# Assessing Cotton Fiber Maturity and Fineness by Image Analysis

Ghith Adel[1], Fayala Faten[2], Abdeljelil Radhia[1]

[1]National Engineering School of Monastir, Monastir, TUNISIA
[2]Laboratoire des Etudes des Systèmes Thermiques et Energétiques, LESTE, ENIM, TUNISIA

Correspondence to :
Ghith Adel email : adel.ghith@enim.rnu.tn

## INTRODUCTION

The quality of cotton fiber depends on a large set of characteristics which includes length, maturity, fineness, strength, colour, trash. Considerable improvements have been made in these measurements. Methods used both in high volume instruments and in low volume apparatus make possible measuring a great number of fibers. The data collected is necessary to obtain quick mean cotton fiber characteristics without any dispersion coefficients in samples themselves. Image analysis is an attractive alternative to existing systems for investigating some quantitative fiber characteristics. It is quick, reliable and unbiased technique which is used to evaluate fiber maturity and fineness. In fact, some researchers have proved that cross sectional and longitudinal methods can be considered as robust approaches to measure fiber maturity and fineness using image analysis [1, 2, 3, 4, 5].

In this paper, we present images processing algorithms developed for longitudinal view analysis of cotton fibers. These algorithms involve a sequence of pixel manipulations in order to resolve problems present in the image for a better analysis. Then, we measure a set of cotton geometric parameters to define newest factors of cotton maturity.

## BACKGROUND

There is two ways for determining mature and immature cotton fibers in a given sample. The first way consist on using qualitative measurements, like near infrared, Shirley FMT, dyeability and micronaire methods. The last cited are the most widely used in laboratories and cotton spinning industry. They give very common parameters with a single value for each sample who is composed with some hundreds of thousands of cotton fibers. The value obtained can be considered as a coarse average of the interesting characteristic with no idea on dispersion coefficients in this sample (composed with very large number of fibers). Moreover, these methods may not take in account the variation in geometrical parameters for different genetic cotton varieties. So, they can be considered as not satisfying as a real measure of fiber maturity [3].

The second way using quantitative methods is based on microscopic evaluations of some geometric parameters in cross sectional or longitudinal views. The disadvantage of these methods is the difficulties to obtain preparations and results in acceptable time (quickly as micronaire methods). In cross sectional approach, the preparation of samples is difficult and need long time to perform microscopic observations, but longitudinal preparation need shorter time and is less difficult. In both cases the microscopic evaluation can be performed by the use of soft computing solutions.

Some authors have developed a number of criteria to estimate maturity parameters in microscopic cross sectional viewing [1, 2, 3, 4, 5, 6, 7]. The most important parameter in this way is the degree of thickening called θ given by the ratio of the cross sectional area of the total fiber wall by the area of a circle of the same perimeter. We may transform this expression using geometrical considerations and characteristics of a cross sectional cotton fiber as:

$$\theta = \frac{4\pi A}{P^2} \qquad (1)$$

Where A is the cross sectional fiber area and P is the fiber cross-sectional perimeter. θ is between 0 and 1, mature fibers have high θ values, immature and dead fibers have low θ values. A reference degree of thickening is defined $\theta_{ref}=0.577$ corresponding to an optimal amount of cellulose in cotton fiber. With this value, it is defined a Maturity ration M as:

$$M = \frac{\theta}{\theta_{ref}} = \frac{\theta}{0.577} \qquad (2)$$

Cotton with maturity ration M closer to unit value is considered mature and is estimated. Whereas, cotton with maturity ratio M lower than 0,8 is composed of a high percentage of immature fibers causing difficulties in spinning and dyeing processes. Matic-Leigh R, and Cauthen D. A. [8], define, circularity which is an approximation of the degree of thickening, to show the importance of the wall thickness (cellulose amount) $W_T$ of the cross-sectional cotton. They define the maturity factor $M_F$ as:

$$M_F = 100 \frac{2W_T}{W_R} \qquad (3)$$

Where $W_R$ is the effective circular diameter or ribbon width obtained by dividing the perimeter fiber cross-sectional by$\pi$. So, the maturity factor is defined by:

$$M_F = 100 \times \frac{2 \times \pi \times W_T}{P} \qquad (4)$$

In longitudinal measurements, Huang Y. and Xu B. [2], define the maximum, minimum mean and standard deviation widths of each fiber. They calculate maturity in longitudinal view $M_l$ as:

$$M_l = \frac{W_{sd}}{W_{mean}} \qquad (5)$$

$W_{sd}$ and $W_{mean}$ are respectively width standard deviation and width mean values in longitudinal cotton fiber observations [5]. They obtain good estimations well correlated with the results given by the cross-sectional observations and AFIS data.

Some other authors [9] focus on image analysis [10, 11] of fibrous materials to estimate some physical properties such as the determination of fiber medial axis. Yang H. and Lindquist W.B. [9], report in their paper the results of geometric and topologic analyse of a three-dimensional image of a simulated fiber mat and a real polymer fiber mat. They use software based on image analysis to treat tomography images, with the application developed they can identify a very large number of fibers in a mat and generate length range for successfully identified fibers.

