IMPROVEMENT OF A HARVESTER BASED, MULTISPECTRAL, SEED COTTON FIBER QUALITY SENSOR

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Abstract

A multispectral sensor for in-situ seed cotton fiber quality measurement was developed and tested at Texas A&M University. Results of initial testing of the sensor using machine harvested seed cotton have shown promise. Improvements have been made to the system and the measurement method to meet the objectives of improving the accuracy and repeatability of micronaire values from the sensor when compared to the quality measured by standard AFIS and HVI machines. The sensor will take five images of a sample of seed cotton - two images in wavebands sensitive to harvester trash and three images in wavebands sensitive to micronaire. Using the two images sensitive to trash, pixels that represent trash in the image will be identified and excluded from further processing. Using the remaining pixels as a map of cotton lint, the images sensitive to micronaire will be processed and the micronaire value compared to standard measurements. As of the writing of this paper, improvements have been made to the system, but testing is not yet completed.

Introduction

The profitability of harvesting cotton is dependent upon two main factors. The most important factor, total yield, accounts for 80% of the expected revenue. The second factor, quality, makes up the remaining 20%. Yield monitors have been tested and proven using optical cotton flow sensors (Sui et al. 2003). These sensors can provide real-time information about the instantaneous flow of cotton and, when GPS coordinates are added can provide a high resolution yield map of the cotton field. This yield map can be used to adjust field management practices to help increase total yield throughout the cotton field, but it contains no information about the quality of cotton that has been picked. If a quality map of the field was also available, adjustments in field management could help each field produce not only as much cotton as possible, but also the best quality cotton possible.

A quality map, when used along with a yield map, price schedule, and cost map, can ultimately provide farmers with a profit map. Determining the quality of seed cotton during the harvest can also provide farmers, ginners, and the market with more information about each module before the module ever leaves the farm. In order to measure the quality of seed cotton before it has been ginned and cleaned, it is necessary to remove the effects that the field trash has on the measurement technique used.

Literature Review

Sjolander et al. (2008) adapted a cotton yield monitor to wirelessly and automatically track the location in the field from which the cotton in each module was picked. This system allowed multiple harvesters and boll buggies to communicate with a module builder while minimizing interaction from the operator. This system opened the door for the first steps of quality mapping, but the average quality of the module was assigned to every cotton row that went into the module. This process results in a very low resolution quality map and is open to large amounts of error when comparing the measured quality of any specific point in the field to the value of the module that it went into. Since a field quality map of finer resolution is desired, quality must be determined using samples smaller than an entire module.

Faulkner et al. (2008) reported on the variation of harvesting methods on the quality of cotton fiber. This research showed that cotton harvested with a picker tended to have a higher micronaire value than the same cotton harvested with a stripper. This research indicates that variations in harvesting techniques will cause a variation in quality. One method for creating a field quality map is to hand harvest cotton at specific points in the field and record the quality. However, since the harvesting method has an effect on the final quality of the cotton lint, there would be an undetermined error between the measured quality of the field and the measured quality of the module. To reduce this error, a sampling method that uses the same harvesting method is needed.

Thomasson and Shearer (1995) found a relationship between NIR reflectance and certain cotton quality characteristics in lint cotton. Their models resulted in the following R^2 values – 0.88 for reflectance, 0.85 for yellowness, 0.60 for trash content, 0.96 for micronaire, 0.73 for strength, 0.79 for length, and 0.67 for length uniformity. Following these findings, Sui et al. (2008) showed that a good method for rapidly determining the fiber quality of lint cotton is to use Near-Infrared (NIR) light. Using lint cotton calibration standards at different micronaire, the quality of lint cotton showed a very good relationship (R^2=0.99) to the reflectance of NIR light in a three waveband system by the cotton fiber. This method was strictly used on lint cotton and will have to be adapted in order for it to be able to determine the quality of machine harvested seed cotton. Unlike the lint cotton standards used, machine harvested seed cotton contains large amounts of field trash and cotton seeds.

Thomasson and Taylor (1995) looked into the relationship between lint cotton and seed cotton color. They found that seed cotton color had a moderate correlation (R^2=0.6) to lint cotton color. They wrote that with a better method to predict color, certain steps could be skipped during the ginning and cleaning processes. A shortened procedure would help improve the efficiency of the production of cotton in a useable state.

