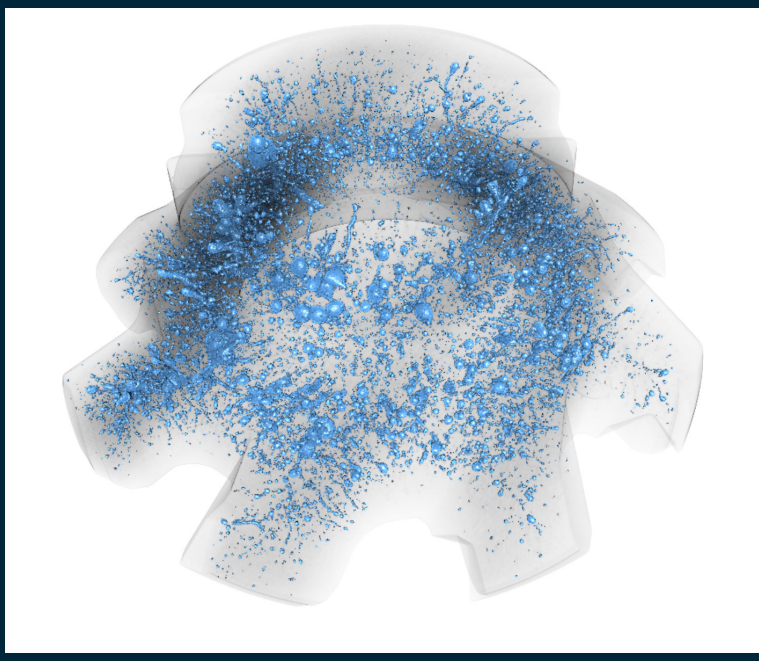
Application Note



Fast Porosity Analysis of Castings

X-ray computed tomography (CT) allows the detailed quality evaluation of castings. Of particular interest is porosity and its distribution and extent within the castings in three dimensions. Since this is often done as a spot check for foundries, high throughput is needed, and hence a simple and fast 3D image processing method is important here. In this application note, we showcase three simple (and fast!) methods in Dragonfly 3D World, all of which can be automated by macro's. They are demonstrated on three different castings representative of typical castings, with varying porosity amounts. The time for the analysis by macro is shown in each case as well. The method can be applied identically to any other sample types with closed (internal) porosity

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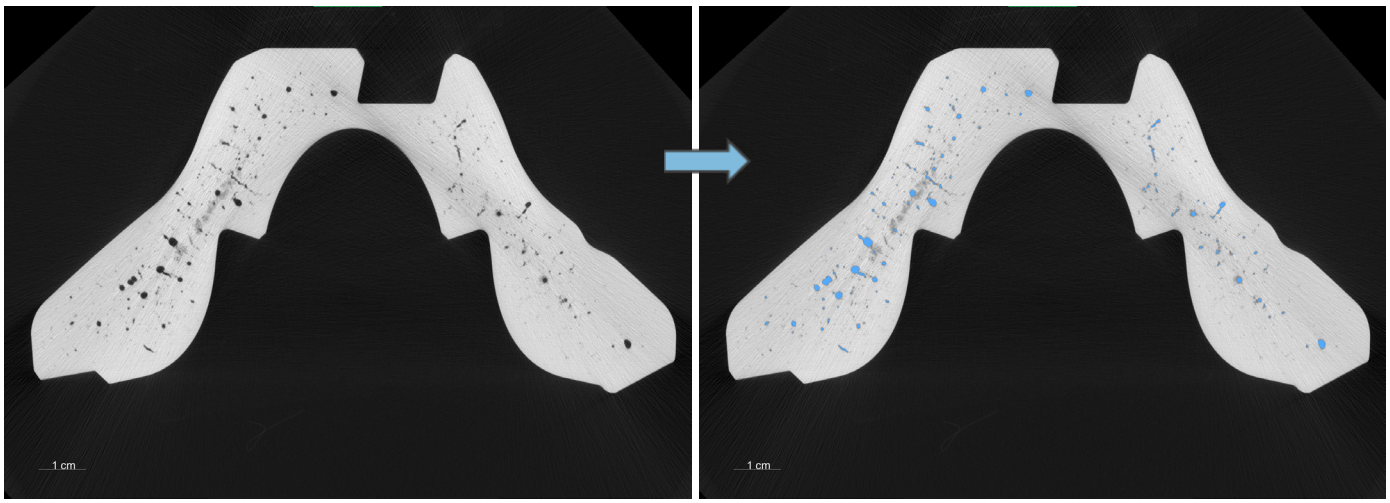
Requirements