The objective our paper is to present a low cost method, easy to perform and which can estimate cotton fiber maturity in a reasonable time. For these purposes we treat a two dimensional longitudinal cotton image analysis.

## MATERIALS AND METHODS

### Sample Preparation And Image Acquisition

Five specimens were examined in this paper from selected raw cotton. H.V.I. principal characteristics of cotton specimens are given in *Table I*:

TABLE I. Cotton origins and some characteristics

| **Cotton origins** | **Greek C_1** | **Syria C_2** | **Mali C_3** | **Spain C_4** | **Tchad C_5** |
|---|---|---|---|---|---|
| **Mic** | 4.1 | 4.1 | 3.9 | 4.0 | 4.2 |
| **Mat** | 0.89 | 0.93 | 0.92 | 0.95 | 0.90 |
| **Len** | 1.22 | 1.23 | 1.19 | 1.24 | 1.18 |
| **Str** | 24.9 | 25.3 | 25.1 | 25.3 | 24.7 |

Samples were cleaned and paralleled by combing. Then, cut into 1 mm snippets. After, the snippets were transferred into a microscope slide and covered with a cover glass. The images were captured at a 512x512 spatial resolution by a CCD camera which was mounted on a Zeiss microscope.

### Image Pre-Processing

The methodology of image pre-processing is presented by *Figure 1*:

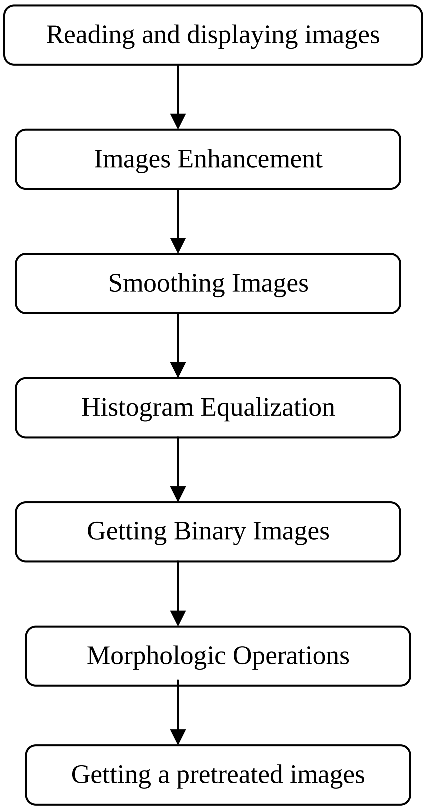

FIGURE 1. Pre-processing image analysis steps

The purpose of image pre-processing is to reduce the noise in the background. To be done, firstly, image enhancement was used to improve its quality. Also, an averaging filter was used to smooth the image before binarization. Secondly, the grey scale image was converted to a binary image by an automatic thresholding technique. Then, the cotton fiber image was shown white on a black background. At next, erosion and dilatation operations were applied to clean background noise, eliminate small holes present inside the fibers and fill gaps in the contours. Ultimately, connected components analysis was applied to the binary image to delete the remaining objects treated as noise by using a size filtering. Note that, after this last step, we have enlarged each image by adding zeros matrices to its four borders. This was done to keep fibers away from image borders. *Figure 2 and Figure 3* show examples of captured images of cotton fibers obtained before and after pre-processing treatment.

FIGURE 2. Cotton fiber Image in longitudinal view: fiber obtained before pre-processing

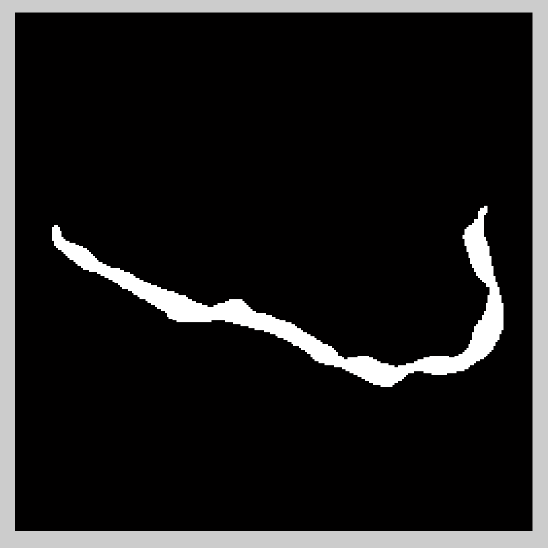

FIGURE 3. The same cotton fiber Image in longitudinal view after pre-processing treatment.

Also, we present an example of images which contains two connected fibers to explain the different steps of our processing procedure.

## Image processing and measurements

The image processing procedure permit respectively the localisation of the medial axis of segmented fibers, the individualisation of connected fibers by analysing junctions, the identification of fiber segments and the separation of the edges of the two sides of each fiber segment.

