SCIENTIFIC REPORT

Multipurpose hemp for industrial bioproducts and biomass

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6.4 Report on the development of an innovative length measurement concept

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Jörg Müssig

Shaoliang Wang

Birgit Uhrlaub

Background

Diverse measurements and inverstigations will be carried out on a great amount of hemp materials (stems, fibres and end uses), with two main topics: one is the quality integration along the production chains, and the other one is the quality evaluation of the raw material and as well as the end products. As an part of these analyses, testing of natural fibres is generally very time consuming because of the work to prepare the fibre samples and their scattering values. Based on this knowledge, it is necessay to develop, verify and implement a new (semi-)automated methodology and equipment for the sample preparation and the fibre characterization regarding the length and fineness of the hemp fibres/fibre bundles to evaluate the quality of the different genotypes (Figure 1).

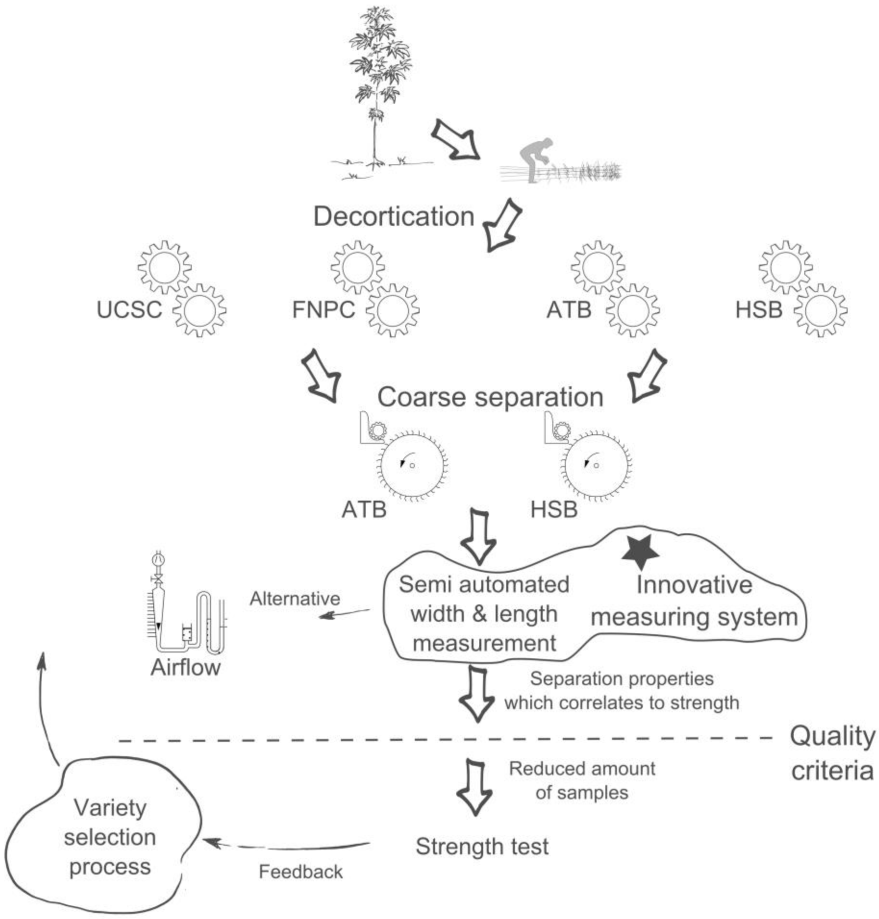


Figure 1: Integrated quality assessment concept from hemp stems through lab-scaled decortication/separation and fibre quality testing with a semi-automated width and length measurement.

Part 1: Length measurement – FibreScanner / Alternative

1) Introduction

As an important aspect of the fibre characterization, within the WP6 the fibre length distribution will be analyzed after the coarse separation process. Because the devices which were usually used to measure the length of the long fibres, such as Almeter, are no more manufactured, and normally not available now, alternative methods are requested. Nowadays, image analyzing methods are widely applied for such purposes, for they offer the opportunity for fast and nondestructive measurements. In order to analyze the great amount of fibres from the WP2 and WP3 on schedule, within WP6 an image analyzing software FibreScanner with less developing time firstly has been written with Matlab at HSB, based on Dr. Seeger's work (Seeger, 2006 [2]). With this method the fibre length will be carried out as followed (see Figure 2): The fibre bundles will be firstly straightened and parallelized machine-made or manually ([1], see Report 6.3), and then the prepared fibre sample is scanned into one or more image file(s) under the optimized resolution and settings. After loading the image(s) of the fibre sample, the FibreScanner takes several steps to analyze the image(s) to get the binary images (see Figure 3). Based on the shading area of the fibres on the image, the fibre length distribution and as well as other characteristic values can be calculated. The new image analysis concept is a part of the quality management system at HSB & ATB.

