

A Customized Microscopic System for High Volume Measurements of Cotton Maturity

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Abstract

Cotton maturity, which refers to the degree of development of the fiber wall relative to its perimeter, is one of the main cotton quality attributes because it directly or indirectly affects most of the other cotton fiber properties. Mature fibers usually possess greater strength and better resilience. The presence of immature fibers may cause excessive fiber waste during processing and may lower yarn strength. Immature fibers have also been recognized as one of the principal causes of the formation of nep. Due to their relatively low dye affinity, neps easily show up as imperfections in a dyed fabric. Hence, information about cotton maturity is desirable to cotton breeders and growers for cotton enhancement and to textile manufacturers for quality control. This paper will report on the development of a dedicated system that facilitates direct, fast and high-volume measurements of cotton maturity from longitudinal views, and the experiment results.

Cotton fibers are convoluted along their longitudinal axes. Therefore, a projected 2-D image of a cotton fiber has large variations in fiber width. Because of the relationship between fiber convolutions and fiber maturity, our hypothesis is that the ratio of the maximum width to the minimum width of a fiber ribbon could be used as a maturity indicator. Another important factor related to cotton maturity is fibers translucence because the translucence with a transmitting light microscope is dictated by the thickness of the secondary cell wall. This paper will describe the methodology for extracting these features from digitized images and how they relate to cotton maturity.

Introduction

Cotton maturity, which refers to the degree of development of the fiber wall relative to its perimeter, is one of the main cotton quality attributes because it directly or indirectly affects most of the other cotton fiber properties. Mature fibers usually possess greater strength and better resilience. The presence of immature fibers may cause excessive fiber damage and waste

during processing and may lower yarn strength. Immature fibers have also been recognized as one of the principal causes of the formation of neps. Due to their relatively low dye affinity, neps easily show up as imperfections in a dyed fabric. Hence, information about cotton maturity is desirable for cotton breeders and growers to enhance cotton fibers and to textile manufacturers to improve their quality control.

The cross-section of a cotton fiber contains measurable information directly related to fiber maturity. Much research has been conducted using image analysis technology to measure cotton maturity and other parameters from cotton fiber cross-sections [1, 2, 3]. In general, the success of a cross-section method using image analysis relies on two techniques: fiber cross-sectioning and image segmentation. The USDA Southern Regional Research Center (SRRC) developed an effective cross-sectioning method that includes sampling, embedding and sectioning procedures [4, 5]. Supported by a previous NRICGP project, we developed an image analysis system devoted to cotton cross-section analysis [3, 6, 7]. The system has been successfully used for research projects in SRRC-USDA and the International Textile Center – Texas Tech University, where a cotton maturity database is being built as a reference for other testing methods [8, 9]. Although the cross-section analysis can provide specific and accurate measurements for maturity, the method is not suitable for routine, high-volume testing because it requires tedious, time-consuming, and costly operations.

Cotton fibers are convoluted along their longitudinal axes. When projected in a 2-D image a convoluted fiber has large variations in fiber width. An exploratory study showed that the ratio of the maximum width to the minimum width of a fiber ribbon could be used as a maturity indicator [10]. Another important factor that is related to cotton maturity is the translucence of the fibers because translucence with a transmitting light microscope is dictated by the thickness of the secondary cell wall. A preliminary investigation demonstrated that the combination of convolution and translucence measurements from longitudinal views of cotton fibers is a good indicator of fiber maturity as measured with fiber cross-sections [11].

In this paper, we report on the development of a dedicated system that provides a direct, fast and high-volume method for cotton maturity measurement from longitudinal views. The discussions cover the hardware descriptions, software algorithms, and experimental results.

Microscopic Imaging System

The schematic design of the customized imaging system made of off-shelf hardware is depicted in Figure 1. A monocular microscope coupled with a CCD video camera produces sharp digital images with a resolution of 1280x1024 pixels. The *x-y* mechanical stage is driven by two micro step motors so that the camera can grab sequential images of fibers across the slide. A short-arc xenon strobe is used to illuminate the sample.