At the first step, a thinning technique was applied to the segmented images to obtain the medial axis of fibers. This technique removes edge pixels iteratively so a fiber without holes shrinks into one-pixel-thick line segment. It has the same principle as skeletonization. But, as shown in *Figure 4 and Figure 5*, it has the advantage that it returns individual fibers with no artefacts and medial axis without any junctions.

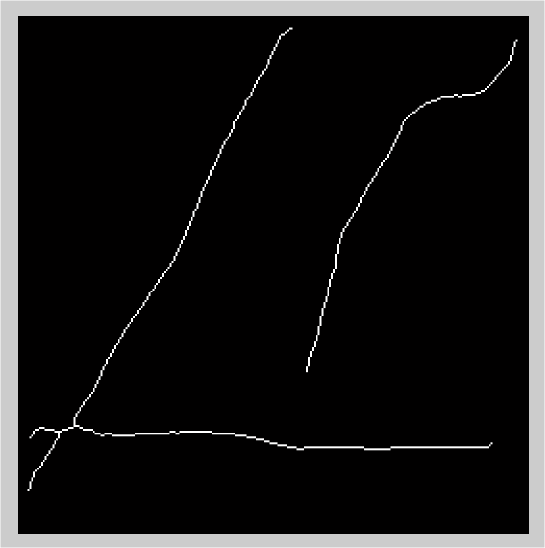

FIGURE 4. Medial axis of fibers obtained by thinning technique

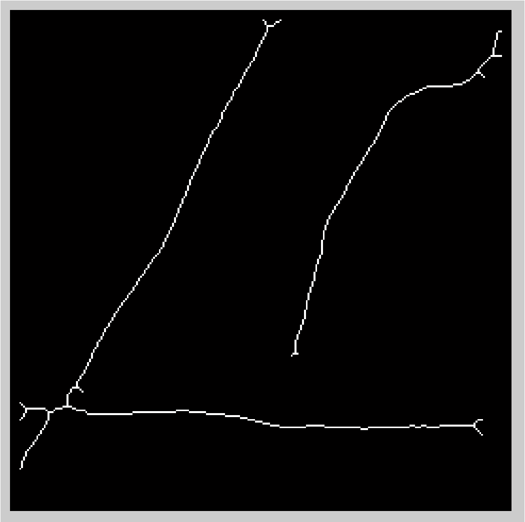

FIGURE 5. Medial axis of fibers obtained by skeletonization

At the second step, a pruning algorithm was applied to the medial axis image to remove junctions. In fact, by analysing the 8-neighbourhoods of each «white» pixel in the medial axis image we can easily extract the coordinates of all the junction points which have three or more «white» neighbours. After this operation, all junction points are detected and deleted from the medial axis image by setting them to «black» pixels as shown in *Figure 6*.

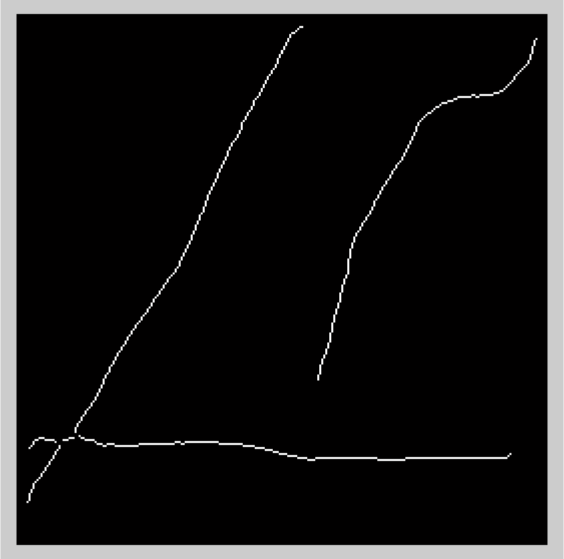

FIGURE 6. Medial axis image obtained after junction points removal.

The next step is to detect relatively short fragments of fibers. We have considered them as branches which must be removed. For this purpose, we have firstly shrunk the medial axis by few pixels to be slightly away from the detected junctions and endpoints of fibers.

*Figure 7* shows a medial axis image obtained after shrinking medial axis and branches removal.

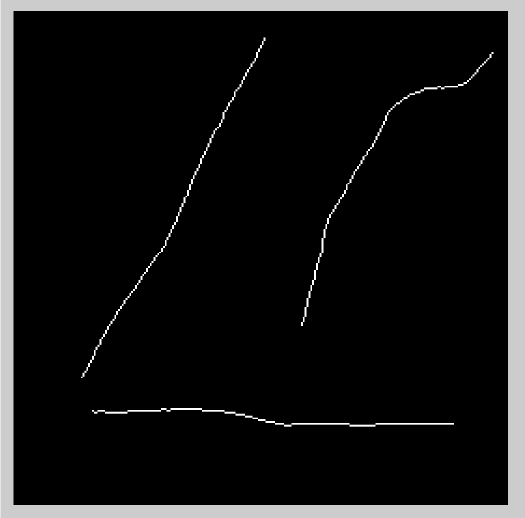

FIGURE 7. Medial axis image obtained after branches removal

Then, the connected fibers may be individualized by using an appropriate algorithm. Firstly, the 8-neighbours of each «white» pixel in the medial axis image were analysed to extract the coordinates of the endpoints which have only one «white» neighbour. Then, we add at each endpoint detected one or two « white » neighbours to obtain a short segment perpendicular to the medial axis at this endpoint. After, we get the coordinates of pixels of these short segments and set them to «black» pixels into the original image see *Figure 8*.