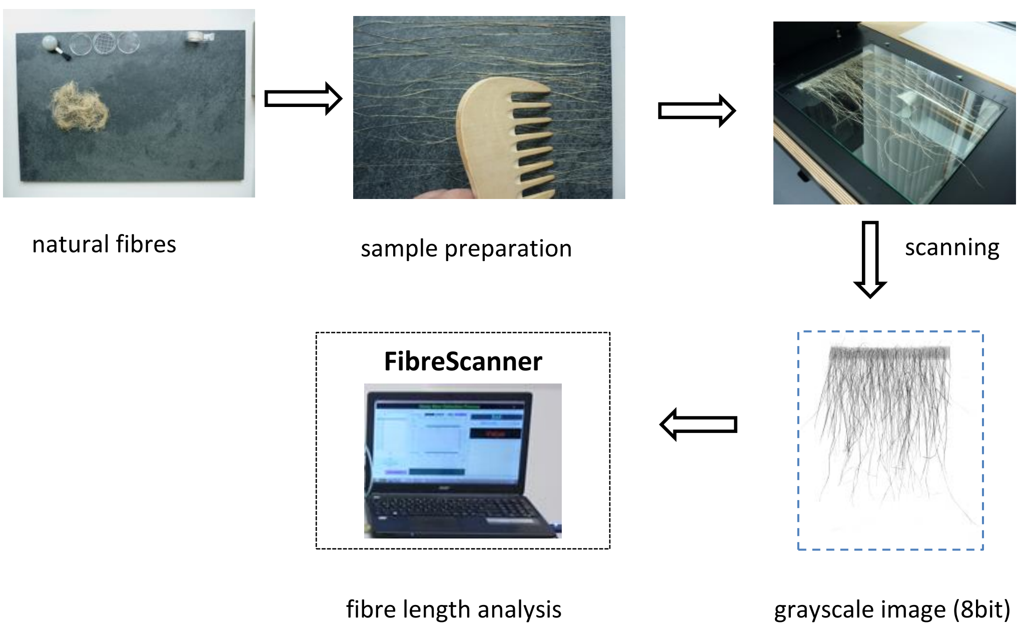


Figure 2: Procedure before the image analysis with the FibreScanner

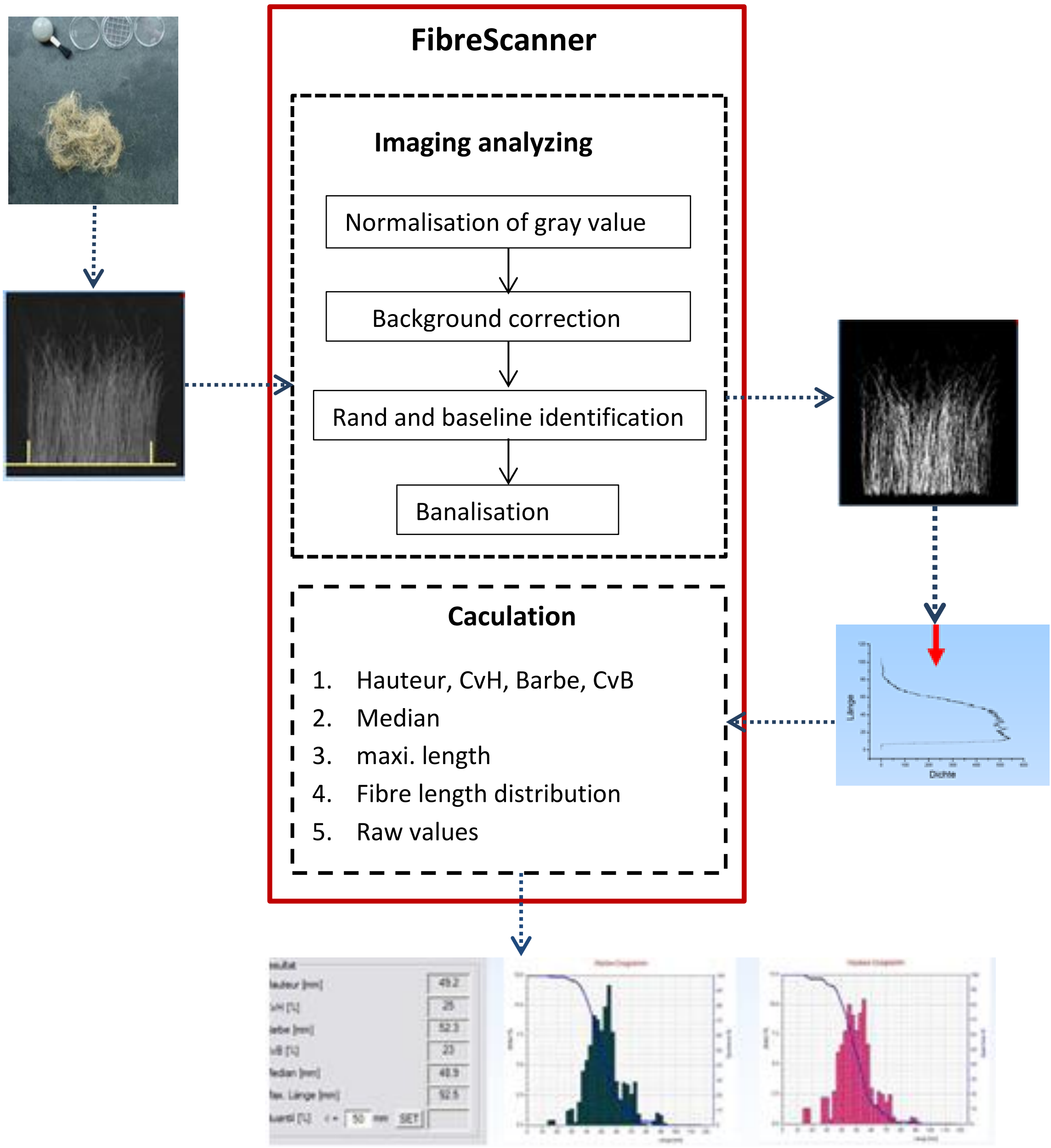


Figure 3: Function blocks of the FibreScanner for the fibre length analyzing

2) Concept and Algorithms

Calculation of the fibre portion (shade area)

The sample of the fibre bundles is firstly scanned as a grayscale image, which is a data matrix whose values represent intensities within some range, for example the range [0, 255], where 0 is black and 255 white, each element of the matrix corresponds to one image pixel. Ideally, the pixels under the shade of the fibres would have the value of 255, while the background area is with the value 0, if the image has the black background. Unfortunately, the values of the pixels are widely distributed along the whole range (see Figure 4), and one sharp dividing value will normally not be given, thus the dividing value (threshold value) should be investigated and determined firstly, in order to extract the shade area – the fibre portion. Instead of 0, the background of the following image take values in the range [80, 100], and the most are by 90.

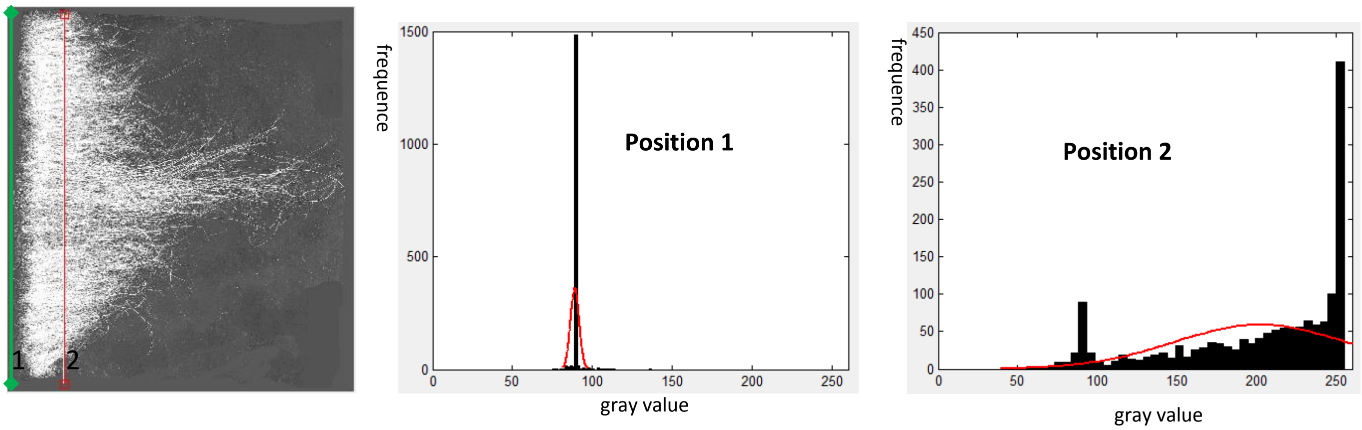
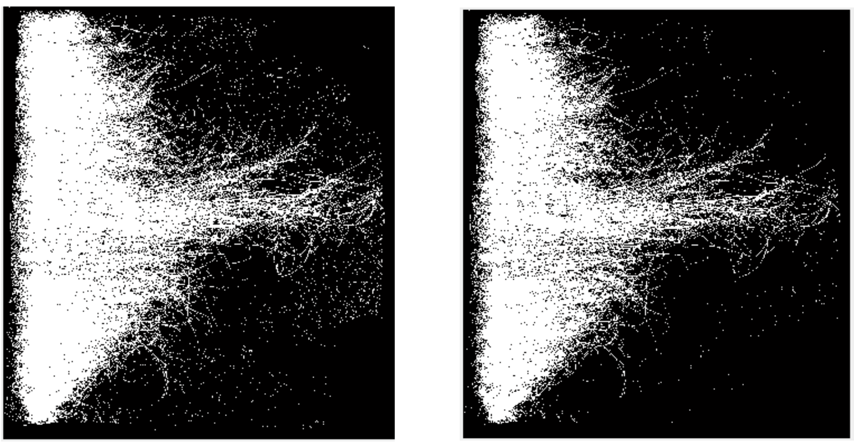


Figure 4: Distribution of grey values at two positons

Figure 5 shows the influence of the choice of the threshold value on the binary image, acquired from the grayscale image in figure 4 (background is black). Hence, because the scanners and the settings are different, close investigations will be carried out on the images from different sources, in order to give the optimal threshold value.