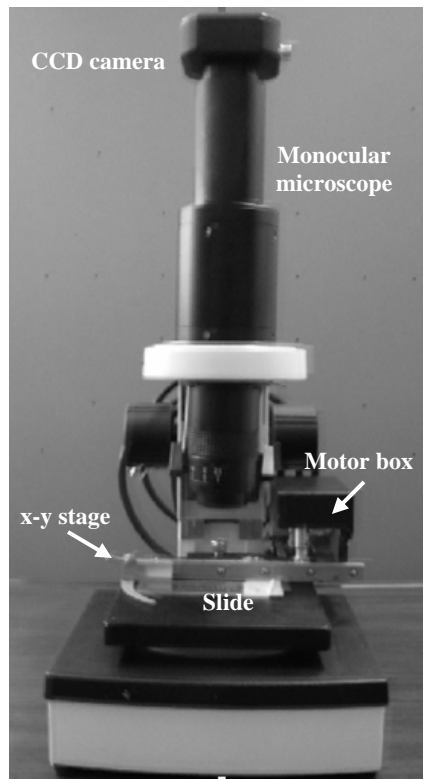


Figure 1 FIAS

Figure 2 shows a flow chart of the imaging system components. The computer sends the motor speed and step information to a programmable counter/timer, which generates two sets of pulses with a certain frequency and width that control the two motor drivers. When the slide travels to a stop, the computer sends a pulse signal to trigger the strobe and freezes the video image through an embedded frame grabber. On the way to the next stop, the grabbed image is analyzed and then discarded before a new image is grabbed. After the whole slide (around 1000 images) is scanned, the computer summarizes the results from the individual images. This setup makes the entire measurement procedure automatic and fast.

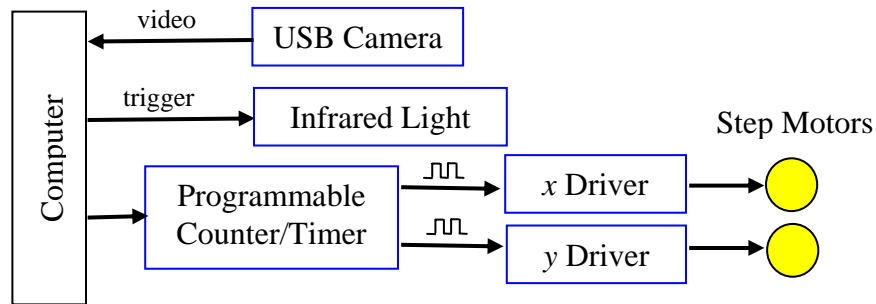


Figure 2 Flow chart of the imaging system components

Pneumatic Fiber Cutter and Spreader

A pneumatic fiber cutter/spreader was designed to expedite the sample preparation for the tests with the FIAS (Figure 3). The device uses pneumatic forces to drive five equally-spaced blades to cut a fiber bundle into 0.5mm long snippets, and to blow the snippets into a chamber so that they can be collected onto a slide. Snippets cut by the multiple blades represent different segments along the fiber axes to reflect the within-fiber variability of fiber width, which is critical for estimating maturity.

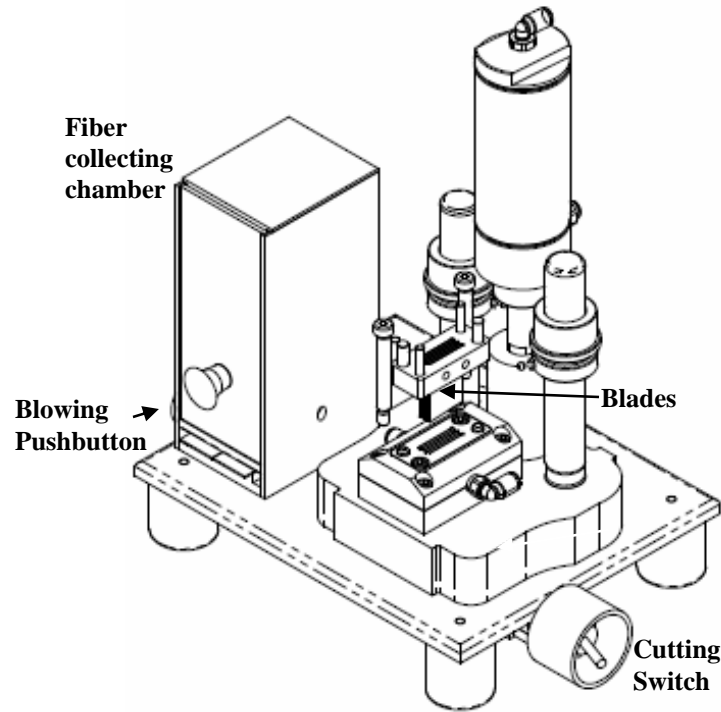


Figure 3. Fiber cutter and spreader

Image Processing Algorithms

This section summarizes the image-processing algorithms specifically designed for the longitudinal analysis of cotton fibers. Unlike the fiber scanning algorithms we developed in the past, the new algorithms are able to deal with unfocused, touching and crossing fibers. It is implemented in such a way that images are analyzed while the system is still scanning the slide. Therefore, our image processing algorithms are both efficient and nearly real-time.