Schielack et al. (2009) began development of a method to remove the effects of seeds and trash particles from a digital image of a cotton sample presented to an image sensor. By identifying pixels that have lower reflectance values and removing them from further calculations, a moderate relationship (R^2=0.56) between NIR reflectance and micronaire was reported, while the same samples as lint cotton also showed a moderate relationship (R^2=0.61).

In order to take images of the cotton on the harvester and insure that recently picked cotton is being sampled, an automated sampling system that traps cotton from the harvesting duct between the spindle head and the basket must be used. Sassenrath et al. (2005) developed a hand operated device to take samples from a harvester duct and store them separately from the harvest to determine spatial variability of quality in the field. Sassenrath et al. (2006) automated this process, thereby increasing the sampling rate. We would like to find a way to take this type of sample, determine the quality immediately, and release it back into the flow of cotton after recording GPS coordinates.

Objectives

A prototype system was built in 2008 at Texas A&M University (Schielack et al. 2009) to remove the effects of field trash and measure the micronaire values of seed cotton samples. The results of this system showed a 0.56 R^2 relationship between the micronaire value calculated and the actual measured micronaire value of the samples. The system was also used to qualify the same samples as lint cotton, resulting in a 0.61 R^2 relationship. Since it is unreasonable to expect the system to be able to more accurately measure the micronaire value of seed cotton than lint cotton, the method of removing the effects of trash appears to work well. We would like to improve the accuracy of the system's micronaire measurement of both lint cotton and seed cotton by making improvements to the materials used to collect data.

First, to make the measurement as accurate as possible, each pixel must represent a small area of the sample. As the area represented by a single pixel becomes smaller, the resolution of the measurement of reflection increases. This also means the image should be much sharper. Next, the lighting must be as uniform as possible. To be able to compare the reflectance of one pixel to another, the two pixels must contain similar information. The only variable of interest is the reflectance of the cotton lint. Since reflectance will vary with the amount of light available to reflect, the amount of light available over the sample must be as equal as possible everywhere. To this same end, the attenuation of the light will vary through each optical obstruction between the light source and the sensor. Optics must be designed to equalize the energy available at the sensor in each waveband observed. Finally, we are looking for a more direct way of identifying trash in the image.

Materials and Methods

Using the results and analyzing the images from Schielack et al. (2009) we can see that in raw form much of the image is removed during processing because it does not represent the sample (Figure 1). There are also two large "hot spots" from the halogen lamps used. Once the images are reduced to a useable size, each image indicates that one side has more light available than the other, causing a negative effect on the accuracy of the measurement. While recreating the procedure, it was noted that trash within the sample which was visible to the eye was not identifiable through the camera.

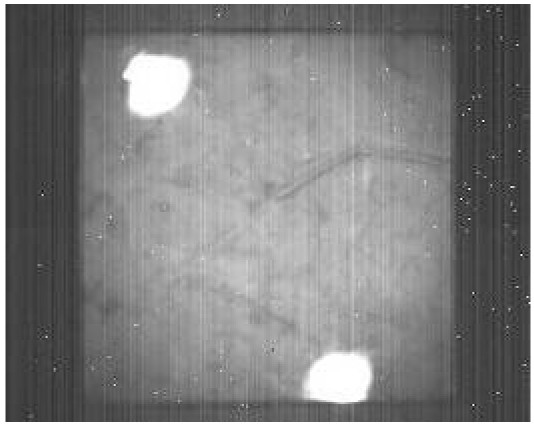

Figure 1: Raw Image of cotton sample (Schielack et al. 2009)

Pixel Area

In order to maximize the resolution of the images of the samples, the area represented by each pixel in the image must be minimized. Two ways to accomplish this are (1) to reduce the distance between the camera lens and the sample while keeping the lens angle the same, and (2) to use a lens with a narrower angle at the same distance from the sample.

In order to reduce the distance between the camera lens and the sample, the sample was raised 1 inch at a time using solid wooden blocks placed underneath it until the sample filled the entire area of the image. This change in design increased the resolution of the image and almost entirely removed the glare from the lights against the glass. While the increased resolution brought out the voids and lines between the cotton bolls, much of the trash stayed invisible to the camera. The distance between the camera and the sample had to be reduced so much that the angle of the lights was greatly increased also. The increased angle of the lights reduced uniformity of illumination even more and was considered a negative effect of the change.