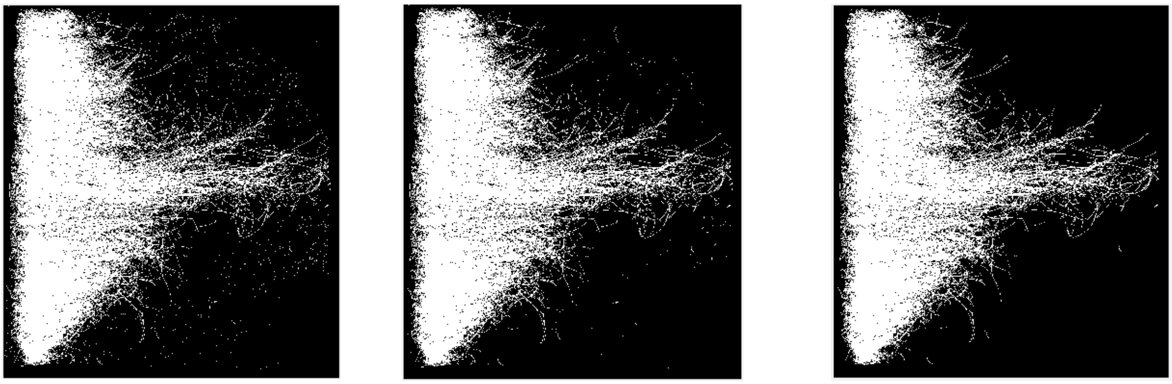


a. Threshold value = 101 b. Threshold value = 124

Figure 5: Influence of the threshold grey value on the converted binary image

After we get the binary images, there are still some separate not fibre like picture/pixel fragments on it, which do not represent the fibres, but rather are resulted from the unclear background of the scanners. Thus, these separate components that have fewer than *P* pixels should be removed, before the binary image is going to be analyzed. The parameter *P* (connectivity) can be adjusted step and step in the programme to achieve a 'clean' binary image. Because the different scanners or configurations influence the quality of the images, close investigations (new adjustment) should be carried out, if the source of the images has changed.

Figure 6 shows the influence of the parameter *P* (connectivity) on the removal of the separat pixels from the binary image. The three images in figure 6 are products of this treatment with different connectivities on the same image in figure 5.



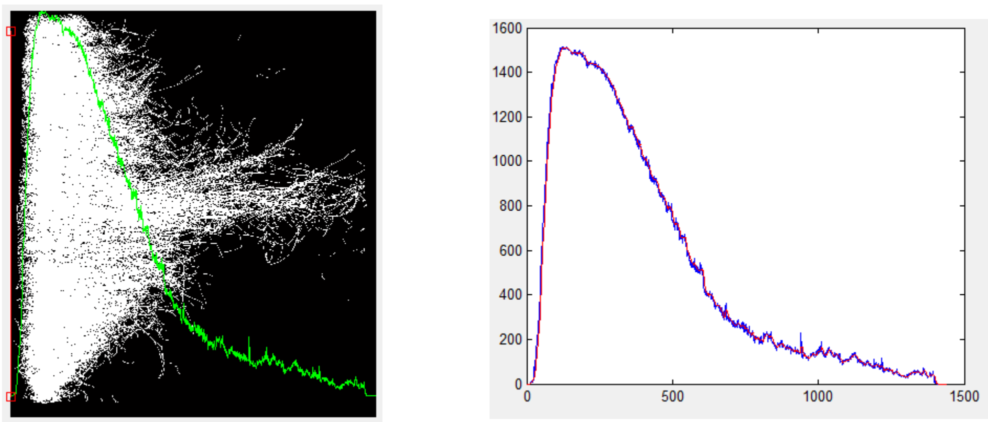
a. P = 0

b. P = 8

c. P = 50

Figure 6: Removal of the separate components from the binary image (Threshold value = 107)

Based on the acquied binary image (2D-Matrix), where the value 1 represents the fibres, the distribution of the optical densities - also the fibre portion- along the fibre length direction can be calculated (see Figure 7).



b. Binay image

a. Optical density distribution

Figure 7: Distribution of the optical densities along the fibre length direction

Calculation of the fibre length distribution

There are several terms to describe the fibre length characteristics in the textile industry, according to the fibre sorts and measuring methods different terms are used [3]. Within this work the hemp fibres will be measured in terms of Hauteur and Barbe. The Hauteur distribution is the fibre length distribution weighted with the cross-section of the fibre bundles, while the Barbe distribution is that one weighted with the fibre weight. With the FibreScanner the calculated optical density distribution is the shade of the fibres, which is also the projection of the fibres. If the fibre bundles in the fibre sample have consistent diameters, the optical density distribution calculated with the FibreScanner method also expresses the Hauteur fibre length cumulative distribution. From the calculated Heuteur distribution the Barbe distribution is easy to calculate, unter the assumption that the fibre bundles have the same density and thickness.

For the two expression terms - Hauteur and Barbe - the mean fibre length of the fibre sampels can be calculated as followed:

$$\mathrm{L} = \frac{\sum(h_j \cdot l_j)}{\sum h_j}$$

where l_j is the average fibre length of the class j, and h_j the frequence.

The coefficient of variance is:

$$\gamma = \frac{\sigma}{L}, \quad \text{where } \sigma^{\mathbf{2}} = \sum(l_j{}^2 \cdot h_j) - L^2$$

3) Software Realisation

As a part of the management system (see Report 6.2) the FibreScanner measuring system is integrated in the total system . Firstly, the main GUI (Guide User Interface) of the management system (see Figure 8) has to run, and then the product data bank to be analyzed will be chosen. After clicking the item of *FibreScanner* on the main menu*,*the programme FibreScanner will be loaded automatically, and start to run (Figure 9). The selected product data bank (Figure 9 (a)) is also loaded at the same time, so that the fibre und the fibre samples can be chosen for analyzing directly.