Immature fibers have thinner secondary cell walls, and are more translucent than mature fibers (Figure 4a). Under the microscope with backlighting, it leads to apparent gaps of various sizes within the fibers in the captured images. After thresholding, the bright portions within the immature fibers may become holes (white pixels) in the binary image (Figure 4b). In order to separate holes within a fiber (corresponding to very thin cell wall) from the background (gaps between fibers), the grayscale information from the background in the original image must be utilized. As shown in Figure 4a, the grayscale intensities within immature fibers are different from the background. After the holes are detected, they are filled with black pixels to make fibers solid. Fibers are then thinned to obtain the medial axis, along which the fibers are

transversely scanned with a given step to measure the widths of the fiber ribbons. Figure 4c shows the scanning over an immature fiber. The detection of these regions with high transparency is particularly useful for identifying dead cotton fibers. The entire data extraction procedure involves many steps of image processing, some of which has been reported in the previous publications. The new algorithm developed will be detailed in a refereed publication.

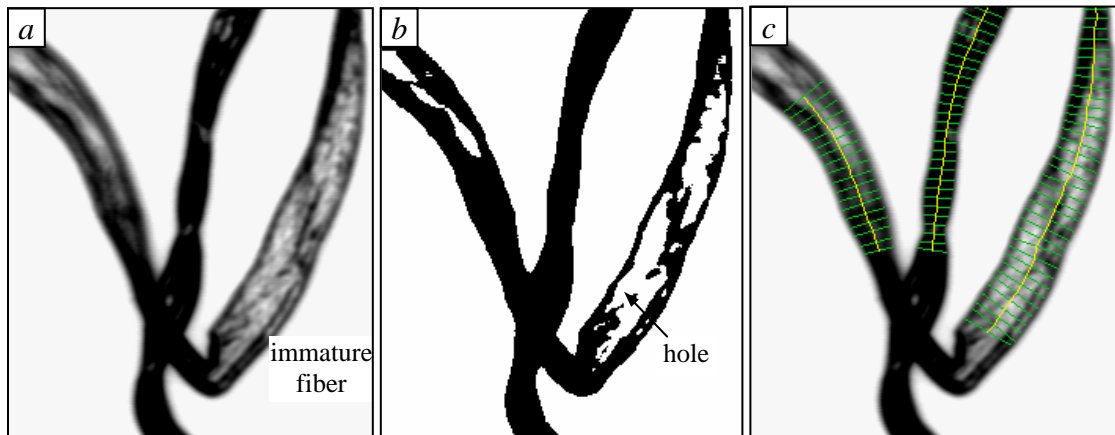


Figure 4 Transverse Scanning Over Immature Fibers

Denoising

It is almost unavoidable to have noise—unwanted objects in the binary image after thresholding (Figure 5a). Most of the noise objects are isolated small regions, which can be readily separated from the fibers (Figure 5b). Figure 5c shows the fiber image after noise removal.