A CT scan of the casting is needed, typically using an industrial X-ray micro-CT instrument. Image analysis is fully digital and a computer with Dragonfly 3D World software is needed. The data can be any format as long as the voxel size is known (typical is a stack of 16 bit tiff images representing the full volume). The parts in this application note were scanned using the Comet YXLON UX20 and FF35 systems. The computer used in this case has 64 Gb RAM, Intel i7 8-core processor and Nvidia RTX3070 graphics card.

Typical outputs

- 3D images and videos highlighting porosity with color coding according to size
- Porosity volume fraction % & pore size distribution

Method 1: Basic Otsu



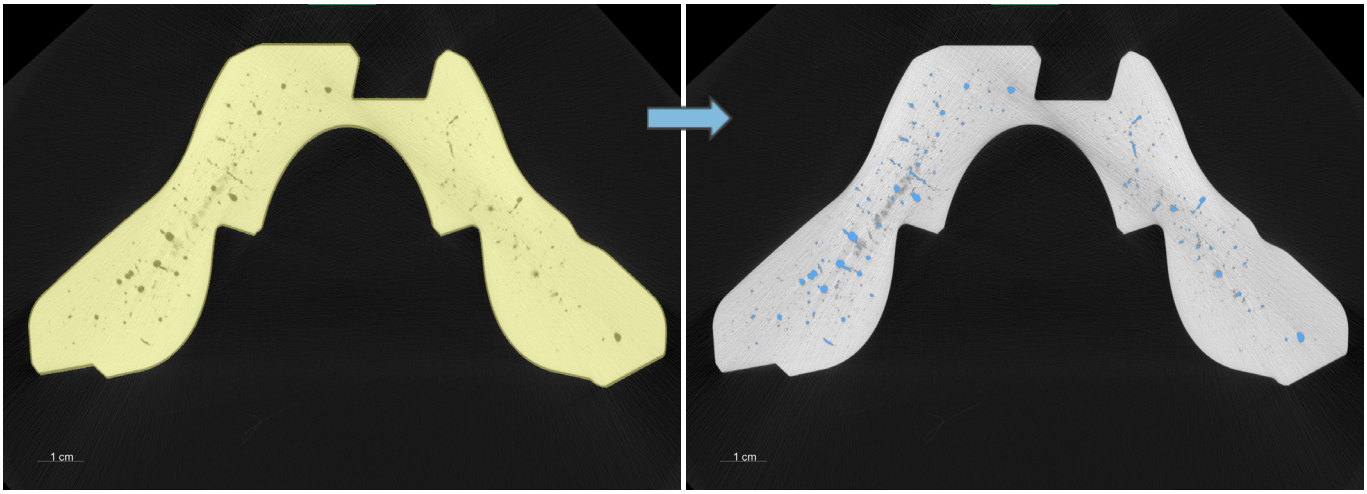
Segmentation of pores according to Otsu method, for a casting dataset shown in CT cross section here.

Otsu thresholding is the most popular and successful method to differentiate two material types in images based on intensity, used since the 1970's and widely used in image analysis in 2D and 3D [1]. The regular Otsu threshold can be applied to define pores in parts and is usually a good first attempt, especially for large pores. The method involves creating a region of interest (ROI) for air based on the Otsu threshold for the full 3D dataset, for all air and void space. This ROI is then refined to remove exterior air using the "process islands" tool.

Method 2: Modified Otsu

The problem with Otsu thresholding is sometimes that the data contains many “exterior air” pixels, making the histogram unbalanced and causing very small internal pores to be potentially missed (it is better suited to large pores). Therefore, a modification of the Otsu method is suggested here, that can be fully automated in Dragonfly 3D World and still provides a reliable segmentation of small pores.