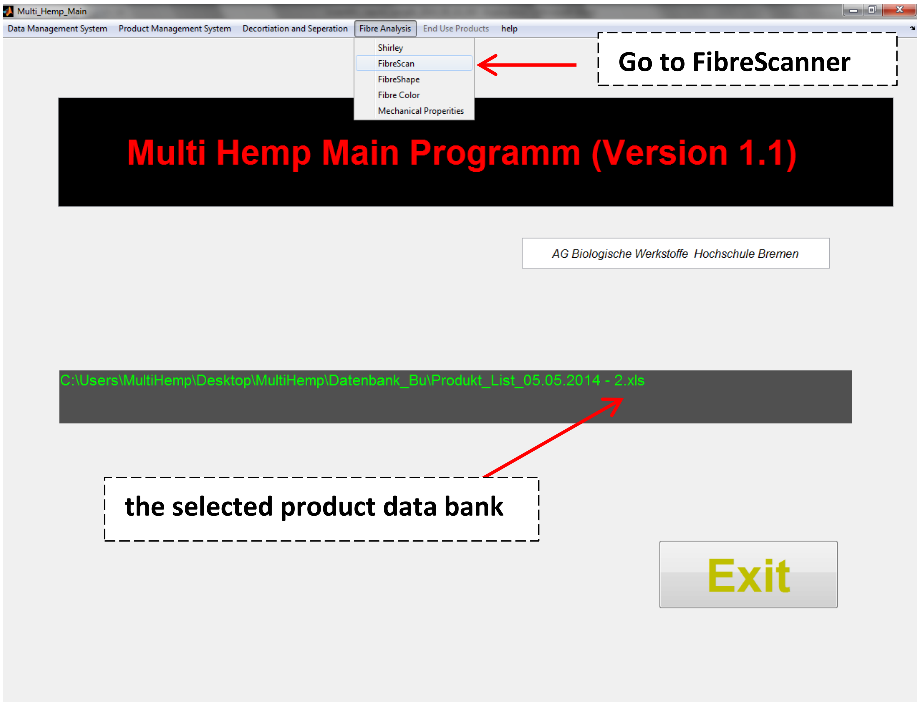


Figure 8: Entrance to FibreScanner from the main GUI of the management system

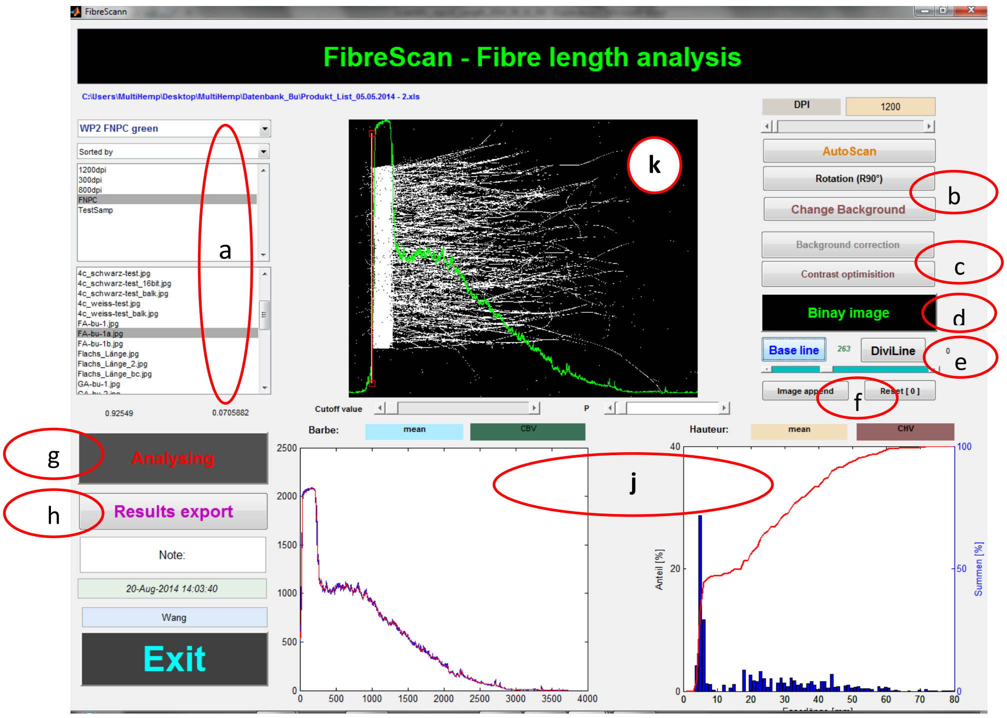


Figure 9: GUI of the FibreScanner with Matlab

Some functions of the FibreScanner are introduced as followed:

a. Area of the product management system

After the fibre provider and fibre name are chosen in this area, all of its avaiable images will be loaded and listed immediately. With one mouse-click man can easily chose the image file / fibre sample under the file list,und the selected fibre image is then loaded on the FibreScanner soon, and ready for analyzing .

b. Change background and Rotation

With these two functions the image orientation and its background color can be adjusted, FibreScanner needs the fibre images with a black background.

c. *Background correction* and *Contrast optimisition*

These two functions aim to improve the image quality, in order to abtain the optimal fibre data.

d. Binary image

With this button the grayscale image will be transformed into the binay formate.

e. *Base line* and *Dividing line*

With these two functions together with the slide control element under them the effective fibre area to be analysed will be determined. The base line is the beginning of the fibre sample, and where the fibre bundles are aligned. Together with the the slide control element the minimal fibre length that is still measurable can be defined. This function is very useful to define a 'blind zone', in case of analyzing fibre samples like that in Figure 10.

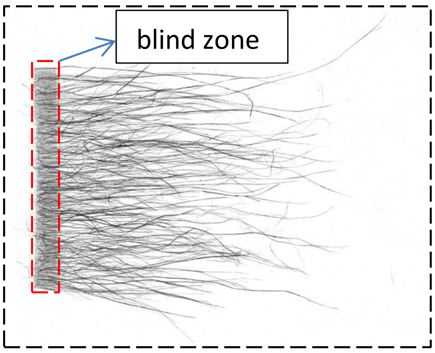


Figure 10: Fibre sample with the blind zone (prepared with the developed method at HSB)

By processing the hemp samples it has been noticed that the fibre bundles of some varieties are still very long after the separation process. These samples are beyond the scan area of the scanner used at HSB, so that we must scan them into two or more images. With the dividing line(s) the separat images can be put together later, manuelly or with programme. The function *Dividing line* enable to detect the dividing line on the image automatically, and it can be also abjusted with the slide control element afterward, if it is necessary.

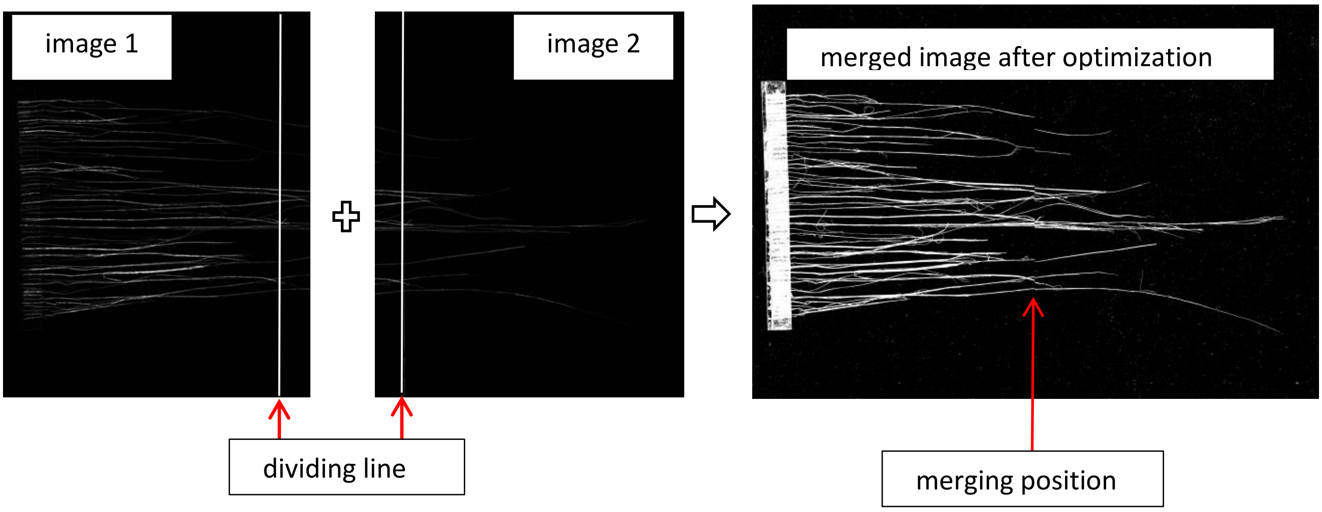


Figure 11: Merging the separat images in one with the *dividing line* function

f. Image append and Reset

In case of the long fibre samples with more than one image, the function 'Image append' enable us to append the currently selected image to the former. With 'Reset' the selected images will be cleared, the FibreScanner is now ready for the new fibre samples.