Lastly, we enlarge the resulting shorts segments by adding to them «black» pixels in the same direction until separating the two segments at either end of each fiber see *Figure 9*. This was done to eliminate incomplete ends of fibers and fiber-crossovers.

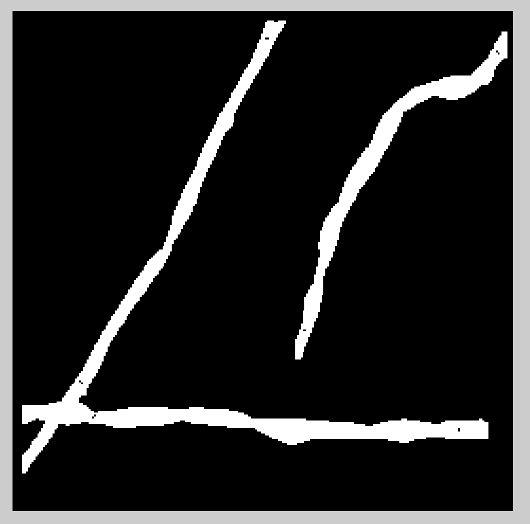

FIGURE 8. Image with black-added segments

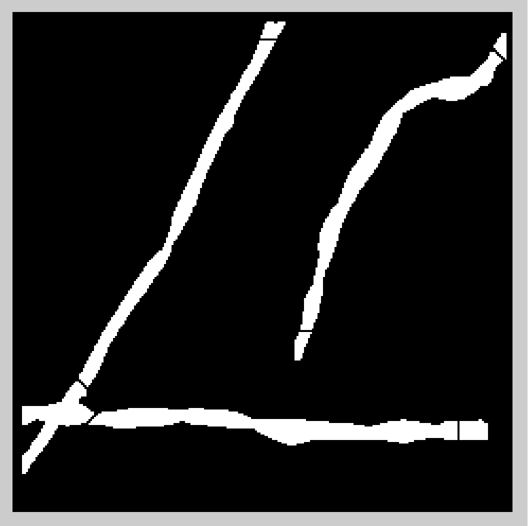

FIGURE 9. Image with fibers individualized

At the next step, the fibers segments used in subsequent analysis are identified. To be done, we shrunk by few pixels the medial axis of fibers and add them to the last obtained image. After, a boundary technique was used to label the objects into the image as shown in *Figure 10*. This technique uses a loop over the boundaries and registers only the coordinates corresponding to the labelled boundaries of fiber segments which contain medial axis.

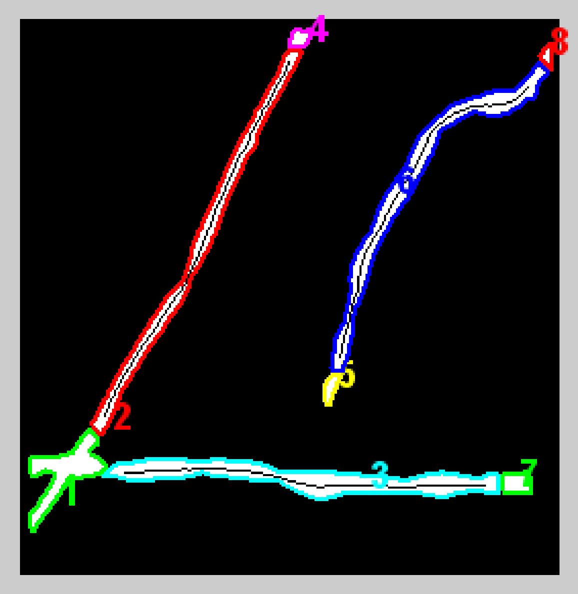

FIGURE 10. Image with labelled objects

When the identification stage was done, the images of fiber segments were manipulated iteratively and individually according to their coordinates. For each image, Canny method [11] was applied to find the edge of the fiber segment. After, the two sides of edge were separated by deleting the small «white» curved branches detected at its both ends see *Figure 11*. At this step, the area was measured by counting the number of pixels belonging to the filled segment. The perimeter was measured by adding the Euclidean distances calculated between consecutive data points of the edges using the following formula:

$$Perimeter = \sum_k \sqrt{\left((x_k - x_{k-1})^2 + (y_k - y_{k-1})^2\right)} \qquad (8)$$

Where $(x_k, y_k)$ and $(x_{k-1}, y_{k-1})$ are pixels on the edges. It should be noted that the area and perimeter were multiplied by scale factors to set them to their real values.