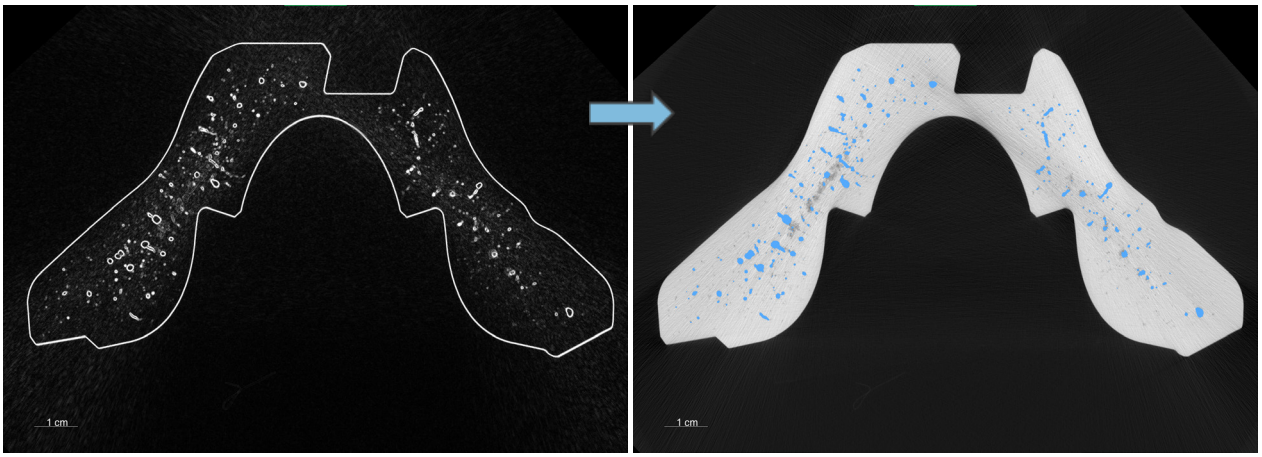
In this method, a region-of-interest (ROI) is defined for the part, using (upper) Otsu thresholding. Once this is defined, the internal pores are filled to define “part plus pores”. A dilate function is applied to increase the ROI size by two pixels beyond the edge of the part. This new ROI is then split according to Otsu as applied to the underlying ROI pixels only (in 3D, actually voxels). The resulting “porosity ROI” includes a layer around the edge of the part, that is removed by “refine – process islands” tool. This method allows a more balanced histogram allowing the Otsu to operate more successfully for cases of small or few pores.



Segmentation of pores according to modified Otsu method, for a casting dataset shown in CT cross section here.

Method 3: Sobel filtered thresholding

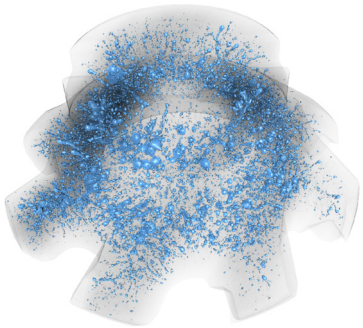
The methods 1&2 are excellent solutions for obtaining fast results. In some special cases, a more advanced method is needed for finding the smallest pores, or in cases with challenging data e.g. having brightness variations across the image. This approach uses the Sobel image filter to highlight edges of pores, using that for the segmentation step. It is slower than the first two methods but can still be fully automated by macro. The Sobel filtering is done using the image filtering toolbox, using a 3D Sobel filtering without any pre-smoothing. This is then used as a basis for thresholding and selecting only the Sobel-image bright regions as an ROI – edges of the part and of the pores. This ROI is then “closed” and “fill inner areas 3D” applied to ensure pore edges are used to fill out the pore cavity. The edge is removed by “process islands” as in previous methods. This method is more complete and captures more pores in cases of low signal to noise in the data and hence smaller pores are identified.



