address this issue, this investigation proposed a method using digital fingerprint and in-process monitoring to obtain the quality of the printing layer, which will be sent to the printer as feedback. Fingerprints are designed, including the dimensional and positional accuracy of 36 squares as indicators of printing quality. A laser profiling system scans the printed surface and generates the heightmaps. Afterwards, the images are post-processed by transformation and alignment. Object detection and measurement are then applied to the heightmaps to obtain the positions and dimensions of the reference fingerprint.

2. Methodology

2.1. STEP printing and laser profilers alignment

The STEP process is illustrated in Figure 1. The building platform (BP) moves back and forth in 3 positions: heating, transferring and cooling. The BP and the previously printed layers are heated up to 120 degrees in the heating position. When the BP moves to the transferring position, the toner on the drum is then transferred to the BP by melting and fusing. The BP is then cooled down to the cooling position.

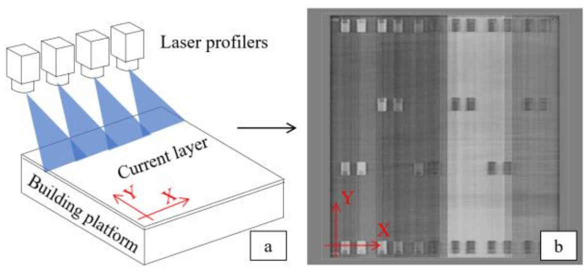

Figure 2. Laser alignment (a) and the generated heightmap of current layer (b).

Figure 2 shows the alignment of four laser profilers that scan the entire building platform. The relative height of the current layer is measured by sampling points on lines. As the BP moves, the sampled lines are stitched and generate a heightmap.

2.2. Finger print object detection and measurment

On the heightmap, 36 finger print structures like squares are designed as references distinguished by the Z direction difference. For each layer, the squares are to be detected with bounding boxes, which are listed as: $[X\ Y\ W\ H\ P]$. X and Y are the absolute coordinates on the heightmap, representing the position of the detected squares; W and H are the width and length of the bounding boxes, as depicted in Figure 3. Finally, P is the confidence of the detection, which is derived based on the mean average precision at the intersection over union, representing the probability of correctly detecting the bounding box.

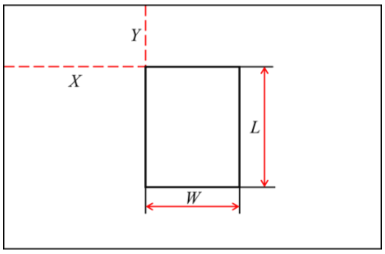

Figure 3. Position and dimension information of the finger print reference squares.

For object detection, a neural network is trained. Data augmentation techniques on images like flipping, rotation, scaling and colour manipulations are performed during the training process. Layered heightmaps derived from the STEP process are submitted to the trained neural network, where positions and dimensions of reference squares are inferenced. The results are then compared to the input mask and the feedback is sent back to the STEP machine to make adjustments. The overall in-process monitoring framework is illustrated in Figure 4.

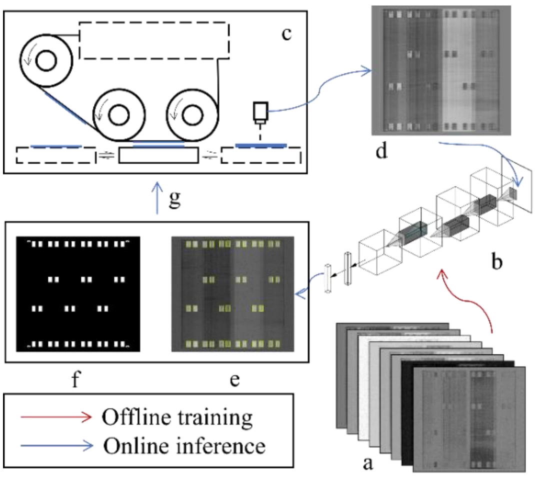

Figure 4. In-process monitoring loop. a. labelled dataset; b. trained neural network; c. STEP process; d. heightmap during the printing process; e. results of reference squares detection; f. input mask; g. feedback to STEP.

3. Results and analysis

The neural network training is conducted on Tesla V100. The training set consists of 30 heightmaps, including 1080 labelled squares, whereas the test set comprises 24 heightmaps. On 21 heightmaps, the model correctly identified all the squares, whereas in the rest 3 heightmaps, there are 34, 22, and 17 detected, respectively.

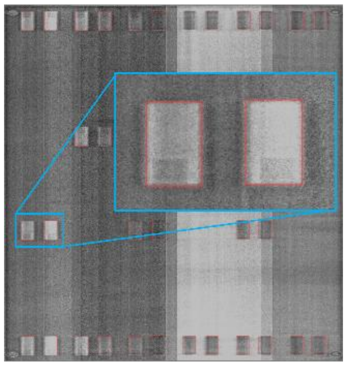

Figure 5. Infereced bounding boxes.

Figure 5 shows the inference bounding boxes of the reference squares. It can be noticed that the reference finger print squares are well detected with dimensions bordered by bounding boxes. The inferencing process takes less than 0.6 seconds on the CPU (Intel(R) Core(TM) i7-1185G7 @ 3.00GHz). Considering the printing time for each layer, the proposed approach is sufficient for in-process monitoring, online printing quality inspection and corrective feedback loop for the STEP process. The confidences of inference squares on corners are shown in Figure 6. The average confidence ranges from 85.2% to 93.3%, with up to 5.6% deviation.

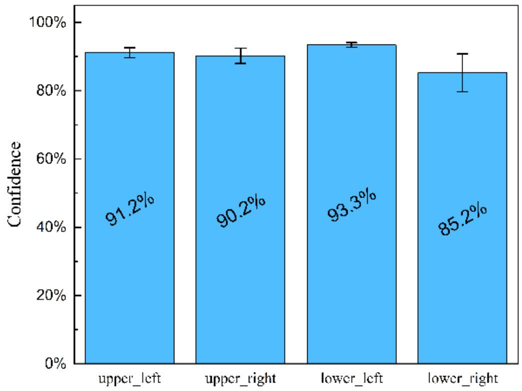

Figure 6. Confidences of inferences of corner reference squares.

4. Conclusion and future works

This investigation proposed an in-process quality inspection and monitoring approach for the STEP process. A laser profiler system is employed to characterize the current printed layer as a heightmap, which is then sent to a neural network to obtain the positions and dimensions of finger print reference squares manufactured as an integral part of the produced component. The results of the experiments show good performance speed. The approach proved a good fit for building a close sensoring loop in the STEP process. Future works include using input masks to crop the heightmap so that the inference areas can be greatly decreased, thus the inference speed can be boosted and other geometries other than reference squares can be applied in the approach.

References

[1] Kumar A V, Dutta A and Fay J E 2004 *Rapid Prototyping Journal.*

[2] Hanson W J, Sanders J R, Bacus M W and Chillscyzn S A 2011 *Electrophotography-based additive manufacturing system with transfer-medium service loops*.