A Novel Approach for Immediate, Interactive CT Data Visualization and Evaluation using GPU-based Segmentation and Visual Analysis

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Abstract
CT data of industrially produced cast metal parts are often afflicted with artefacts due to complex geometries ill-suited for the scanning process. Simple global threshold-based porosity detection algorithms usually fail to deliver meaningful results. Other adaptive methods can handle image artefacts, but require long preprocessing times. This makes an efficient analysis workflow infeasible. We propose an alternative approach for analyzing and visualizing volume defects in a fully interactive manner, where analyzing volumes becomes more of an interactive exploration instead of time-consuming parameter guessing interrupted by long processing times. Our system is based on a highly efficient GPU implementation of a segmentation algorithm for porosity detection. The runtime is on the order of seconds for a full volume and parametrization is kept simple due to a single threshold parameter. A fully interactive user interface comprised of multiple linked views allows to quickly identify defects of interest, while filtering out artefacts even in noisy areas.

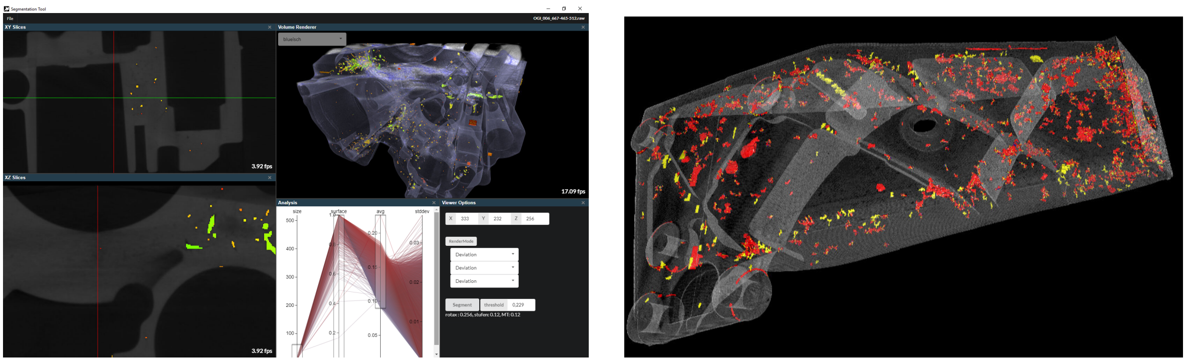

Figure 1: Left: Our novel segmentation tool with multiple linked views: 2D slices, direct volume rendering, and an interactive parallel coordinates. Right: CT data set rendered at real-time frame rates using Direct Volume Rendering.

Keywords: CT, GPU, Inclusion Detection, Interactive Visualisation, Visual Analysis, Parallel Coordinates

1 State of the Art

Volume rendering [11] is a standard technique in the field of non-destructive testing to detect and visualize volume defects [1–5]. In addition to standard 1D transfer functions, multi-dimensional transfer functions can be used to visualize interesting parts and to emphasize different materials. Hadwiger et al.[6] use a region merging approach to extract regions of similar density (pores, defects etc). They use multiple parameters for their segmentation method, which can later be explored interactively by using multi-dimensional transfer functions. Weissenböck et al. [7] combine parameter space exploration for segmentation parameters with highly customizable segmentation pipelines. Our system, in contrast, works with a simple single-parameter segmentation approach combined with real-time interactive analysis for a selected set of feature measures.

2 Our Approach

In contrast to time-consuming parameter space exploration approaches, where a fixed result set can be filtered after a preprocessing step, we propose a novel interactive analysis framework. The main idea is to perform an extremely fast over-segmentation with a single parameter with local threshold adjustment using a statistical region merging approach [8] and then apply live filtering and merging based on the explored findings. The segmentation algorithm exploits the massive parallelism available on GPUs and can also handle out-of-core data larger than GPU- and system memory. For live exploration, we use a *Parallel Coordinates* view to visualize descriptive properties (e.g. size, average density, standard deviation over density, volume/surface ratio, etc.) of all detected artefacts. Through interactive filtering by brushing and selecting regions on the coordinates, a fast and intuitive exploration of the desired defects is made possible *without prior knowledge*.
After the initial segmentation, a user typically uses the *size* descriptor to filter away large features (such as the surrounding air). Secondly, noise in the data is taken into account: Instead of prefiltering our data, we apply our algorithm to the unfiltered, raw