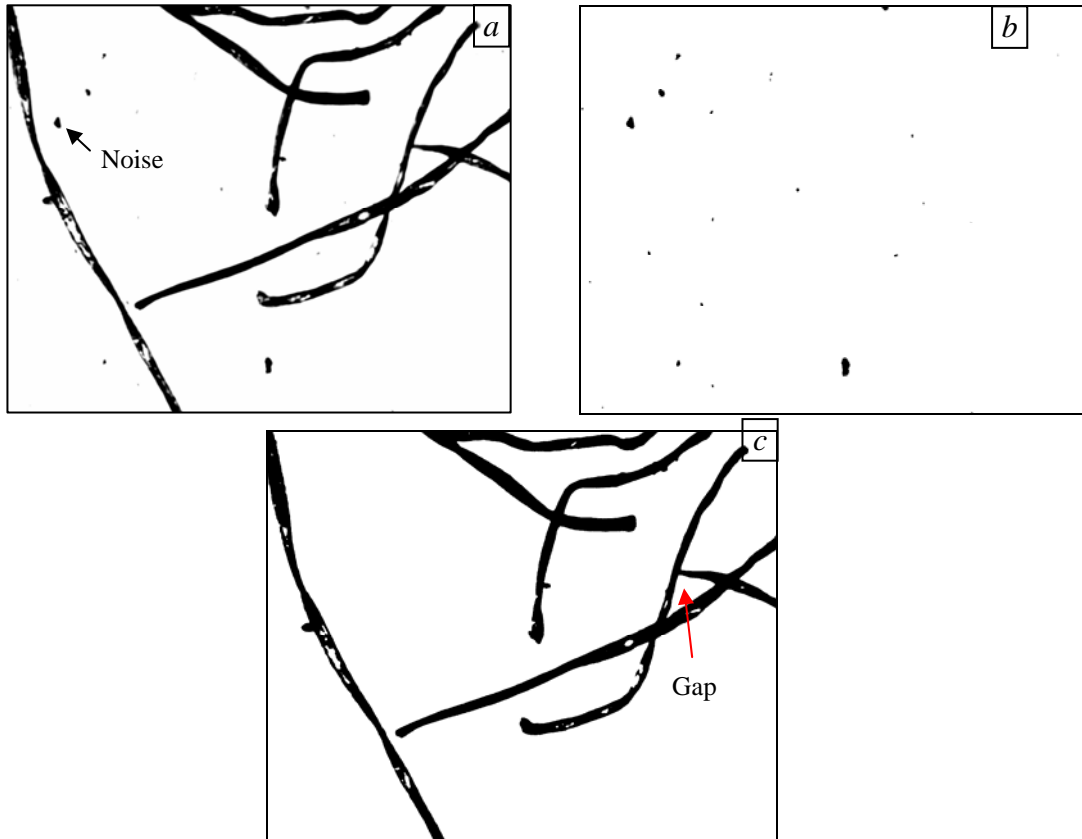


Figure 5 Noise removal, *a*: original binary image; *b*: noise objects; *c*: cleaned image.

Filling Voids

Immature fibers have thinner cell walls, and often appear as twisted flat ribbons. When flat ribbons face the light source, they become highly transparent, causing voids of various sizes along the fiber axes in the captured image. The void sizes depend mainly on the thickness of the cell walls and the twist spans. Generally, the voids in binary images are defined as a set of '1' value pixels which are surrounded by '0' value pixels (or vice versa). The presence of voids within the fibers makes difficult subsequent processing, because the voids, which are actually parts of the fibers, could be simply classified as background. Hence, a filling procedure to remove the voids is needed.

In addition to voids that exist within individual fibers, gaps can be formed between fibers when they intercept each other. As shown in Figure 5c, the region pointed by an arrow is a gap formed by three crossing fibers. Obviously, only the voids within single objects need to be

filled. By using the fiber cutter/spreader, we could adjust the density of the fiber snippets on the microscope slide minimizing the occurrence of gaps between fibers.

Thinning

Thinning (or skeletonization) means reducing binary objects to single-pixel medial axis. Numerous algorithms have been developed to implement this operation. The Hilditch thinning algorithm[12] is a widely used method, and was adopted in our application for fiber thinning.

Pruning

Thinning often produces short extraneous spurs due to the noise on the edges of the fibers. Pruning is the process of removing these spurs without damaging the main skeletons (Figure 6).



Figure 6 Skeleton pruning

Measurements

The processed image is then analyzed to extract significant features (length, width, voids area, average line density, number of fibers, etc..).

Length L : The total length of fibers in an image can be calculated based on the skeleton of the fibers.

Width w_i : The width of fibers. Taking all the skeleton points into account, we can calculate the maximum, minimum, mean, standard deviation, and the distribution of the fiber width (Figure 7).

