

# MAVIparticle – Modular Algorithms for 3D Particle Characterization

version 1.0

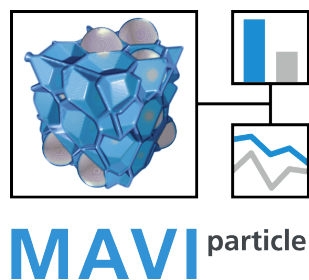


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## 1 Introduction

MAVIparticle is a software tool for characterizing particles based on 3D images. It allows the complete analysis of large 3D gray scale data, from segmentation via particle features up to automatic visualization. From the wealth of MAVI's 3D image processing and analysis methods, it uses those particularly suited for quantitative analysis of particle sizes and shapes. Namely, MAVIparticle offers size and shape descriptors generalizing concepts from 2D particle analysis unambiguously to the spatial setting. Moreover, MAVIparticle adapts to the user's requirements interactively using dialogue windows and is easy to use thanks to its "button structure".

MAVIparticle is particularly suited for investigating residual dirt particles in technical cleanliness applications. In machinery and automotive industries, a certain level of cleanliness has to be ensured in order to guarantee the expected durability and performance of the assembled products. Dangerous dirt particles can be detected reliably and with high throughput based on 3D images obtained by micro computed tomography. MAVIparticle extracts the particles and subsequently computes features yielding information on the types of contaminants and their potential to cause damage.

Here, we propose a users' guide to MAVIparticle with an outline of the main features. We refer the interested reader to [2] for more details on the particle characterization, on the algorithms implementation and on the possible usage of the features proposed, including a classification of the particles in three classes depending on their shapes.

## 2 The program

The functionalities offered by the program are available as buttons. The button bar can be positioned on the right hand side or on the top. Buttons are clickable only when it makes sense to apply the function to the current data.

## 2.1 Framework

This section will be available soon, for now refer to MAVI [1].

## 2.2 Settings

By selecting **Settings**, see Figure 1 one can set some global options, namely:

- the volume thresholds for classification depending on the particle volume, cf. Particle types in Section 2.5 for details;
- for how many particles the volume data and 2D visualizations should be saved by exporting (see Section 2.6), either for all particles, the largest 10, the largest 20 or all the large particles.
- the color for the 2d particle visualizations generated by exporting.

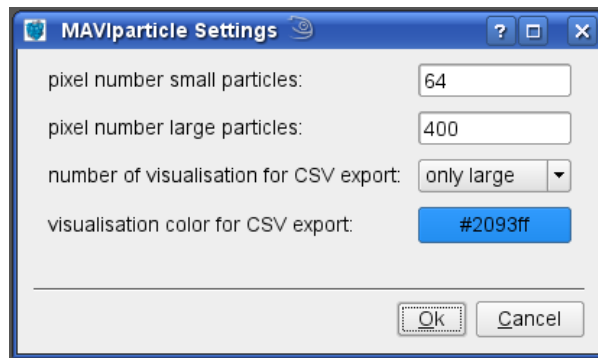


Figure 1 Settings dialog window.

## 2.3 Loading files

### Load SkyScan Image Stack

Load a LOG file generated by a SkyScan imaging device. The corresponding image stack is loaded and the pixel size is automatically set.

### Load Image Stack

Open stacks of two-dimensional images in JPG, BMP, TIFF and other formats. The pixel size is not set automatically, but can be given by clicking on **Meta Data**, see below.

### Load Image

Open volume images, in IASS or IASS.GZ format. Namely, both gray scale or binary images can be opened, including the volume data generated by the export

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function. The pixel size is not set automatically, but can be given by clicking on **Meta Data**.

#### Meta Data

Use this button to set spacing information and provide a data description. Note that the particle features support only isometric spacing, i. e. equal in each direction. 'Creator', 'Description' and 'History' information will be included in the CSV file of the exported features.

It is possible to have 3D visualizations of the data via **Volume Rendering**. For details on the available features for the slice and the volume rendering views, refer to the MAVI handbook, Chapter 8 [1]. Moreover, the reconstructed image can be saved as a volume data via **Save IASS**.