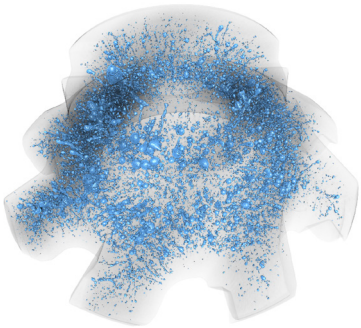
Segmentation of pores according to Sobel method, for a casting dataset shown in CT cross section here.

Method comparison: how fast is it really?

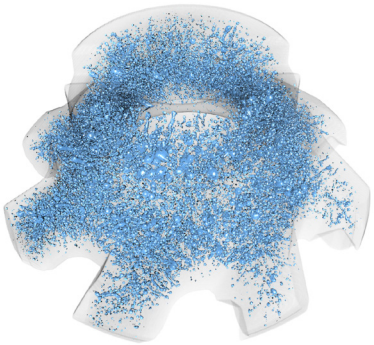
All three methods show reliable results for the milling head sample which contains large porosity. The method 1 is fastest, with time shown below for each method. Please note that times may vary depending on computer hardware, and macro's run slightly faster than human manual operation. The quoted times were recorded using the image analysis recipe in a macro on a workstation with 64 Gb RAM with the dataset size 1430x1430x1430 voxels at 16-bit (5.5 Gb).



Method 1 / Otsu: 5 seconds



Method 2 / Modified Otsu: 30 seconds



Method 3 / Sobel: 4 minutes & 20 seconds

Method comparison: automotive part

This part of 892 x 643 x 1244 voxels (1.3 Gb) contains only small isolated pores and there are some differences in the results of the three methods, due to the size and contrast of the pores, in combination with the resolution of the CT scan. The resulting 3D images and times per method are shown below. All methods show the largest pores.