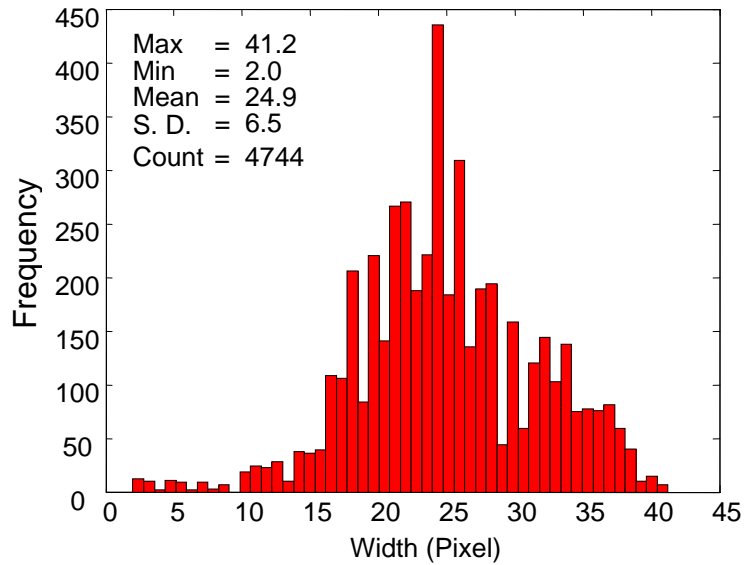


Figure 7. Fiber width distribution

Count C : The number of the fiber segments in an image can be estimated using the number of the endpoints. Normally, C is equal to half of the number of endpoints.

Fiber area F_a and void area V_a : F_a and V_a are calculated using the total numbers of the pixels in the image after and before filling the voids, respectively.

Maturity Quantification

A set of the parameters that can be used to quantify fiber maturity are derived from the basic measurements of fiber features.

Bright = the brightness of the fibers = G_{mean} / the grey scale of entire image

Fine = Fiber Fineness = $D_{\text{mean}} \exp(-0.1G_{\text{mean}})$

D_{mean} = the mean fiber width or diameter of the scanned segments

D_{cv} = diameter coefficient of variation

G_{mean} = the mean grey scale of the scanned segments

G_{cv} = grey scale coefficient of variation

DS = Dead Scan ratio = immature or dead fiber scans / total scans

DA = Dead Scan Area Ratio = Area of immature fiber / Total fiber area

Material and methods

We selected 102 cotton bales representing the two principal cultivated species (*Gossypium hirsutum* and *Gossypium barbadense*, C. W. Smith and J. T. Cothren, 1999 [13]). The vast majority of the bales originated in the U.S.A., but some foreign-grown cotton bales were also selected (Egypt, Uzbekistan, Pakistan, Cameroon, Syria, Benin, and Australia). The bales were opened and ten samples per bale were taken. Each sample was tested using a HVI Uster 900A. For each bale a total of 40 micronaire tests and 100 length and tenacity tests were done. This allowed us to conclude that the intra-bale variability was acceptable and that we had a wide range of micronaire, length, and tenacity.

A representative sample of approximately 30 kg (70 pounds) was taken from each bale. Each sample was homogenized according to the protocol used by the ICCSC (International Cotton Calibration Standard Committee, 1999 [14]) to produce reference cottons. As shown in Hequet et al (2006 [15]) this population of bales constitutes a good base for the calibration of the indirect measurement instruments for maturity and fineness. From the card web produced, 20 samples were taken and then sub-samples were delicately mixed manually. From this new sample 10 fibrograph combs were formed. We chose to sample with the fibrosampler because this method, unlike Lord's method, is not length biased (Chu and Riley, 1997 [16]). Each fibrograph sample was cut into snippets using the device described above and the fibers were spread onto a microscope glass slide. The 20 samples were also tested on the HVI Uster 900 A with 4 micronaire, 10 length and strength, and 4 color determinations. In addition, the samples were tested on the fibronaire (4 replications per sample) and on the AFIS (5 replications of 3,000 fibers).

Results and discussion

Forward stepwise multiple regression analysis was used to evaluate the potential of longitudinal cotton fiber measurements to evaluate cotton fiber maturity. In a first step, the eight features extracted from the new measurement system were used as predictors. In a second step the eight features combined with the micronaire (measured with the fibronaire instrument) were used. Table 1 summarizes the results obtained. For all dependent variables the prediction is far superior when the micronaire is added to the independent variables. All maturity related

measurements obtained from image analysis or from the AFIS can be predicted with an R^2 around 80%. This result is very encouraging knowing the large within sample variability of maturity measurements.

Fiber maturity is defined as the degree of cell wall thickening relative to the diameter of the fiber. A measure of fiber maturity that is independent of fiber perimeter is theta. Theta is the ratio of the cross-sectional area of fiber wall to the area of a circle having the same perimeter. After boll opening, fibers dry out and collapse, and the degree of collapse from the original circular shape depends on the thickness of the cell wall (Bradow et al., 1997 [17]). Figure 8 shows the relationship between the measured Theta (circularity of fiber cross-section) obtained from the analysis of cotton fibers cross-sections and the predicted theta.

