# HIGH-RESOLUTION COTTON FIBER LENGTH AND MATURITY MEASUREMENTS USING IMAGE ANALYSIS

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## Abstract

In a previous study, H. Wang from our group developed a reference method for automatic and accurate measurement of cotton fiber length using image analysis. To improve on this, a new imaging system has been developed that will decrease the computation time for the length measurement algorithm and can also deliver higher-resolution images suitable for maturity measurements. The main idea is to develop a prototype system that can perform both length and maturity measurements of cotton fibers simultaneously, quickly and accurately so that a bivariate distribution of cotton can be obtained.

The improved system runs a faster version of the length algorithm that has already been validated on 20 cotton samples of 500 fibers each for a total of 10,000 fibers. For maturity algorithm, three different features are determined from a fiber image: 1) Change in fiber width, 2) Number of convolutions per unit length, and, 3) Light transmitted through fibers. Mature fibers generally have more convolutions per unit length and hence show more changes in fiber width. In addition, mature fibers transmit less light through it, and are more likely to show greater intensity variations along its length. In near future, once the set of features have been generated using reference cotton samples, a classifier will be developed that would help predict the maturity level for a given unknown cotton sample using our proposed approach.

The previous hardware prototype includes an off-the-shelf grayscale scanner connected to image acquisition software. Cotton fibers are placed under glass slides and scanned at 1000dpi resolution before being saved on a computer by a technician. The length algorithm software is programmed in *Matlab*, and includes an easy-to-use graphical user interface. This allows the technician to load saved cotton fiber images and execute the length measurement algorithm. The time taken to process images depends on the complexity of the fibers in the image and generally takes a couple of minutes for images containing several fibers. However, it is a robust algorithm capable of fiber separation in presence of inter-fiber intersections and intra-fiber crimps and crossovers.

For maturity measurements, it is important to have a high-resolution image. A study was performed to been determine if that the previous system was capable of integrating both maturity and length measurements. Although a scanner can obtain higher resolution images than 1000dpi, it has been discovered that the execution time for the length algorithm suffers considerably. In addition, the images from the previous system do not show any significant change in fiber contrast among different types of fibers, which is one of the important features to look at for assessing fiber maturity. Moreover, the system itself requires a technician to save images from acquisition and load images into Matlab before processing can occur. As a result, a new imaging system with more sophisticated acquisition has been designed to address these issues.

The new prototype system consists of an industrial type 8K gray-scale line-scan camera connected to a 5x optical lens system, delivering 25400dpi resolution images. This means that acquired images can resolve objects which are as small as 1 micron wide, so the resolution is 25 times better than the previous system. It uses a fiber-optic backlight on a very-high-resolution (nanometer-scale) moving stage that traverses the cotton fibers (sandwiched between two flat glass slides) under the camera - capturing a detailed image that is ideal for maturity measurements. The acquisition software to grab images from the camera and transfer them to the host computer is programmed in *LabVIEW*. *LabVIEW* is selected because it has allowed us to develop software to communicate with all system components (camera, stage, illumination and computer) allowing changes in acquisition parameters. In addition, it provides a framework to generate easy-to-user graphical user interfaces for technicians to use.

Under the new system, a typical scan takes anywhere from 10 to 30 seconds depending on the acquisition exposure settings and length of fiber to be scanned. A fiber will appear as dark gray on a light gray background whereas in the previous system a fiber appears white on a near-black background. Once acquisition by *LabVIEW* is complete, the image passes to the length algorithm. Since the images acquired by this system look different and are of higher resolution, the pre-processing step in the length algorithm has to be modified. The first step is to resize the images down to a resolution at which the length algorithm can run sufficiently fast. The second step is to use image processing techniques to binarize the resized image. Morphological image processing and adaptive thresholding are some of the image processing techniques used to achieve this. Once the pre-processing is complete, a binary image is ready to be processed by Wang's fiber length algorithm.