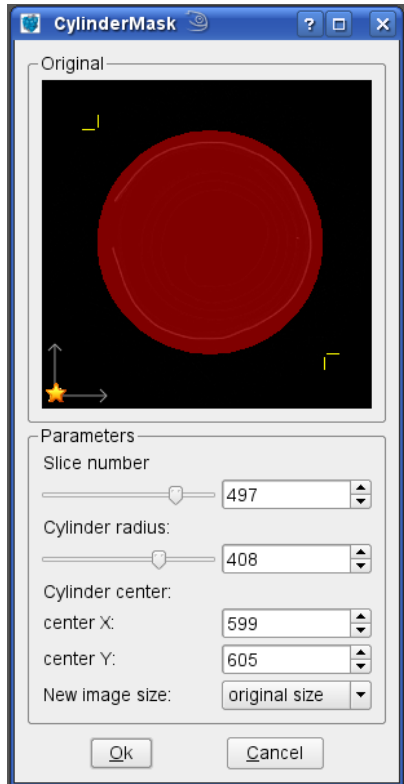


Figure 2

Cylinder mask dialog window. The region of interest is highlighted in red, overlapped to the gray value image.

The function `Cylinder Mask` gives the possibility of selecting a cylindrical region of interest. The pixel outside this region are set to zero. An interactive dialog window pops up, Figure 2. Previews on the 2D slices of the selected region allow the user to set the most suitable radius. Set the axis of the cylinder by selecting the according slice in the sliceview, by clicking on it before calling `Cylinder Mask`. The coordinates of the center can be chosen to better fit to the data. The

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new image can have the size of the original or the minimum size to contain the cylinder (select 'bounding box' in the dialog).

## 2.4 Segmentation

Given a gray values image, it can be segmented via Particle Segmentation. Via this function, the image is first binarized and then automatically labeled.

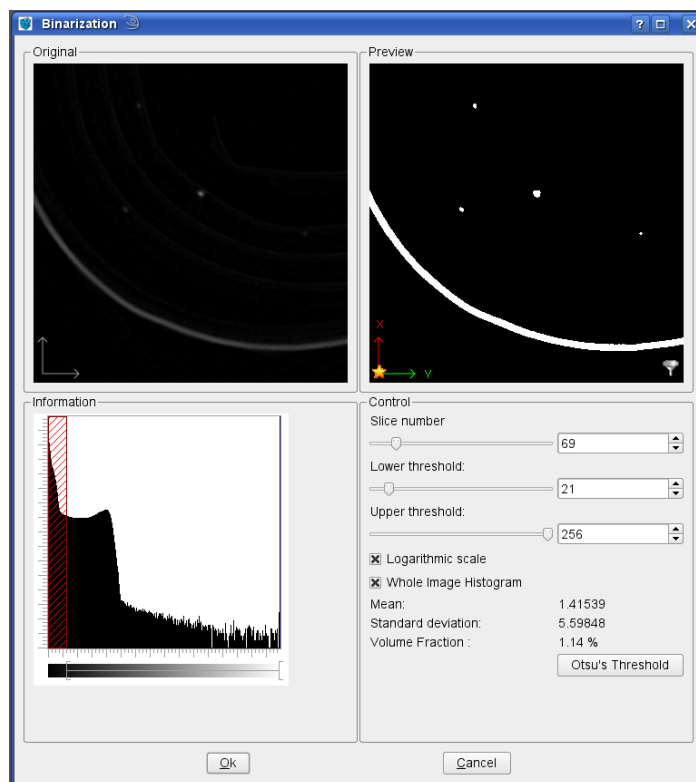


Figure 3 Binarization dialog window.

First, the binarization transforms a gray scale image into a MONO image by checking for each pixel whether its value is within a user-defined range. The new value of the current pixel is one or zero, depending on whether the pixel's value lies inside or outside the given range. This process is also referred to as global thresholding, and the user defined parameters are the threshold values. MAVIparticle guides you through the binarization process with a dialog box showing a preview, see Figure 3. This dialog allows you to set a threshold parameter and interactively shows a preview of the binarization result. By clicking on the Otsu's threshold button, you can obtain a suggestion for a suitable lower threshold. This button is activated whenever the Whole Image Histogram box

is checked. Otsu's method computes a global threshold for which the variance of gray values between the classes thus created is as large as possible while the variance within the classes is held as small as possible. Secondly, the labeling is performed: that is each connected component w. r. t. 26/8 neighborhood is given a different integer value. The final image is a gray value image and in the sections, the labels can be seen as different colors.