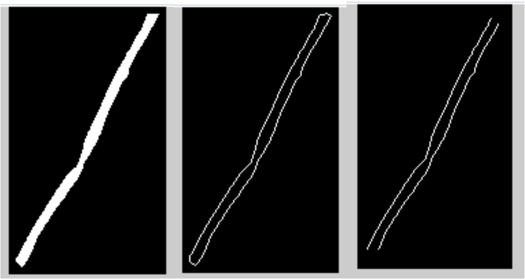

FIGURE 11. Separation of the two sides of edge of fiber segments.

At the last step, a scanning algorithm was used to calculate the widths of each fiber segment. To be done, the two sides of edge were coded. After, the scanning algorithm calculates the Euclidian distances between data points of the lower side, at a spacing interval of five pixels, and the corresponding data points of the upper side in a direction perpendicular to the medial axis. The calculated distances were multiplied by a scale factors and assigned into an array. In this manner, we obtain for each fiber segment a set of values corresponding to the calculated widths at various positions of the fiber. Therefore, the number of the segment can be determined by measuring the length of the corresponding array. Also, the minimum, mean, maximum widths can be measured and the width standard deviation can be calculated.

By exploiting previous measurements, we calculate others parameters related to maturity and fineness using the following definitions and formulas.

## Circularity Index

Cotton fiber is characterized by its collapsed aspect as shown in *Figure 12*. It often presents a set of various widths along its axis. The deviation of width depends on the degree of secondary wall thickening.

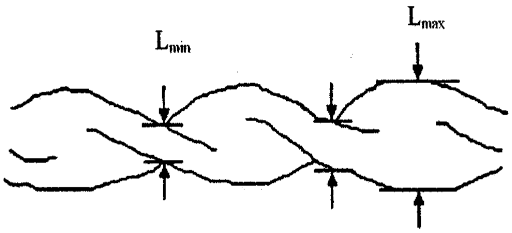

FIGURE 12. Cotton fiber collapsed aspect

A high convolution often indicates a low level of maturity [5]. Therefore, the difference between the minimum and maximum widths is more significant for immature fibers. So, we can define a geometrical coefficient called circularity index. It represents different maturity stages and it can be calculated using the following equation:

$$Circularity \quad Index = CI = \frac{L_{\min}}{L_{\max}} \tag{9}$$

Where $L_{max}$ (µm) and $L_{min}$(µm) are respectively the maximum and minimum widths of fiber. The range of This index is [0 , 1]. *CI* is quite close to unit value when fibers are very mature or mature and it is less important for immature fibers.

## Maturity Index In Longitudinal View

B. Xu and Y. Huang [5] define the maturity $M_L$ based on longitudinal measurements as:

$$M_L = \frac{W_{sd}}{W_{mean}} \tag{10}$$

$W_{mean}$ and $W_{sd}$ denote the mean and standard deviation of the scanned widths. More the fiber is immature, more $W_{sd}$ is important and more $M_L$ is important. So, we can define a maturity index as follows:

$$Maturiry \quad Index = \left( \frac{1}{M_L \times 10} \right) \tag{11}$$

The reciprocal of $M_L$ was divided by 10 to get a maturity index values between 0 and 1 since $M_L$ is higher than 0,1 which is the case in cotton fibers (see results in *Table II*).

## Specific Surface

We calculated also the specific surface of cotton fibers, assuming a cylindrical shape, using the following formula:

$$Specific \; s\,urface \; = \left( \frac{4}{Wmean} \right) \tag{12}$$

*Wmean* (µm) is the mean equivalent width of cotton fibers.

## ShapeParameter

For the purpose for extracting more features from cotton fibers, we have introduced a shape parameter defined as follows:

$$Shape\ parameter = \left(\frac{2P}{A}\right) \qquad (13)$$

P(µm) and A(µm²) are respectively the fiber perimeter and area.

**Fineness**

Many researchers have developed and defined cotton fineness [5, 10, 11] as:

$$T(tex) = \frac{\rho(g/m^3) \times \pi \times d^2(m^2) \times l(m)}{4} \times 1000 \qquad (14)$$

Where $T$ is the linear density of fibers. $\rho$, $d$ and $l$ are respectively the density of cotton fibers, the mean equivalent diameter of fibers assuming a cylindrical shape and the length of the cotton fiber.

**Micronaire**

J. G. Montalvo and al. [12] and other researchers assume that:

$$MT = 3.86Mic^2 + 18.16Mic + 13 \qquad (15)$$

$MT$ and $Mic$ are respectively the maturity ratio and the micronaire value.