Dependent Cross-section variable	Ind. Longitudinal variables 1	Ind. Longitudinal variables 2	Adj. $R^2$1	Adj. $R^2$2
IA Cell wall area	8 features	8 features + micronaire	57.4%	78.3%
IA Theta	8 features	8 features + micronaire	72.5%	82.5%
IA Wall thickness	8 features	8 features + micronaire	63.8%	84.8%
AFIS Mat. Rat.	8 features	8 features + micronaire	67.0%	79.8%
AFIS fineness	8 features	8 features + micronaire	64.8%	88.0%

Table 1. Forward stepwise multiple regression analysis summary.

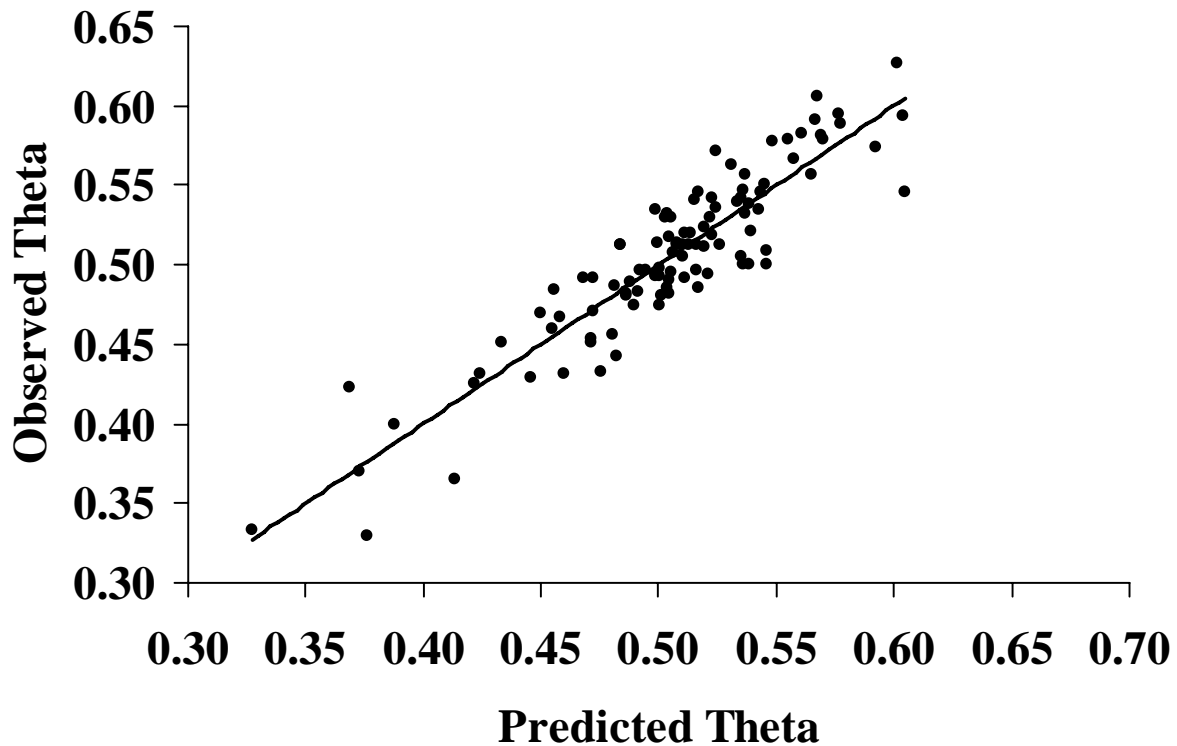


Figure 8. Predicted Theta vs. Observed Theta

Conclusions

This paper summarized the technical development of a customized microscopic imaging system for direct, fast and high-volume measurements of cotton maturity from longitudinal views. Experiment results obtained on 102 commercial cotton bales selected worldwide (to represent a wide range of cotton maturity) demonstrate that this new measurement system has a great potential because of its high efficiency in sample preparation and data processing compared to cotton fibers cross-sections. The prediction of fiber maturity using several features extracted from the digitized images in combination with the micronaire is excellent. This method is a good candidate for routing testing, for breeding programs for example.

Acknowledgement

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