input. Therefore, detected regions at this stage either consist of noise, or actual (possibly separated) defects. By interactively filtering away all features with a *standard deviation* close to zero in the parallel coordinates view, the noise can be removed. We then perform a second segmentation refinement step which re-applies the merge criterion based on the selected filters, ending up with a high-quality segmentation that is robust to noise and non-uniform density values. Additional information about the system and additional material can be found here [10]. Our application combines multiple linked views (2D slices, Direct Volume Rendering, Parallel Coordinates and Settings) into a single user interface (see Figure 1, left). For in-depth analysis, each view can be made full-screen (see Figure 1, right). The UI is based on standard web technologies (e.g. parallel coordinates are implemented using D3 [9]) and can be used with any modern web browser. Our system runs locally on the user's machine, but the architecture has been designed with cloud-based deployment in mind to make users independent of costly hardware (any device with a web browser works) and to enable collaborative and distributed work environments in the future. Cloud-based rendering will also address data transfer (next-generation CT detectors will approach 4000^3 resolution) and security issues.

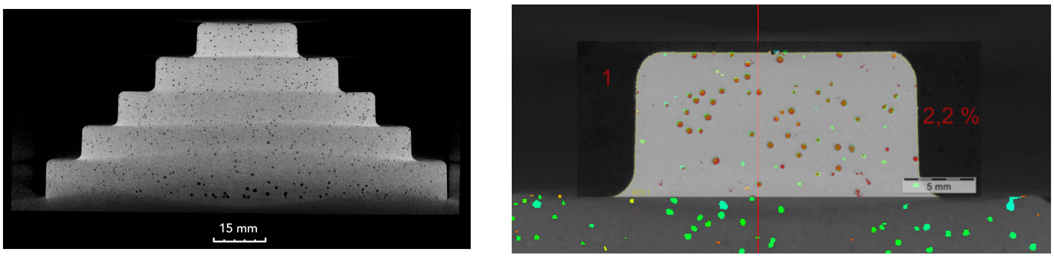

Figure 2: CT image of the step cylinder comprising artefacts (left) and comparison with a metallographic analysis (right). Accurately detected pores are marked orange.

3 Evaluation

Test objects: For test measurements an artefact-provoking 6-step aluminum cylinder with diameters ranging from 20 to 120 mm was constructed and cast with intentionally gas-induced melt in order to introduce volume defects such as pores (see Fig. 2, left). Different component cast parts were used as further test objects (Fig. 1).
CT Scan parameters: CT scans were performed on a GE/phoenix v|tome|x L equipped with a 240 kV microfocus cone-beam X-ray tube and a DXR 250 RT flat panel detector. CT parameters of the cylinder scan were as follows: 180 kV, 200 μA and 0.5 mm Sn prefilter, no beam hardening correction, voxelsize: 70 μm, dimensions: 1850x1850x1000 px, filesize: 6.37 GB
Comparison with metallography: In order to check the accuracy of the porosity analysis, the cast step cylinder was cut, subdivided in 6 regions for the 6 steps, embedded, ground, polished and analysed metallographically. The determined porosities values were used as ground-truth data for analysis by means of CT. As long as it was possible to find the same slice images the determined porosity values were well comparable (see Fig. 2, right). .
Quality, Performance & Usability: Since our segmentation method does not perform any pre-filtering, we detect even small pores while noise can be filtered out interactively. The software prototype is currently used and tested at the Austrian Foundry Research Institute on a daily basis. Due to the explorative, interactive approach and the simplicity, users adapted to the workflow extremely fast und successful. This is also driven by the factor that the high performance segmentation (3-16 seconds for the test data sets) outperforms existing tools, increasing productivity significantly. A more elaborate user study will be conducted soon.

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