## 2.5 Particles features

Once the image is segmented and labeled, by `Particle Analysis`, the features are computed for each object. A dialog box pops up (Figure 4):

- select from which gray value image the current one has been segmented to calculate the **Mean Grey Value**, see below;
- check "biggest particle is reference" if a reference particle, e. g. a steel cylinder, occurs in the image. The corresponding object is labeled 'reference', see below.

An object-wise tree view of the features is displayed.

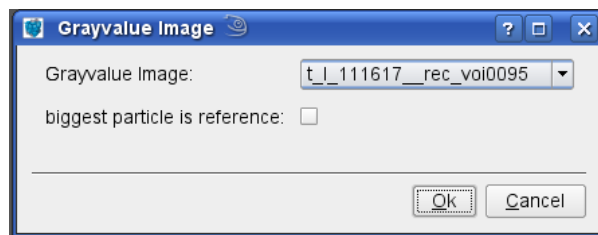


Figure 4

Particle analysis dialog window.

### Particle types

The particle type depends on the volume of the particle. The threshold values can be set in `Settings`. The default values are the following:

**small:** particles constituted of 64 pixels or less,

**medium:** particles constituted of more than 64 pixels but less than 400 pixels,

**large:** particles constituted of more than 400 pixels.

**reference:** if present, it is the biggest particle. Only volume and gray value are computed for this object.

It is not meaningful to calculate some of the features for small particles, thus only the volume is computed from the object. The other features are calculated from the volume assuming the particle to be spherical. For what concerns 'medium' and 'large', it will be specified in the following, whether the features are computed for both types or not.

### Mean Gray Value

Calculated from the original gray value image for each particle, it is the average

of the gray values of the pixels of which the object consists.

### **Volume**

Number of pixel of which the particle is formed (volume [px]) and volume in micrometers (volume [ $\mu\text{m}^3$ ]). Calculated from MAVI's Field Features, see [1].

### **Surface Area**

It is an estimate of the area of the surface of the object, calculated in [ $\mu\text{m}^2$ ]. Calculated from MAVI's Field Features, see [1]. For 'small' particles, calculated from the volume.

### **Euler Number**

The Euler number is a topological characteristic. The following examples illustrate its meaning: The Euler number of an object having no holes ('caves') nor 'tunnels' is 1, if the object has a hole then its Euler number is 2, if the object is topologically equivalent to the torus, we get 0, if the object has two 'caves', we get Euler number 2, and if it has two 'tunnels' one obtains -1. Calculated from MAVI's Field Features, see [1]. For 'small' particles, set to 1.

### **Shape Factors**

Calculated for 'medium' and 'large' particles from MAVI's Field Features, see [1]. They are set to 1 for 'small' particles. In 3D there are three shape factors which can be computed from the volume  $V$ , the surface area  $S$ , and the integral of mean curvature  $M$ :

$$f_1 = 6\sqrt{\pi} \frac{V}{\sqrt{S^3}}, \quad f_2 = 48\pi^2 \frac{V}{M^3}, \quad f_3 = 4\pi \frac{S}{M^2}.$$

Shape factor  $f_1$ , also known as sphericity, takes values between 0 and 1, shape factors  $f_2$  and  $f_3$  take values between 0 and 1 only for convex bodies; for poly-convex objects they may be greater than 1. All shape factors take value 1 for balls. These shape factors are also called the three isoperimetric shape factors of a 3D object. Values for some reference particles can be seen in Table 1. In [2], it is suggested how to use them to induce a classification of the particles depending on their shapes.

### **Axes aligned bounding box**

Computed for all particle types. It is defined by the minimum and maximum coordinates of the particle. Values for 'start' and 'end' respectively represent the two diagonally opposite vertices of a box bounding the particle with edges parallel to the coordinate axes. It also gives information about the position of the particle in the image.

### **Minimal bounding box**

Calculated for 'medium' and 'large' particles. It is the box of minimum volume bounding the particle and with axes arbitrarily oriented. The measures of the edges, sorted in decreasing order, are called 'length', 'width' and 'thickness'.