With regard to the software environment, several changes are needed to boost efficiency to allow processing in real-time. For the length algorithm, the "*C/C++*" programming language is preferred to *Matlab* since the execution time can be reduced significantly. The *OpenCV* "*C*" image processing library is an open-source software that has been integrated for use in the new environment. As a consequence, considerable development time has been spent to port the existing length algorithm from Matlab to C. Special care has been taken to ensure that the new code produces results as similar to the old one that has been well verified. If we consider Wang's length algorithm, there are four distinct stages that must be processed in order, namely, pre-processing, branch-removal, resolving and curve-fitting. The table below summarizes the improvements in execution time (in seconds) as a result of converting each stage to "*C*".

**Table 1. Relative times for stages of length algorithm before and after changes**

| **Stage** | ***Matlab* (old)** | ***OpenCV "C"* (new)** |
|---|---|---|
| Pre-processing | 28.00 | 3.00 |
| Branch-Removal | 97.00 | 5.00 |
| Resolving | 2.60 | 0.5 (est) |
| Curve-fitting | 2.00 | 0.10 |

In addition to porting the existing algorithm to "*C*", a verification study has been done on Wang's length algorithm. In particular, the consistency of the results returned by the length algorithm has been investigated. Important parameters for the Adaptive Control Point Selection (ACPS) were extracted and their relationships with regard to application determined. It has been verified that variation of parameters over an acceptable range produced length measurement which are within 1% of the true length. These regions are shown in dark blue in the figure 1 and 2 shown below.

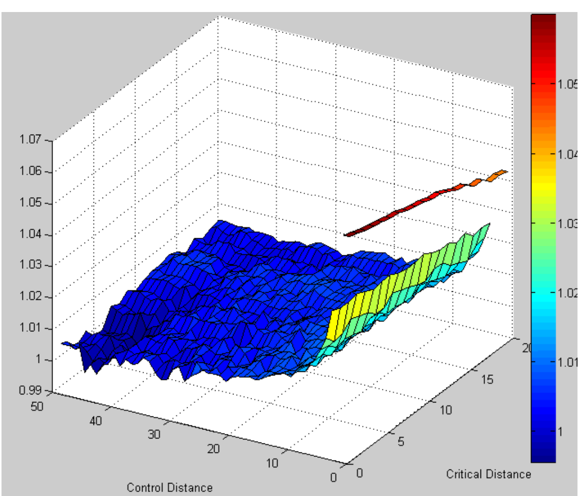



Figure 1: Mesh plot of fiber length for various combinations of control-distance(M) and critical-distance(N) parameters.

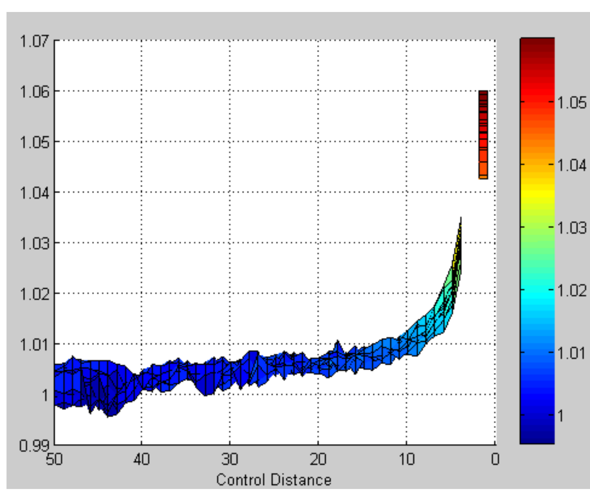



Figure 2: Plot showing the variation of fiber length as control-distance (M) is changed. The actual length of fiber here is 1.00 inch.

Furthermore, preliminary work on maturity software has also been carried out. Scans of fibers of different maturities have shown differences in intensity values and profile. Therefore, one feature of interest is the change in image intensity between the two edges of the fiber. This can be repeated at different points along the length of the fiber using a profile generation technique. Another feature of interest is to trace the change in fiber width along the fiber. From this, we can estimate the mean fiber width and the number of convolutions per unit length of the fiber. Figure 3 shows an enhanced image and the process of profiling which is which to obtain the changes in fiber width. Figure 4 shows the fiber width profile and the 25$^{th}$ percentile width which are used to estimate the number of convolutions. Using these features, a classifier can be developed that would help predict the maturity level of a given fiber sample from image analysis.

