# High-Speed Image Analysis and Dispersion for Size and Shape Characterisation of Fibres

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## ABSTRACT

*Image analysis is widely in use for the characterisation of shape and size of particles. A highly diluted particle flow is required for reliable particle size analysis, because overlapping particle images must be avoided. Separation of particles is often replaced by sophisticated image processing algorithms. Proper dry dispersion techniques, which usually accelerate the particles to high speeds (up to 100 m/s), are not applicable to standard imaging methods due to the motion blur of the particles. The limited amount of images leads to low particle counts and large statistical errors.*
*An innovative imaging sensor has been developed, which even allows for the direct use of well established dry and wet dispersers. It combines a new light source which provides an exposure time of less than 1 ns and an adaptable optical system for perfect illumination and imaging of the fast particles on a high speed camera, an integrated image pre-processor and a Gigabit digital transmission line to the computer. A first device has been exhibited on the ACHEMA 2003 and was presented on the Innovators forum on the PSA 2003, showing that particles can be clearly imaged and analysed at the output of a well established and proven dry dispersing injection system.*
*Meanwhile the device has proven its prospected performance in a plurality of applications. Up to 450 images with 1024 x 1024 square pixels of 10x10 µm² can be acquired, processed, compressed, transferred and stored in a powerful database per second. Different measuring ranges can be selected by software: 1 to 340 µm, 3.3 to 1,140 µm, 10 to 3,410 µm and 20 to 6,830 µm (according to ISO 13322-2) are currently implemented. Different dispersion units can be applied to an open measuring zone, e.g. a dry disperser with injection system for fine particles or a gravity disperser for coarser particles. A powerful selection and display facility of particles has been implemented in the software, which is fully compliant with CFR 21 Rule 11 and concurrently supports other particle sizing instruments using laser diffraction, ultrasonic extinction or photoncross-correlation.*
*The combination of powerful dispersion and high frame rate allows for the acquisition and analysis of extreme numbers of even > 107 randomly oriented particles in short times. This results in statistical errors far below 1%, showing that image analysis now even reaches the reproducibility of renowned laser diffraction with traceability to the individual particles and shape information in addition.*
*Now the field of applications has been extended to the analysis of fibres. The particular possibilities of dry and wet dispersers for the dispersion of fibres are displayed. Different algorithms for the evaluation of the fibre length, their width and the curl index have been investigated on complex fibre structures. Examples are given, that today's algorithms are capable for precisely evaluation of fibres, even if they look like Chinese characters.*

**Keywords:** High Speed Image Analysis, Fibres, Particles Size, Particle Shape

## 1 INTRODUCTION

Image analysis (IA) is widely in use for the characterisation of shape and size of particles. There are different shape characteristics of a particle and one of the most challenging attribute is the length and the diameter of a fibrous particle. In contrast to a needle, which can easily be described by the maximum and minimum Feret diameter, a fibre is curved. This creates the first challenge for the evaluation.

In addition to this, a fibre can consist of branches, forming a more or less complex structure. To describe all possible variants of fibre structures, new definitions have to be found which are unambiguous but still comply with common sense.

## 1.1 Definitions

- The **Length of a Fibre** (LeFi) is defined as the length of the shortest path between the two most distant end points of the fibre. This definition holds for both, simple fibres with only two ends and complex structures.

- The **Diameter of a Fibre** (DiFi) is defined as the projection area of the fibre divided by the length of <u>all</u> fibre sections (not only those sections contributing to the value of LeFi).

- The **Curl Index** describes the curviness of a fibre and is defined as the length of the fibre divided by the maximum Feret diameter minus one.

## 1.2 Approach to find the thin line in the middle of the fibre

In a first step the isolated fibre particle is cleaned up by some standard morphological operations in order to advance the following length calculating algorithms.

To find the centreline of a fibre, an algorithm is needed, which fits to particles with an arbitrary shape. This is a common task in image analysis and is called skeletonization. Numerous skeletonization algorithms have been published [3][4][5][6][7][8], but most of them have some disadvantages when applied to a great number of arbitrarily shaped particles. Some are too slow, some are not exact enough and some have too many parameters which can not be determined fast enough for sometimes millions of particles.

Figures 1.a and b show two examples of unsuccessful skeletonization algorithms. In Figure 1.a the tested algorithm fails on diagonal lines. This problem is common to many morphological skleletonization algorithms. Figure 1.b shows an algorithm that generated an unconnected skeleton. This skeleton can not be further processed.

**(a)** **(b)**

**Figure 1 (a)-(b): Examples of unsuccessful skeletonization algorithms**

So the task is to find and implement an accurate, fast and robust skeletonization algorithm for fibres. Figure 2.a shows a fibrous particle and the applied algorithm (2.b). The algorithm deletes border pixels in an iterative manner until a centreline of one pixel is reached. The implementation derived from [7] is highly optimized for 8-bit black and white bitmaps and is considerably faster than the (unpublished) reference implementation. The implemented algorithm can be applied to arbitrarily shaped particles and it always yields a reliable skeleton.

