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Powder Bed Analysis in Additive Manufacturing Using Image Processing

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Abstract. *Systems for additive manufacturing are experiencing an enormous upswing in the industry. In this paper a method for the optical control of powder beds is presented. The system is based on a camera and directional lighting and is suitable for detecting two types of defects, including (i) areas where too little/too much powder has been applied, and (ii) areas with different porosity. The system is evaluated for both types of errors.*

1. Introduction

Binder-Jetting is a popular method for additive manufacturing of high-resolution components. In this process, powder is applied in layers, which is then selectively cured by a binder [3]. In order to prevent dead times and production downtimes in powder-bed-based additive manufacturing, a system was sought that would reliably find defects in the individual powder layers. Defects in the powder bed can occur either in the form of excess/missing powder, or as insufficient porosity of the powder. If such defects are not detected, components may be produced which do not achieve the expected strength values or contain predetermined breaking points inside. The analysis system should be simple in design and reliable in operation.

Three different types of optical analysis are used in existing plants: Laser triangulation [2], a camera with structured illumination [4] or a camera with directed illumination [1]. All approaches aim at creating a geometric image of the powder surface. Laser triangulation or structured illumination can be used to create three-dimensional models of the plane, while directed light can only be used to find qualitative deviations from the plane. Since a qualitative evaluation of the surface is sufficient, the method with directed light is chosen.

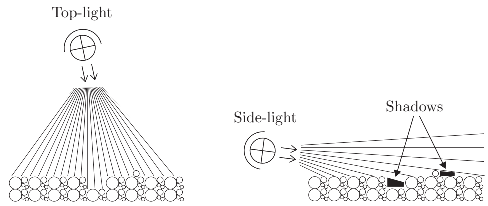

Figure 1. Side-light causes shadows at defective positions

2. Imaging System

The prototypical image system is installed in an existing machine for additive manufacturing.

The system consists of a camera and two lights. One light source illuminates the powder bed vertically from above to achieve the most uniform illumination possible (top-light). The second light source shines on the powder bed at a very flat angle (side-light). 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 in the powder are not misinterpreted as shadows.

3. Image Processing

After acquiring the images of one layer, the processing of the images is done. The two images are high-pass filtered to minimise global illumination differences. (A constant correction is not possible because differences in the powder mixture lead to different reflection properties.) Afterwards the images are subtracted from each other to extract the shadows. A powder layer without defects thus produces an image with very low grey values, as there is no difference between top-light and side-light. Defects

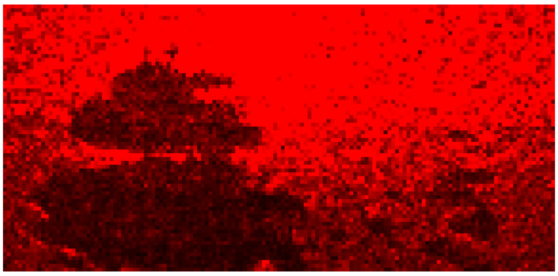

Figure 2. Variance of the difference image: high red intensity = high variance = missing powder

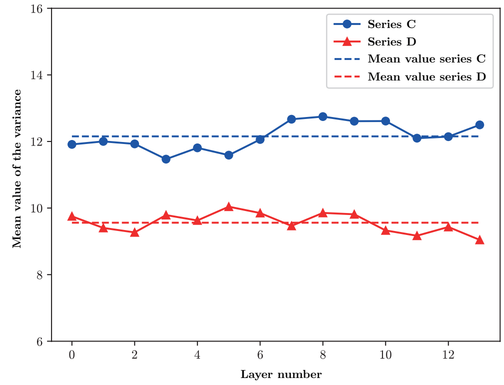

Figure 3. Variance of the grey values of the powder layers of two layers of test pieces with different porosities

or high porosity stand out from the image in the form of high grey values. The variance of the grey values in small, rectangular sectors is used as an indicator of quality. The observation in sectors is needed to locate the defects. A low variance indicates that few defects occur in the powder bed, the layer is well compacted. High values of the variance can indicate defects or high porosity.

3.1. Large defects

A difference image with powder missing over a large area can be seen in Figure 2. Areas with missing powder (or too much, albeit an unlikely case) produce large shadows, which appear as high grey values in the difference image. If the defects are larger than the sectors of the detection, the mean value of the grey values have to be considered in addition to the variance. A weighted average of the two factors is used as a criterion for the evaluation.

3.2. Porosity

Another factor that is evaluated is the porosity of the powder layers. The strength characteristics of the printed components are directly related to the degree of compaction of the powder. If the porosity is too high during the printing process, lower strength values are expected. Porous powder layers create shadows in the area of the grain size of the powder used, which appear as noise in the differential image. The variance of the grey values in the sectors is sufficient for detection. It should be noted that areas close to the light source tend to be overexposed, which makes evaluation more difficult.

4. Experimental Validation

To test whether the strength of components can be estimated during the manufacturing process, several series of test specimens were printed and then tested. It was confirmed that layers with few defects and a low porosity achieve higher strength values. The evaluation of the test is shown in Figure 3. Series C achieves $S_C = 10.8\,\mathrm{MPa}$ with a compression ratio of 10%, while series D achieves $S_C = 11.4\,\mathrm{MPa}$ with a compression ratio of 15%. Test specimens with higher density and better strength characteristics show lower porosity in the printing process, which is reflected in the differential images as a lower variance of the grey values.

5. Conclusion

Our tests have shown that a simple system consisting of one camera and two light sources is well suited for process control of powder bed based additive manufacturing processes. Both coarse defects in the powder bed and different porosities can be detected, which avoids production downtimes and enables quality control already while printing.

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