## EXPERIMENTAL RESULTS

In our paper five different cottons are used for validation testing. The samples were cut into 1mm long segment, randomly spread on a microscope slide and imaged by a CCD camera. One hundred images were captured, at a 512x512 spatial resolution, for each variety. Due to the difference in the density of fiber segments spread on the slide, the actual number of analysed fibers per variety varied from 250-500. Width, area and perimeter for each fiber segment were measured directly from the image. Circularity index, maturity index, shape parameter, specific surface, fineness and micronaire were calculated from the measured data. It should be noted that a short time was needed (about 3 minutes) for image processing and calculation for one sample.

By testing the five varieties, we have noted a high correlation ($R^2$=0.946) between the values of micronaire measured by the longitudinal method and the micronaire measured by HV.I spectrum method as shown in *Figure 13*.

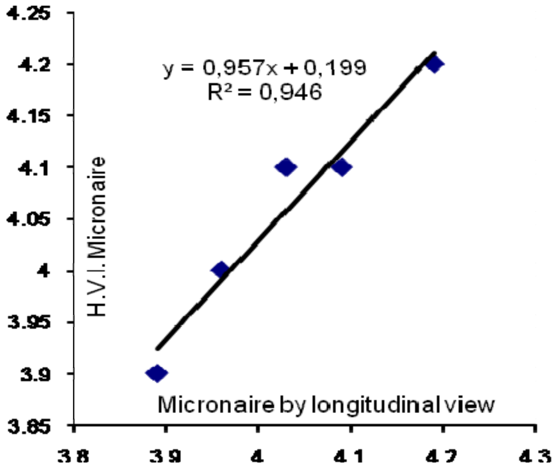

FIGURE 13. Correlation between Micronaire measured by longitudinal view and micronaire methods.

*Table II* presents the average and standard deviation (in parentheses) of the longitudinal data of the varieties as measured by the image analysis algorithms developed in this paper.

TABLE II. Average longitudinal measurements of cotton fibers.

| **Parameter** | **C_1** | **C_2** | **C_3** | **C_4** | **C_5** |
|---|---|---|---|---|---|
| **Width (µm)** | 21.582<br>(2.399) | 20.689<br>(2.303) | 20.37<br>(2.607) | 21.721<br>(2.412) | 20.849<br>(2.125) |
| **Circularity** | 2.182<br>(0.464) | 2.071<br>(0.385) | 2.107<br>(0.493) | 2.205<br>(0.422) | 2.152<br>(0.365) |
| **Index of circularity** | 0.477<br>(0.073) | 0.498<br>(0.075) | 0.499<br>(0.081) | 0.512<br>(0.089) | 0.482<br>(0.071) |
| **Maturity Index** | 0.167<br>(0.038) | 0.156<br>(0.031) | 0.162<br>(0.043) | 0.151<br>(0.036) | 0.164<br>(0.048) |
| **Index of maturity** | 0.633<br>(0.123) | 0.672<br>(0.122) | 0.669<br>(0.147) | 0.681<br>(0.132) | 0.652<br>(0.136) |
| **Shape parameter µm$^{-1}$** | 0.226<br>(0.027) | 0.237<br>(0.027) | 0.242<br>(0.035) | 0.244<br>(0.031) | 0.231<br>(0.033) |
| **Specific surface (µm$^{-1}$)** | 0.188<br>(0.021) | 0.196<br>(0.021) | 0.2<br>(0.025) | 0.205<br>(0.023) | 0.192<br>(0.020) |
| **Fineness (mtex)** | 143.223<br>(31.5) | 131.62<br>(30.11) | 127.838<br>(33.3) | 129.232<br>(32.1) | 145.321<br>(32.5) |
| **Micronaire** | 4.09<br>(0.861) | 4.036<br>(0.929) | 3.89<br>(0.95) | 3.96<br>(0.841) | 4.19<br>(0.877) |
| **H.V.I. Maturity** | 0.89 | 0.93 | 0.92 | 0.95 | 0.90 |
| **H.V.I Micronaire** | 4.1 | 4.1 | 3.9 | 4.0 | 4.2 |

Results presented in *Table II* give an excellent idea of cotton maturity and fineness. This is significant in *Figure 14 and 15*.

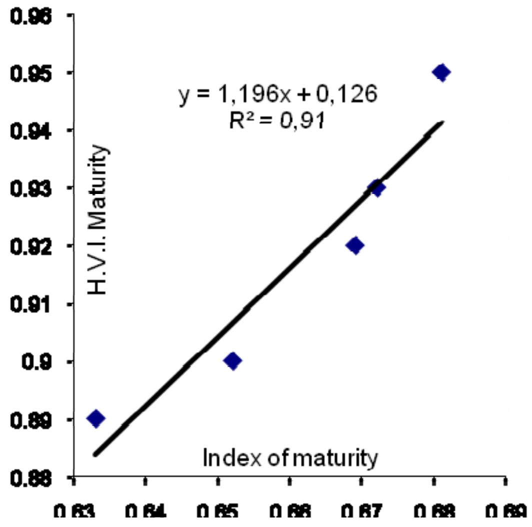

FIGURE 14. Correlation between Index of maturity measured by longitudinal view and H.V.I. maturity.