## 1.3 Calculating the skeleton graph

The particle skeleton can be transformed into a graph representation $G = (V, E)$ (Figure 2.c) with $E$ as the set of undirected rated edges, and $V = V_c \cup V_e$ as the set of all vertices, with $V_e$ as the set of all end vertices and $V_c$ as the set of all cross vertices. To find the vertices, the pixel structure of a bitmap is used, whereby the neighbourhood of the single pixels is considered. Existing algorithms such as the inversion of the Bresenham algorithm can be applied to calculate the lengths of single edges.

With the graph $G$ a distance graph $G_d = (V_e, E_d)$ can be calculated using the Dijkstra algorithm, where $E_d$ is the set of undirected rated edges connecting all end vertices $v \in V_e$. The length of the fibre is then the highest rated edge $e_i \in E_d$ with $e_i > e_j, e_j \in E_d, i \neq j$ of graph $G_d$.

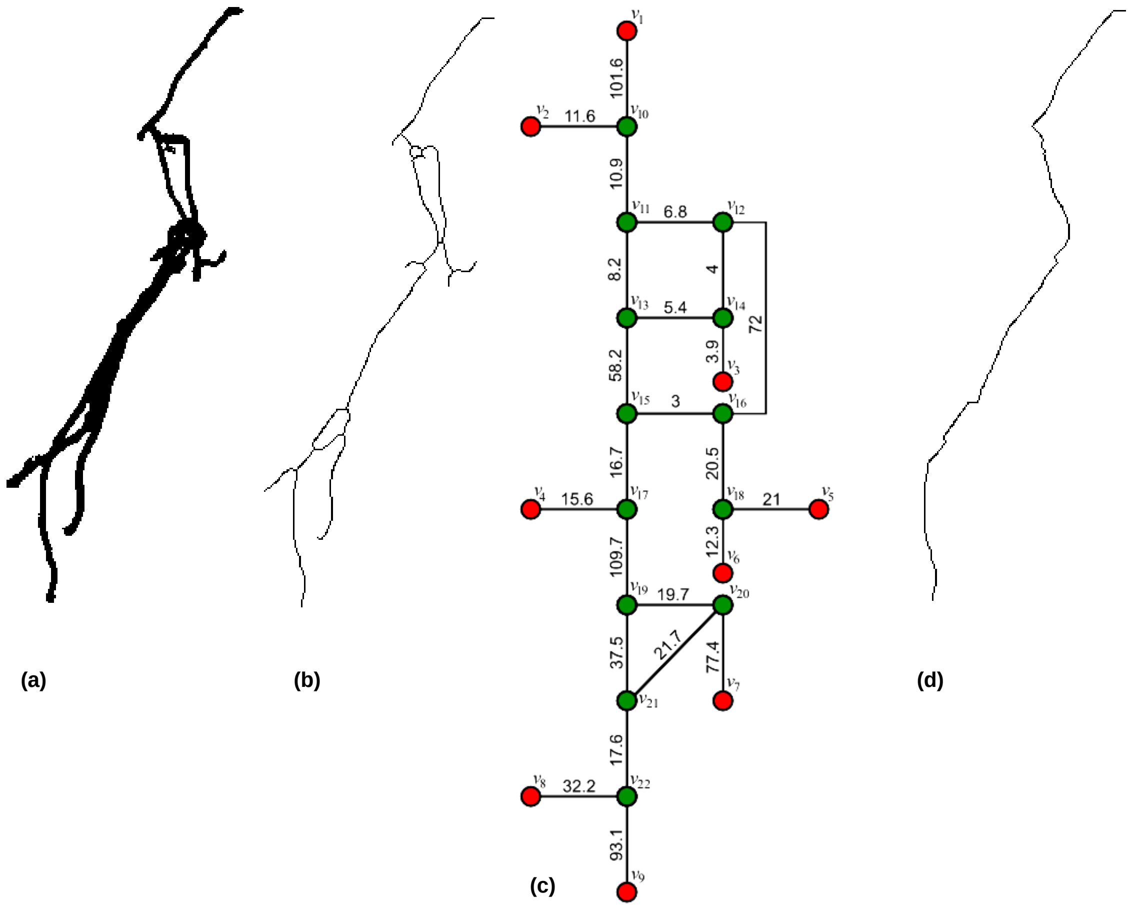



**Figure 2 (a)-(d): Skeletonization and graph transformation of a fibre particle**

Figure 2.d shows the resulting path on the particle. The length of this path describes the length of the complex fibre. The diameter of the fibre is calculated as the particle area divided by the cumulative length of all particle sections.