They are returned in pixel and in micrometers. The directions of the edges are also given, specifying to which edge they refer. This is a measure of the size of the particle and can be used to classify the particles by comparing the ratios of the edges lengths, for details see [2].

### **Maximal Feret diameter**

Calculated for 'medium' and 'large' particles. It is the largest (Euclidean) distance between two points in the particle. It is returned in pixel and micrometers. It is larger or equal to the length above defined, being equal in the case of a sphere for example, but larger for a cube or a parallelepiped, where it corresponds to the diagonal.

### **Elongation**

Calculated only for 'large' particles. It is the geodesic length of the particle, that is the maximal geodesic path connecting two points within the particle. It is an estimate of the length of the medial axis. For fibrous particles, it can be interpreted as the real length of the fiber. The **elongation index** can be used to compare particles:

$$IG_g = \frac{\pi L_g^3}{6V}.$$

It is equal to 1 for spheres and gets larger, the more elongated a particle is. Values for some sample particles can be found in Table 1.

### **Maximal local thickness**

Also known as inner diameter, it is calculated only for 'large' particles. It is the diameter of the largest ball completely contained in the particle, it yields the maximal local structure thickness. This measure is an estimation of the real thickness of a fiber or a chip. Moreover, for particles with no holes, it gives a measure of the largest core of a particle.

## **2.6 Export**

The function `Export Particle Analysis (CSV)` creates a CSV text file compatible with Microsoft Excel and Open Office containing the particle features, spacing, history and parameters, e. g. particle types thresholds.

For large particles, an automatic 2D visualization in PNG format and a 3D volume image in IASS format are saved, too. The color of the particles in the screenshot can be set in `Settings`. The volume data can be opened via `Load Image` and visualized via `Volume Rendering`, by which the particle can be rotated and visualized in its spatial complexity.

It is possible to save the current image, for example the segmented data, as a volume data in IASS format by selecting `Save Image`.

## References







|                              |  |  |  |  |  |  |
|------------------------------|---|---|--|---|---|---|
| volume [px]                  | 179 579   | 91 125  | 49 977   | 24 941  | 22 773  | 216 862   |
| Euler number                 | 1   | 1   | 1  | 1   | 1   | 1   |
| length [px]                  | 70.00   | 45.00   | 79.60  | 120.00  | 60.92   | 116.78  |
| width [px]                   | 70.00   | 45.00   | 59.70  | 19.40   | 53.25   | 116.78  |
| thickness [px]               | 70.00   | 45.00   | 20.00  | 19.40   | 14.61   | 96.23   |
| maximal Feret diameter [px]  | 70.00   | 76.21   | 80.00  | 120.00  | 61.38   | 150.24  |
| shape factor $f_1$           | 0.992   | 0.827   | 0.651  | 0.583   | 0.529   | 0.236   |
| shape factor $f_2$           | 0.989   | 0.733   | 0.511  | 0.188   | 0.148   | 0.007   |
| shape factor $f_3$           | 1.000   | 0.923   | 0.851  | 0.471   | 0.428   | 0.094   |
| elongation [px]              | 72.07   | 78.41   | 79.38  | 120.00  | 98.59   | 639.12  |
| elongation index             | 1.09  | 2.77  | 5.24   | 36.28   | 21.99   | 630.29  |
| maximal local thickness [px] | 70.03   | 45.00   | 20.10  | 20.10   | 15.48   | 20.00   |
| convexity factor             | 1.00  | 1.00  | 1.00   | 1.00  | 0.62  | 0.27  |

Table 1

Particle features for some reference shapes.

## References

- [1] Fraunhofer ITWM, Department of Image Processing, *MAVI – Modular Algorithms for Volume Images*, 2011, <http://www.mavi-3d.de>.
- [2] Irene Vecchio, Katja Schladitz, Michael Godehardt, Markus J. Heneka, *Geometric characterization of particles in 3d with an application to technical cleanliness*, Bericht des Fraunhofer ITWM, Nr. 207, 2011, <http://www.itwm.fraunhofer.de/presse-und-publikationen/berichte-des-itwm.html>.