g. Analyzing

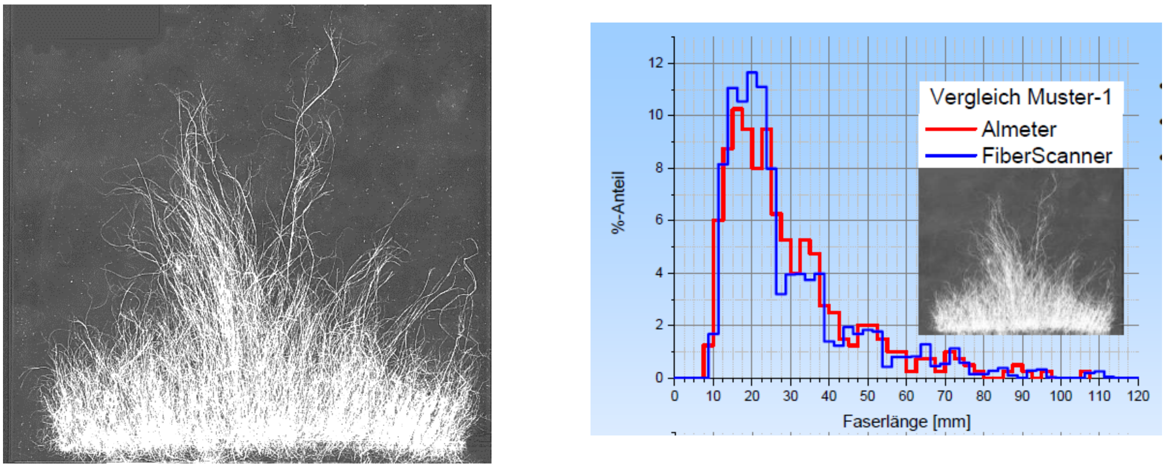
This executes the analysis on the sample image(s) to give the Hauteur and Barbe fibre length distrubition.

h. Results export

With the function the results (data and graphics) can be exported in the excel file.

4) Example

In order to verify the software which is developed at HSB, comparison test analyses have been carried out. Figure 13 shows the Hauteur and Barbe fibre length distributions which are calculated and reported by the FibreScanner of HSB, the measurement data is in the attachment. The test object is one fibre sample used by Dr. Seeger at his previous work, Figure 12 shows the fibre sample, as well as the results analyzed by Dr. Seeger's programme and the Almeter. By comparison (see table 1), three methods give a good conformity, more discussion is in the following chapter.



a) b)

Figure 12: Test fibre sample and its length distributions analysed by Dr.Seeger's programme and Almeter [2]

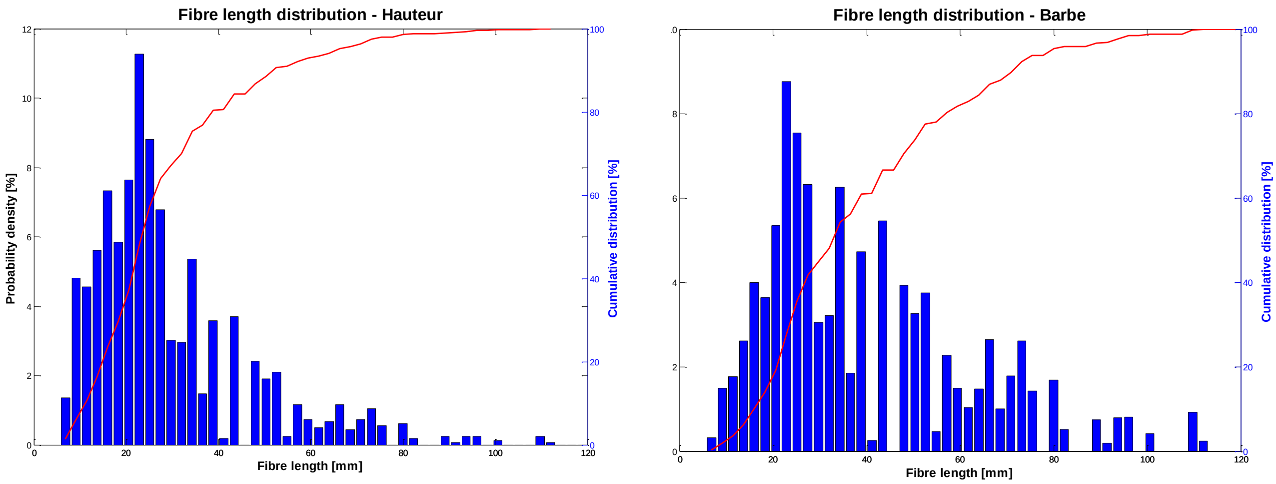


Figure 13: Hauteur and Barbe fibre length distributions analyzed by the FibreScanner of HSB

Table 1: Comparison of three different methods on the sample in figure 11

	FiberScanner (Dr. Seeger)	Almeter	FibreScanner (HSB)
Hauteur [mm]	28,8	28,9	29,4
CvH [%]	60	56,8	59,5
Barbe [mm]	39,3	38,2	39,83
CvB [%]	58	53,8	54,96

Discussion and Outlook

Influencing factors

In order to achieve optimal analyses with the FibreScanner method, some influencing factors basically from there catagories will be analyzed and optimized :

a. Quality of prepared fibre samples

On one hand, the fibre sample should have a great number of fibre bundles, in order to achieve a better statistical certainty of the analyses, due to the measuring concept of the FibreScanner the overlap of the fibre bundles should be avoided during their preparation on the other hand.

b. Image quality

The image quality plays an important role to carry out a successful anlaysis. Firstly, treasures and optimal configurations of the scan process should be taken to improve the image quality to give a clear threshold gray value which divides the fibre area and the background. On this view, a clean scan background is very necessary. Besides that, the position and orientation of the fibre sample should be arranged correctly by the scanning process. Figure 14 shows four images with different fibre orientations and base lines, but only image d is correct.

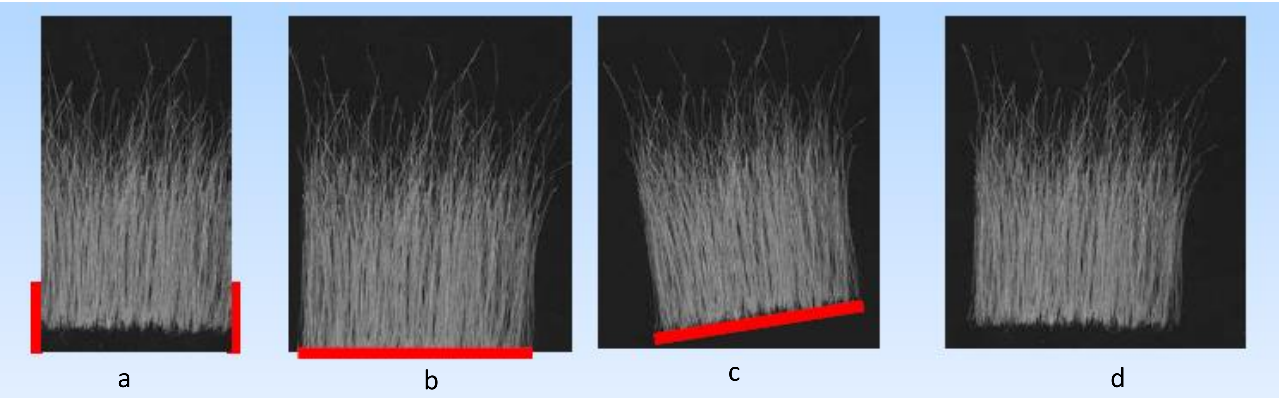


Figure 14: Orientation and base line of the fibre sample on the image [2]

c. Software and algorithms

The optimal determination of the programme parameters plays also an important role, for example, the determination of the threshold gray value to divide the fibre area and the background. For this purpose the image processing techniques could be used.