Good correlation (0.91) is established between index of maturity and H.V.I. maturity. The factor measured in the longitudinal view can be considered as a good estimation of a cotton maturity.

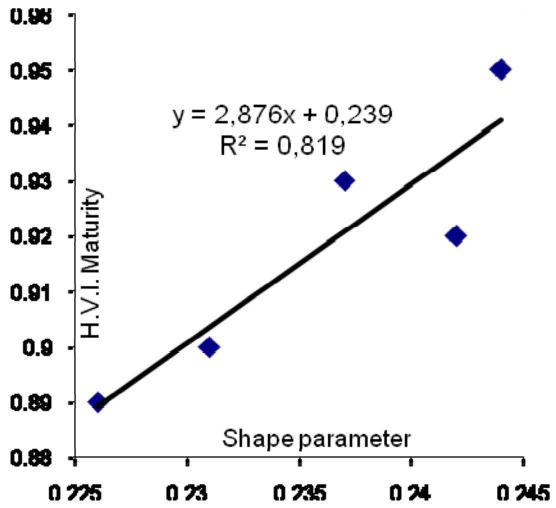

FIGURE 15. Correlation between shape parameter measured by longitudinal view and H.V.I. maturity.

Shape parameter and H.V.I. maturity are dependent; the correlation between them is not very significant (0.81). This is due to the collapsed aspect of cotton fibers.

Also, we have selected for each parameter the whole individual values measured within examples taken from the first three varieties (C_1; C_2 and C_3) samples to improve the correlations and relationships between the longitudinal parameters, The correlation coefficients ($R^2$) may be determined for nonlinear curve fitting, as well as linear functions. The results are listed in *Table III*.

TABLE III. Relationships and correlations between longitudinal data.

| **x-axis** | **y-axis** | **Relationships** | **$R^2$** |
|---|---|---|---|
| Width | Specific surface | Y=-0.009x+0.3839 | 0.9752 |
| Width | Shape parameter | Y=-0.0119x+0.4847 | 0.957 |
| Specific surface | Shape parameter | Y=1.308x-0.0119 | 0.9721 |
| Width | Fineness | Y=12.9502x-136.282 | 0.9955 |
| Micronaire | Fineness | Y=25,4685x+32,035 | 0.7194 |
| Width | Index of maturity | Y=-0,0055x+0,7747 | 0.1051 |
| Width | Index of circularity | Y=-0.33x+56.0564 | 0.1065 |
| Index of circularity | Index of maturity | Y=0.0144x-0.0527 | 0.8454 |
| Fineness | Shape parameter | Y=-9.0188x+0.356 | 0.9392 |
| Micronaire | Shape parameter | Y=-0.0233x+0.3285 | 0.6859 |
| Micronaire | Specific surface | Y=-0.0155x+0.2653 | 0.6952 |
| Index of circularity | Shape parameter | Y= ($4.86571^E$-4) x+0.2111 | 0.1206 |
| Index of circularity | Specific surface | Y= ($3.1795^E$-4) x+0.1793 | 0.1060 |
| Micronaire | Index of circularity | Y=4.2839x+31.9931 | 0.5084 |
| Micronaire | Index of maturity | Y=0,0875x+0,3075 | 0,607 |

The width and shape parameter are two independent measurements but *Figure 16* shows that a reciprocal correlation ($R^2$=-0.957) exists between them. This means that more the fiber is coarser more the shape parameter is lower. Therefore, the shape parameter can be used as indicator of fineness. In fact, the specific surface calculated as function of width had a good correlation with the shape parameter ($R^2$= 0.9721) see *Figure 17* and the both parameters reveal consistent correlations with the others parameters.

However, the index of maturity and circularity have a reasonably good correlation ($R^2$=0.8454) see *Figure 18* but they show no correlation with the width. This is due to depends between the deviations of width within samples. We can find, in each variety of cotton, coarse fibers whose are immature and fine fibers whose are mature.

The fineness and the index of maturity have respectively low correlation with the micronaire as shown in *Figures 20 and 21*. This can be attributed to the fact that micronaire is a combined measure of both fineness and maturity. The width and shape parameter are two independent measurements but they are highly correlated ($R^2$= 0.957) see *Figure 16*. This means that more the fiber is coarser more the shape parameter is lower. Therefore, the shape parameter can be used as indicator of fineness. In fact, the specific surface calculated as function of width had a good correlation with the shape parameter ($R^2$= 0.9721) and both parameters reveal consistent correlations with the others parameters.