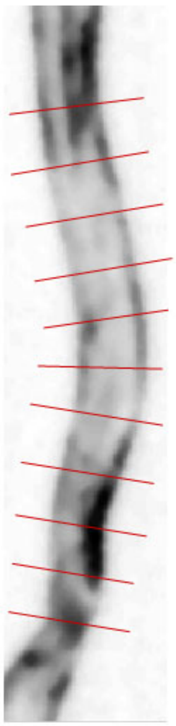
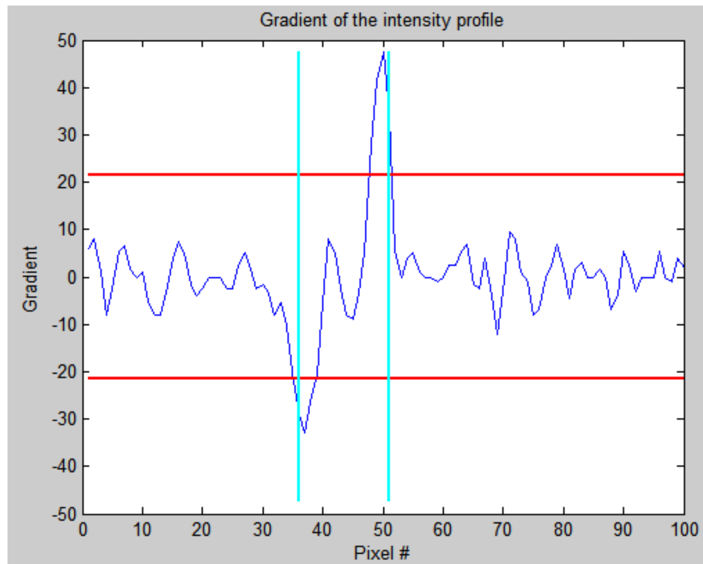


Figure 3(a) Profiles set on enhanced image




3(b) Gradient Intensity profile: A width is the Euclidean distance between the pixel points that the cyan colored lines intersect. Width = 15 microns.

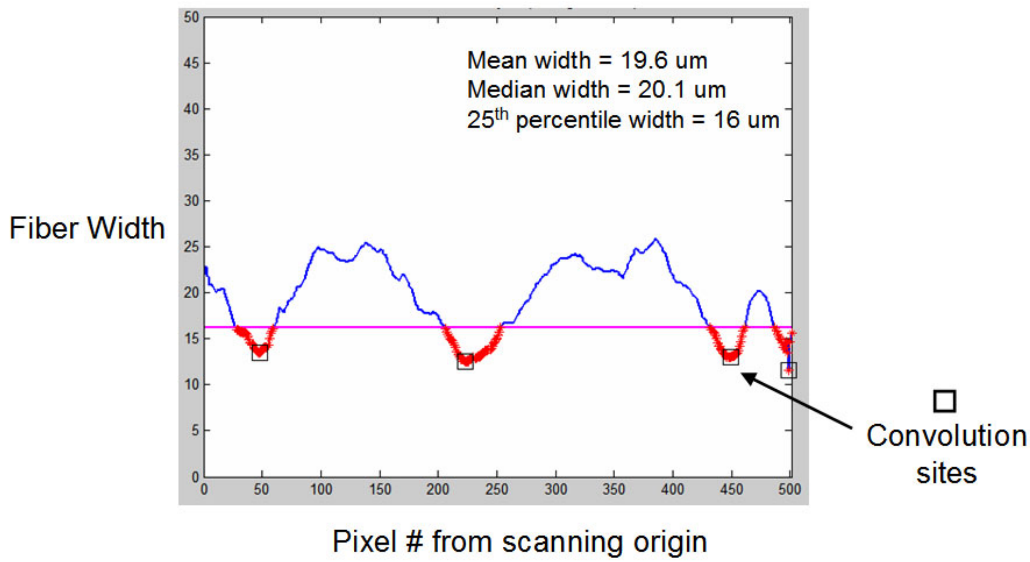



Figure 4: Fiber width profile (expressed in microns)