Comparation of results from different measuring methods

Different instruments und methods measure and express the length of fibre samples in different way. Depending on the method of sample preparation (and how much manuall intervention is applied to the fibres during preparation and measurement), they may rise to different results. For example, FibreScanner gives fibre length distributions, which calculation is based on the fibre projection area. If the fibre bundles within the sample have the same fineness (width), the distribution offered by the FibreScanner could be in good proximation with the fibre length distribution counted by the fibre bundle number. Unfortunately, this condition is normally not be given by our multi hemp fibres (see Figure 15).

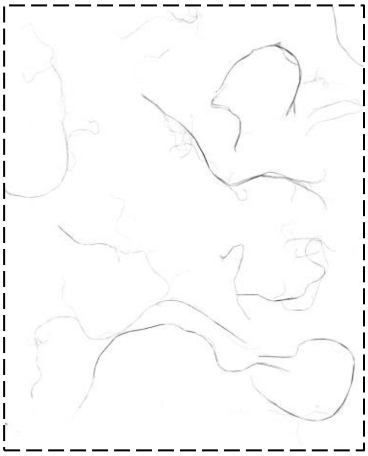


Figure 15: Hemp sample with fibre bundles of very different width.

References:

1. B. Uhrlaub, Sh. Wang, J. Müssig, H. Gusovius, C. Lühr, Bremen, Germany, August 2013: MEASURING INSTRUCTION: Sample preparation for lengths measurement of hemp fibre bundles
2. Stefan Seeger, BAM, Berlin 2006: Auswertesoftware FiberScanner zur Faserlängenmessung
3. R.-D. Reumann, Springer 2000: Prüfverfahren in der Textil- und Bekleidungstechnik

Attachment: Hauteur and Barbe Fibre lenght distribution analyzed by FibreScanner HSB

Fibre length [mm]	Hauteur-D [%]	Hauteur-SUM %	H [mm]	CvH [%]	Barbe-D [%]	Barbe-SUM %
6,858	1,36	1,36	29,41	59,50	0,32	0,32
9,144	4,81	6,16			1,49	1,81
11,43	4,56	10,72			1,77	3,58
13,716	5,61	16,33	B [mm]	CvB [%]	2,61	6,20
16,002	7,33	23,66	39,83	54,96	3,99	10,19
18,288	5,85	29,51			3,64	13,82
20,574	7,64	37,15			5,34	19,17
22,86	11,28	48,43			8,76	27,93
25,146	8,81	57,24			7,53	35,46
27,432	6,78	64,02			6,32	41,79
29,718	3,02	67,04			3,05	44,84
32,004	2,96	69,99			3,22	48,05
34,29	5,36	75,35			6,25	54,30
36,576	1,48	76,83			1,84	56,14
38,862	3,57	80,41			4,72	60,86
41,148	0,18	80,59			0,26	61,12
43,434	3,70	84,29			5,46	66,58
45,72	0,00	84,29			0,00	66,58
48,006	2,40	86,69			3,92	70,50
50,292	1,91	88,60			3,27	73,77
52,578	2,09	90,70			3,74	77,51
54,864	0,25	90,94			0,46	77,97
57,15	1,17	92,11			2,27	80,25
59,436	0,74	92,85			1,49	81,74
61,722	0,49	93,35			1,03	82,78
64,008	0,68	94,02			1,47	84,25
66,294	1,17	95,19			2,64	86,89
68,58	0,43	95,63			1,01	87,89
70,866	0,74	96,36			1,78	89,68
73,152	1,05	97,41			2,60	92,28
75,438	0,55	97,97			1,42	93,70
77,724	0,00	97,97			0,00	93,70
80,01	0,62	98,58			1,68	95,38
82,296	0,18	98,77			0,52	95,90
84,582	0,00	98,77			0,00	95,90
86,868	0,00	98,77			0,00	95,90
89,154	0,25	99,01			0,75	96,64
91,44	0,06	99,08			0,19	96,83
93,726	0,25	99,32			0,79	97,62
96,012	0,25	99,57			0,80	98,42
98,298	0,00	99,57			0,00	98,42
100,584	0,12	99,69			0,42	98,85
102,87	0,00	99,69			0,00	98,85
105,156	0,00	99,69			0,00	98,85
107,442	0,00	99,69			0,00	98,85
109,728	0,25	99,94			0,92	99,77
112,014	0,06	100,00			0,23	100,00
114,3	0,00	100,00			0,00	100,00
116,586	0,00	100,00			0,00	100,00

Part 2: Concept of the innovative length measurement technique

After we have finalised the length measurement of a collective of fibre bundles via scanning with a flatbed scanner and a subsequent analysis with a software programme developed within the MultiHemp project, we still see a need for a much faster innovative length measurement. Together with ATB we as a team have developed several new ideas and planed the realisation. A very promising approach is described in detail as follows. The design of the 1st test setup to evaluate the possibilities for an orientation of smaller and longer fibre bundles in an uniform air stream is given in Figure 16. The channel was produced from plexiglas for a better observation of the orientation and the flow of the fibre bundles. A high-speed camera mounted above the channel was used to track the fibre bundles passing the channel.

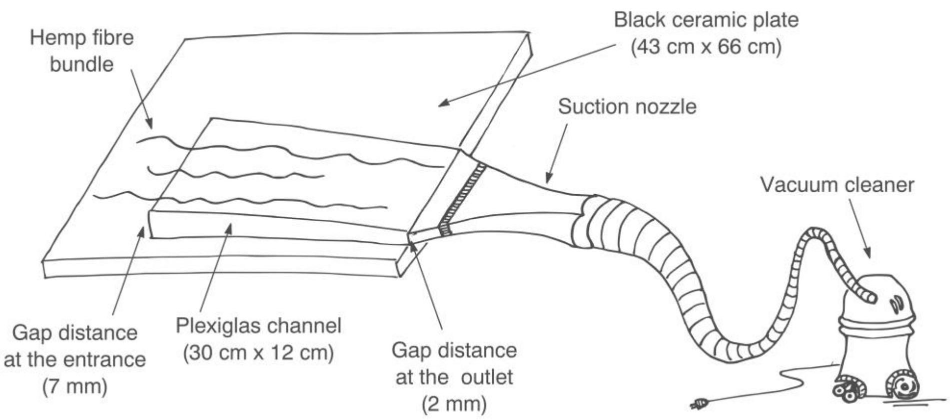


Figure 16: First test setup to evaluate the possibilities for an orientation of smaller and longer fibre bundles in an uniform air stream.

For the first experiments the fibre bundles were separated manually in front of the channel entrance and were clamped using the operators fingers. Single bundles were exposed, one after another, to the air flow and after the ortientation in the air stream – maintaining the clamping – the bundle was carried away with the air flow in an oriented form. Although the speed of a small and long fibre bundle being carried along in the air stream was high, the oberservation of the movement of the bundles was possible using the movie taken by the high-speed camera. Based on the first experiments we came to the conclusion that the rectangular channel geometry needs to be optimsed into a more tapered form. A first concept is given in Figure 17.