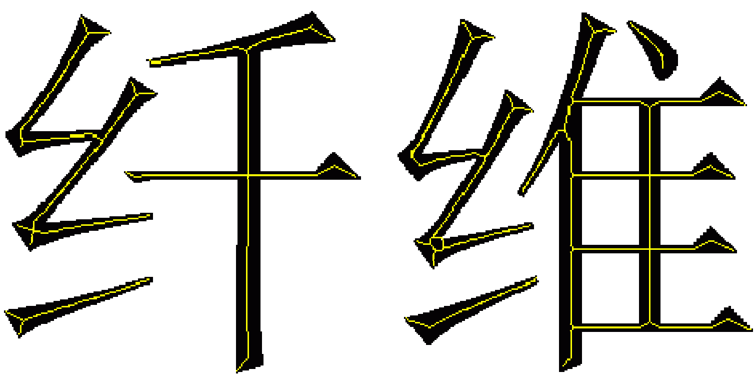
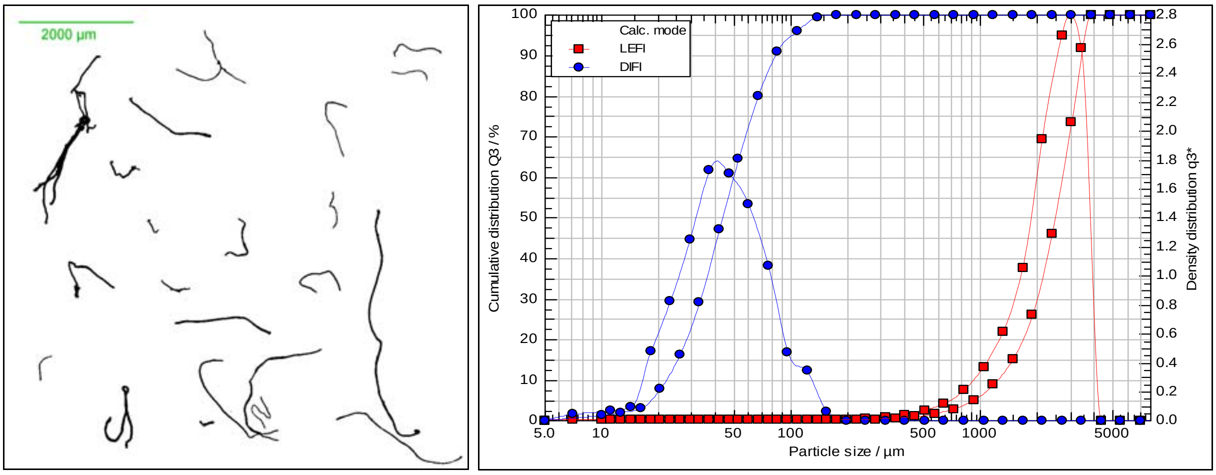



**Figure 3: Skeletonized Chinese characters**

Figure 3 shows the skeletonized Chinese characters for “fibre”. Chinese characters have different stroke sizes and many nodes and sections so this is a good test for the selected skeletonization algorithm.

## 2 RESULTS

The discussed skeletonization algorithm and the shortest path calculation of complex fibres have been programmed into the software WINDOX of our high speed image analysis system, QICPIC [9]. The new fibre dimensions LeFi and DiFi as well as the shape parameter “Curl Index” can be selected in the software as a diagram output. Figure 4 shows a LeFi/Difi-distribution of recycling fibres. The distance in x direction between the fibre length and the fibre diameter curves is a simple indication of the fibrous character of the measured product.




a) b)

**Figure 4: The distributions of length and diameter and a sample image of recycling fibres, measured by QICPIC, with the measuring range R7 (10 µm to 3410 µm) and the dry disperser RODOS/L with injector diameter 4mm.**

Recycling fibres have been dispersed with the dry disperser RODOS/L and imaged by QICPIC. An example of an image at high fibre concentration is given in Figure 4a. The measurement was performed at low concentration with about one fibre per image. The resulting LeFi and DiFi distributions are shown in Figure 4b for 31279 fibres each.

## 3 SUMMARY

The presented method shows its capability to measure the length and the diameter of fibrous particles. Even complex particles can be analysed using sophisticated algorithms. It has been shown that the choice of a reliable skeletonization algorithm is essential for the subsequent length calculations.

The proposed solution is already implemented in the standard software of a commercial image analysis system and is successfully applied by various users. Along with a high speed image acquisition, it is a reliable and statistically relevant source of fibre characteristics.

## 4 OUTLOOK

An idea for future software releases is to present two more characteristics of fibres:

1. The **total length** of a fibre, which will include the length of all sections of a fibre.
2. A **complexity index** based on the number of nodes of a fibre.

Contributions to a meaningful definition of these parameters are welcome.

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