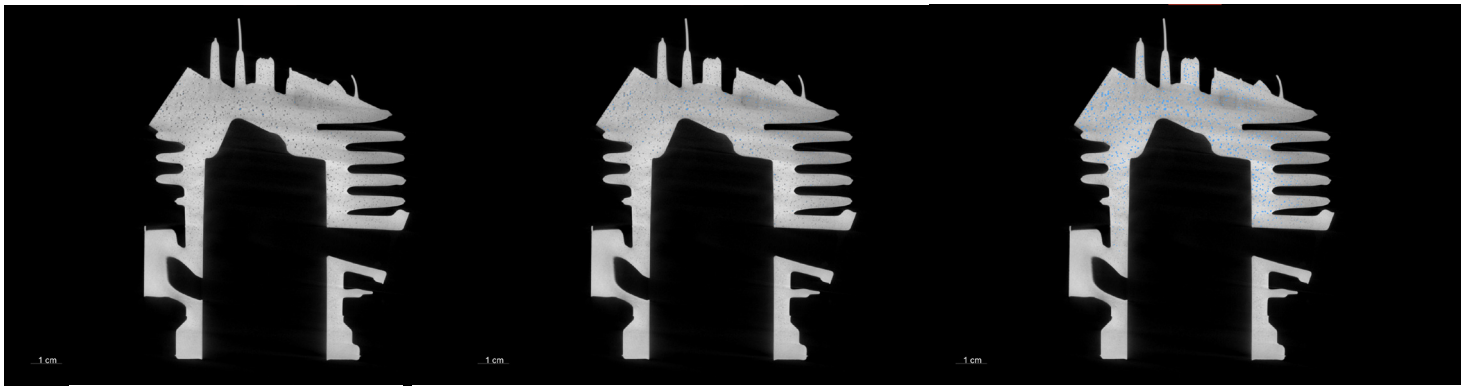
Method 1 / Otsu: 4 seconds

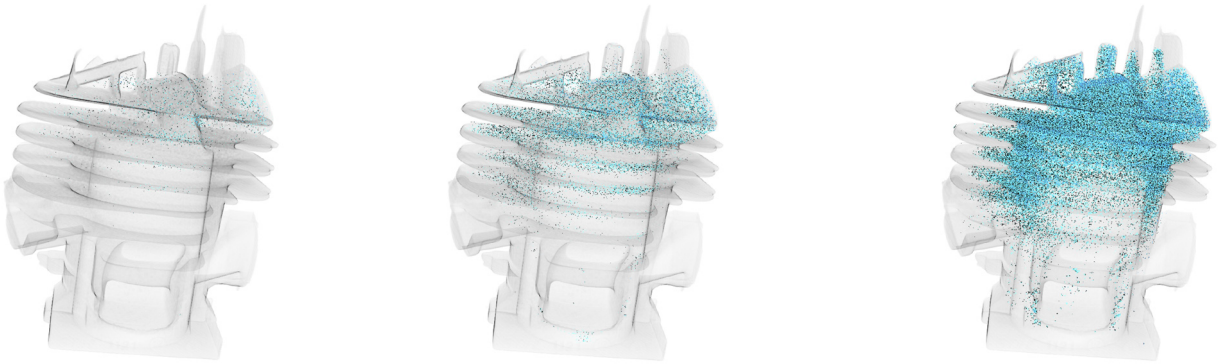
Method 2 / Modified Otsu: 8 seconds

Method 3 / Sobel: 1 minute & 24 seconds

Method comparison: engine part

This casting of 1704x1704x1932 voxels (10.7 Gb) contains many small pores, making the segmentation more challenging. The simple Otsu methods miss many pores as seen on the left, but are very fast and still show the biggest pores. The Sobel method captures all pores as shown on the right, taking longer to calculate.





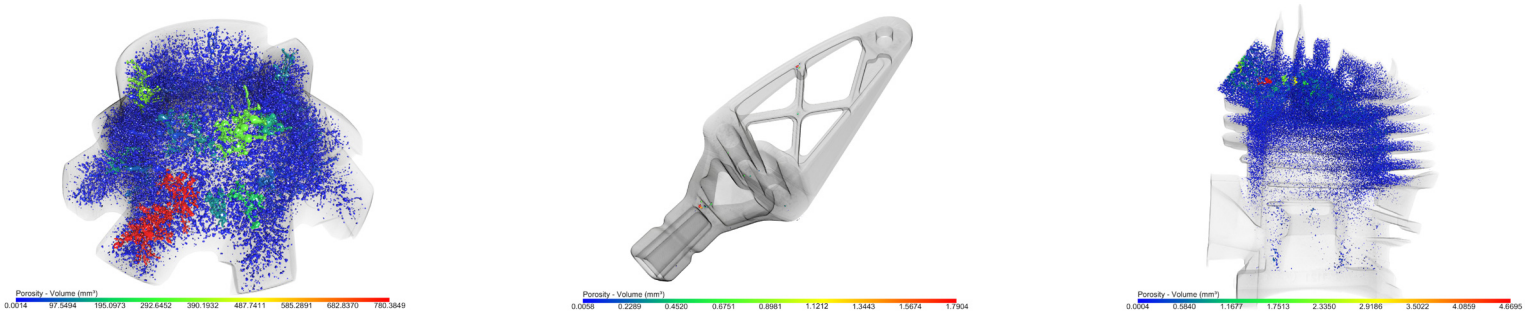
Method 1 / Otsu: 7 seconds

Method 2 / Modified Otsu: 40 seconds

Method 3 / Sobel: 7 minutes & 37 seconds

What's next?

Further analysis is possible by color coding the porosity by volume, diameter, sphericity or more, and then exporting this data as needed (e.g. largest pore size, porosity volume fraction, etc.). An example is shown below.



Porosity analysis: color coding of pores by volume and 3D visualization of each example used in this application note

Summary

This application note demonstrates fast simplified casting analysis – specifically using automated thresholding methods that are directly compared using macro's and recorded run time for different typical casting samples. In summary, three basic methods are shown that can be used in Dragonfly and all can be automated if needed:

- Basic Otsu thresholding: fastest method, captures largest pores in reliable way but does not work well when very small or no porosity is present
- Modified Otsu method: very fast, reliable in case of no pores, captures smaller pores than basic Otsu method
- Sobel method: slower method, capturing the smallest pores.

It is recommended to use the method that works best for the sample type and scan quality involved. Dragonfly 3D World provides the freedom to choose the best solution without any "black box" hidden algorithms.

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