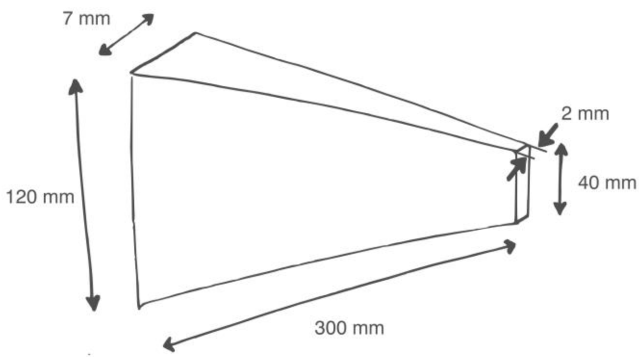


Figure 17: Optimisation of the rectangular plexiglas channel geometry to a more tapered form.

Because the amount of samples in the WP2 experiment is limited, we need to collect the samples after a non-destructive test. Using the test setup shown in Figure fibres will be lost under normal conditions. In this context, and in order to collect the fibres/fibre bundles, we have developed the concept shown in Figure 18.

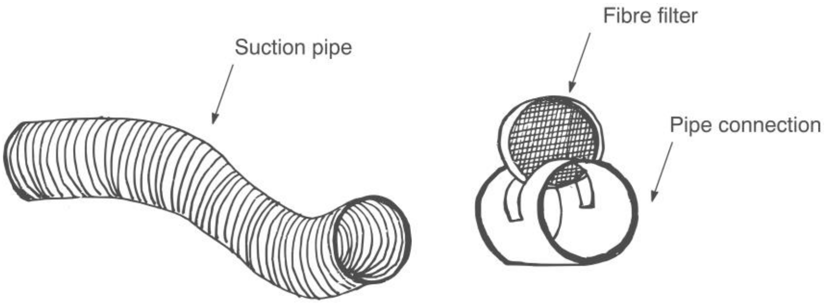


Figure 18: Collection of the fibre bundles after passed through the channel using a fibre filter integrated into a suction pipe.

The plexiglas channel (see Figure 116 & Figure 17) should not only be used for the acceleration and orientation of the fibre bundles but also for integrating the measurement equipment. For this purpose, we need to integrate in our construction a parallel section of the channel in which the air stream will not be accelerated. Ideally, this section should be as long as the longest fibre bundle. Figure 19 represents a further development of the previous channel which is based on the concept of the Venturi nozzle.

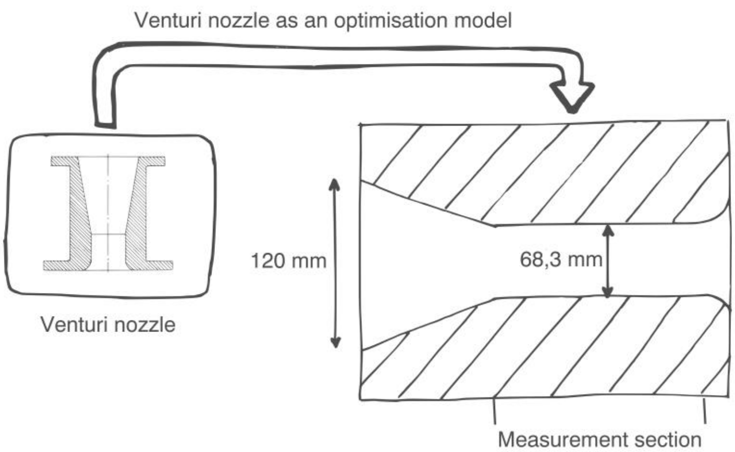


Figure 19: Optimisation of the plexiglas channel geometry based on the concept of the Venturi nozzle.

Because of a possible influence of fibre bundle length on the flow behaviour we have decided to perform a two-speed evaluation of the manufacturing process for an optimised channel. The general principle is illustrated in Figure 20.

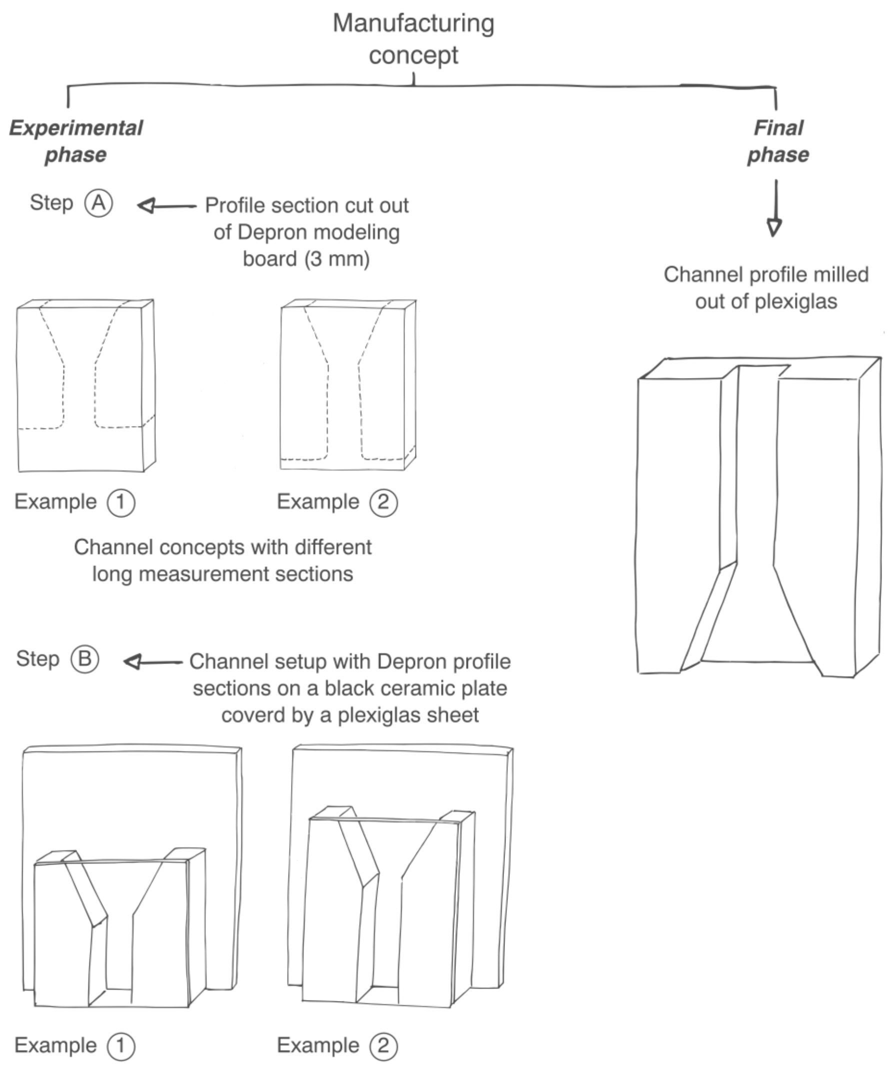


Figure 20: A two-speed evaluation of the manufacturing process for an optimised channel.

The sensor position to measure the passaging fibres and the speed of fibres is given in Figure 21.

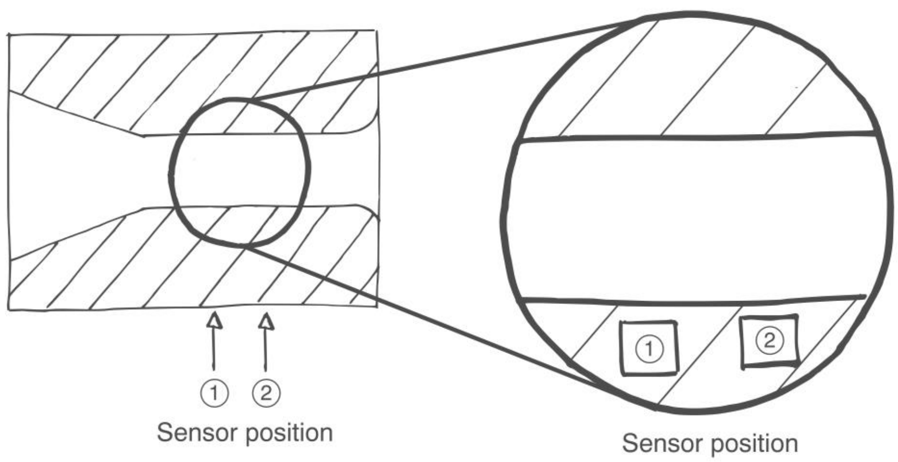


Figure 21: Sensor position in the plexiglas channel.