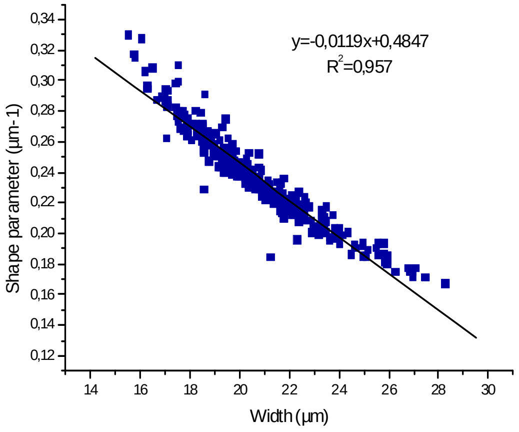

FIGURE 16. Correlation between width and shape parameter

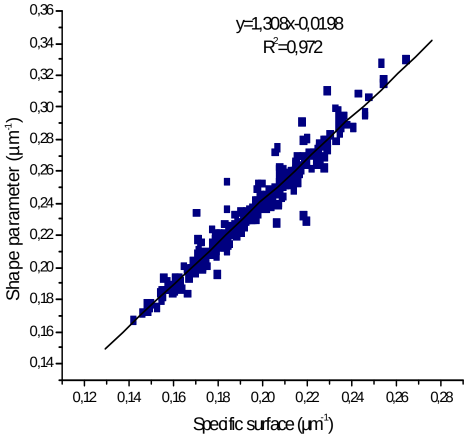

FIGURE 17. Correlation between specific surface and shape parameter

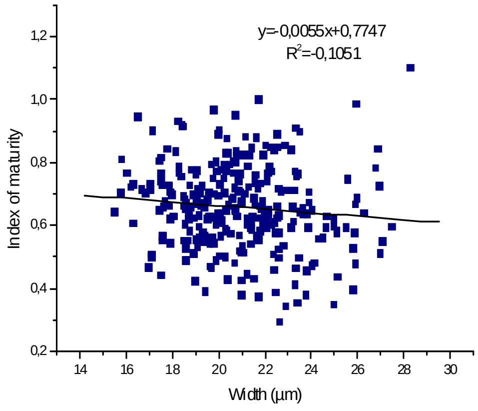

FIGURE 18. Correlation between index of circularity and maturity

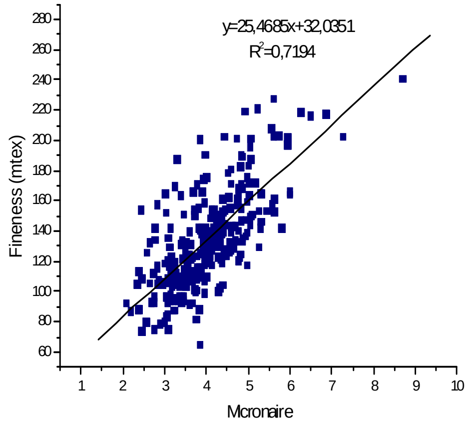

FIGURE 19. Correlation between Fineness and micronaire

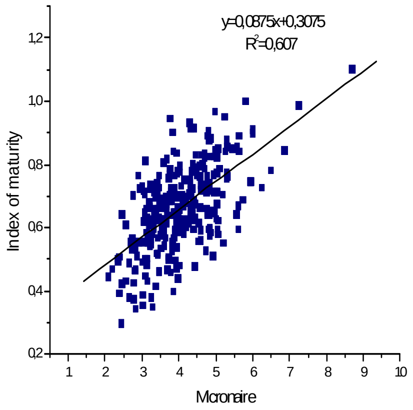

FIGURE 20. Correlation between Index of maturity and micronaire

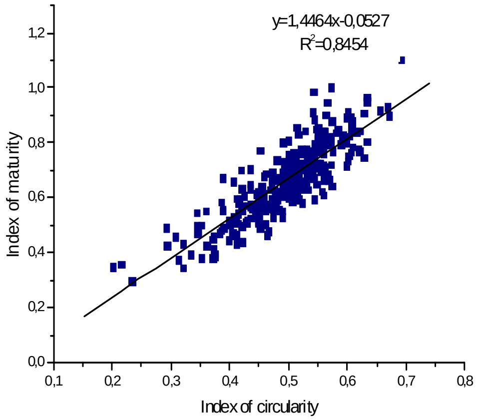

FIGURE 21. Correlation between Index of maturity and index of circularity

## CONCLUSIONS

In this paper, we have presented image analysis algorithms developed for processing longitudinal images of cotton fibers. These algorithms increase the automation and accuracy of fiber individualization. Five varieties of cotton were used for testing. Statistical analysis shows that the deviations among the tested fibers are much greater than the differences between varieties. The correlation study reveals that the two independent measurements, width and shape parameter, are highly correlated. These two parameters can be used to estimate the fineness and maturity of cotton fibers. Longitudinal data of the varieties samples show high correlation with the H.V.I. micronaire and maturity. It should be noted that good sample preparation is a required for satisfactory results.

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## AUTHORS' ADDRESSES

**Ghith Adel**
**Abdeljelil Radhia**
National Engineering School of Monastir
Avenue Ibn El Jazzar
Monastir, Monastir 05000
TUNISIA

**Fayala Faten**
Laboratoire des Etudes des Systèmes
Thermiques et Energétiques, LESTE, ENIM,
TUNISIA