The measuring principle is based on the idea that a single bundle will be oriented in the air flow while it is clamped at the entrance of the channel. The clamping mechanism will be released after the bundle is oriented in the channel and the bundle passed the two sensors. The passing fibre will trigger a signal from the first sensor which can be used as a starting signal. When the end of the fibre bundle passed the first sensor the ending signal can be detected. The result is a passing time for each fibre bundle. Because different long bundles will have different velocities in the channel the information from only one sensor is not sufficient to calculate the length of an element. To get physical exact data the concept needs a second sensor to measure the velocity of each fibre bundle. Having the passing time and the velocity we can easily calculate the length value.

At present, we are evaluating two different kinds of sensor:

- light barrier principle and
- scattered light principle.

The two different sensor concepts are illustrated in Figure 22.

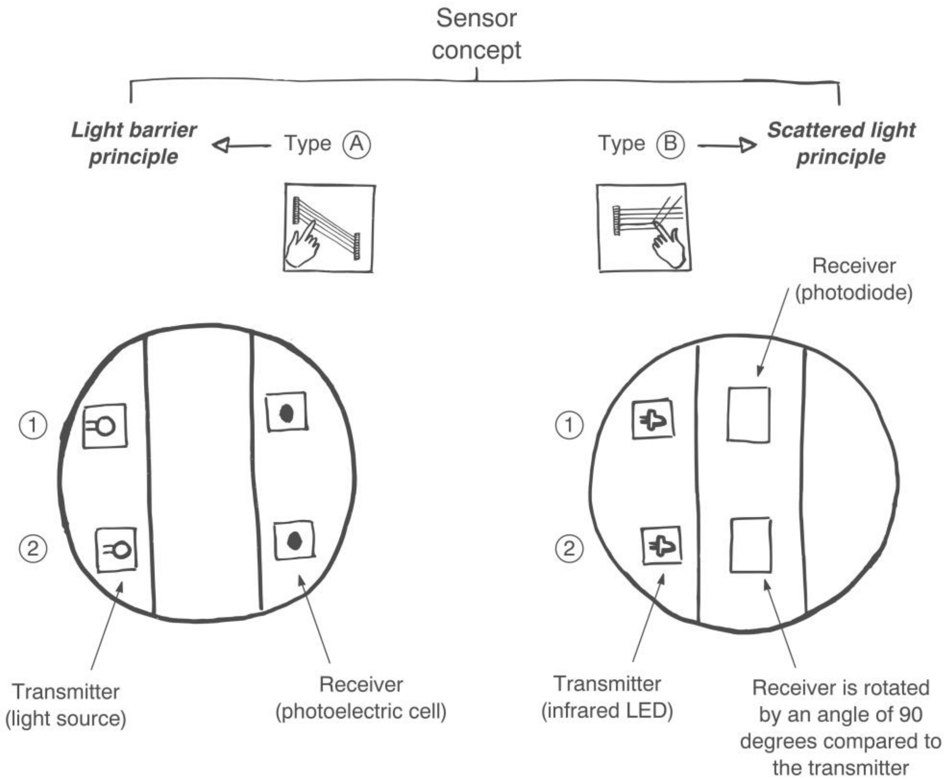


Figure 22: The light barrier and the scattered light principle for the sensor concept.

In the next step we will transfer the sensor concept into a test setup. We will focus our work at the first attempt on the sensor concept type B (see Figure 23). The scattered light principle seems to us to be a better solution and easier to implement.

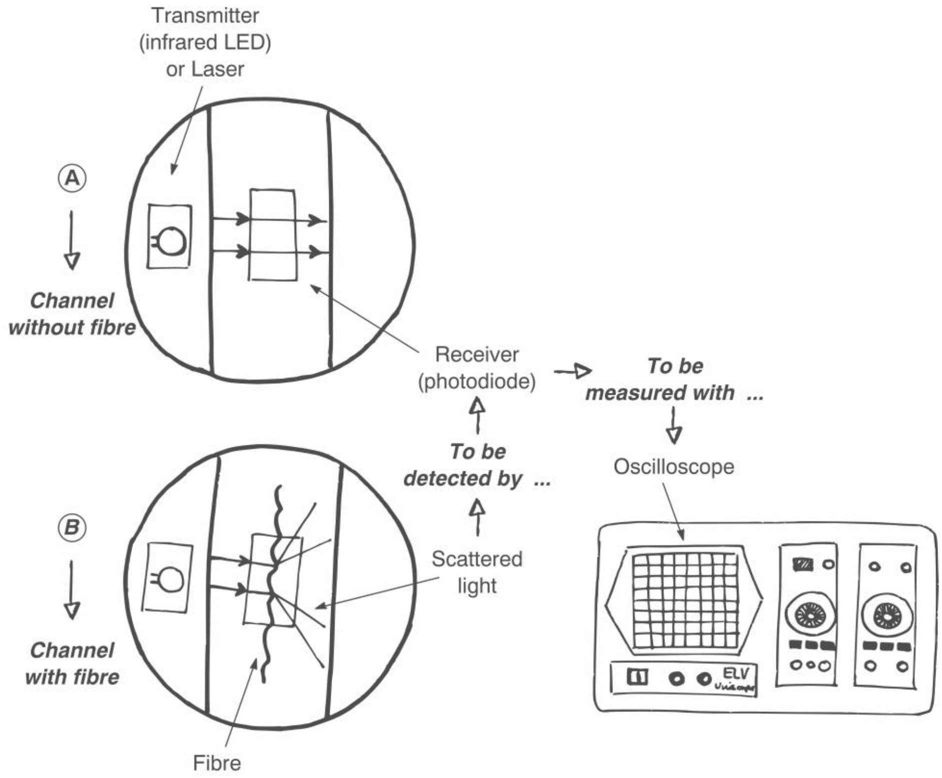


Figure 23: The scattered light principle in Detail.

If our concept will work we can offer for the first time a semi-automated length measurement for long bast-fibre bundles. With this device we can reduce the preparation and measuring time for the length measurement of hemp fibre bundles from more than 1 hour per sample to at least to one quarter. With the implement of the new (semi-)automated equipment for the fibre characterization regarding the length we will be able to evaluate the quality of many different genotypes.

Acknowledgements

The authors are grateful to Dipl.-Biol. William Thielicke for very helpful discussions and his engagement helping us to design and install the first setup.

Using mainly handwritten graphics, we have tried a new way of illustration in this chapter. Our special thanks to Ms. Kathina Müssig for her creative work.

References

Müssig, J. / Fischer, H. / Graupner, N. & Drieling, A. 2010: *Testing Methods for Measuring Physical and Mechanical Fibre Properties (Plant and Animal Fibres).* In: Müssig, J. (Editor): Industrial Applications of Natural Fibres – Structure, Properties and Technical Applications. Chichester, United Kingdom, John Wiley & Sons, Ltd, 2010, (ISBN 978-0-470-69501-1), p. 269 – 309