With the original distance from sample to sensor, a lens with a narrow angle was attached to the camera to replace the one that had been used. While this change greatly increased area of the image that represented a cotton sample, there were still pixels on the outer edges of the image that were useless, as they represented other parts of the sampler itself instead of the cotton sample. This change increased the resolution of the image of the cotton sample, and once again, while the voids between the compressed cotton bolls were easier to identify, the trash stayed nearly invisible to the NIR camera. The lights were able to stay at nearly vertical angles, which did not affect the distribution of illumination of the sample.

Illumination Uniformity

To improve the distribution of illumination of the cotton sample that is presented to the system, an improved light source was found. The lamps originally used had reflectors that allowed NIR and IR light to exit the rear of the lamp without being reflected. This undesired property was corrected by using QTH lamps with aluminized reflectors. These reflectors reflect all light, and while they are advertised to reduce IR light (and thus heat) to the lamp base, we are using them to increase NIR and IR light to our sample. These lamps also have a reflector pattern that helps diffuse light off of the reflector to distribute the light evenly onto its target. The new lamps also use an axial filament which is centered on the axis of the parabolic reflector.

The illumination from the new lamps (Figure 2) compared to the illumination from the old lamps (Figure 3) shows a much more even distribution. There are no distinct "hot spots" from the new lamps. These figures show each style of lamp reflecting against a solid white sample tile. Between the images, only the lamps were changed in the bases. The images in the figures are both adjusted to show a 1,000 unit band of reflection values.

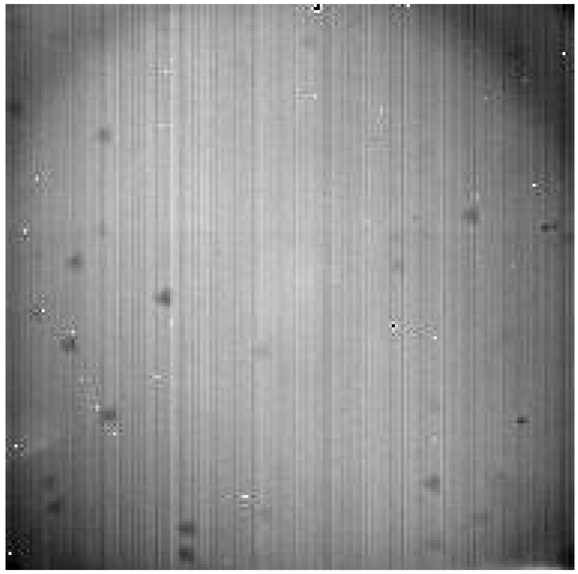

Figure 2: New 50W QTH Lamps with aluminized reflector and axial filament through 1450nm x 12nm bandpass filter

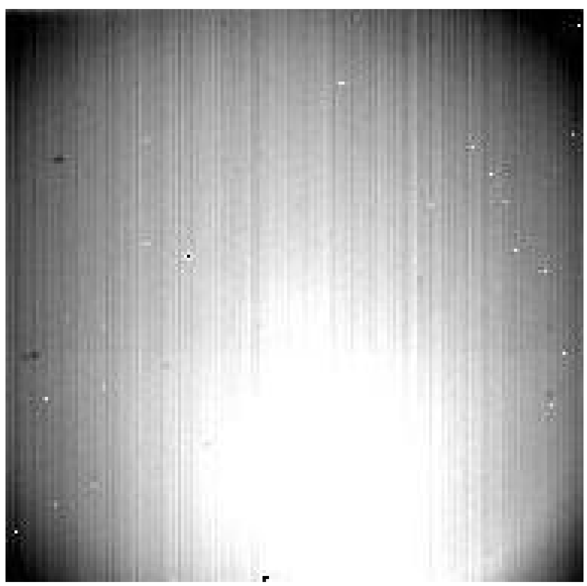

Figure 3: Old 20W QTH Lamps with IR backspill through 1450nm x 12nm bandpass filter

Energy Balance

To minimize the need for changes in camera settings, the energy through each combination of optical components that reaches the sensor must be equalized. This goal is accomplished by calculating the attenuation effect of each optical component in the system. Since the lamps do not provide a uniform illumination over the entire range of wavebands (Figure 4), the first component to look at is the lamps themselves.

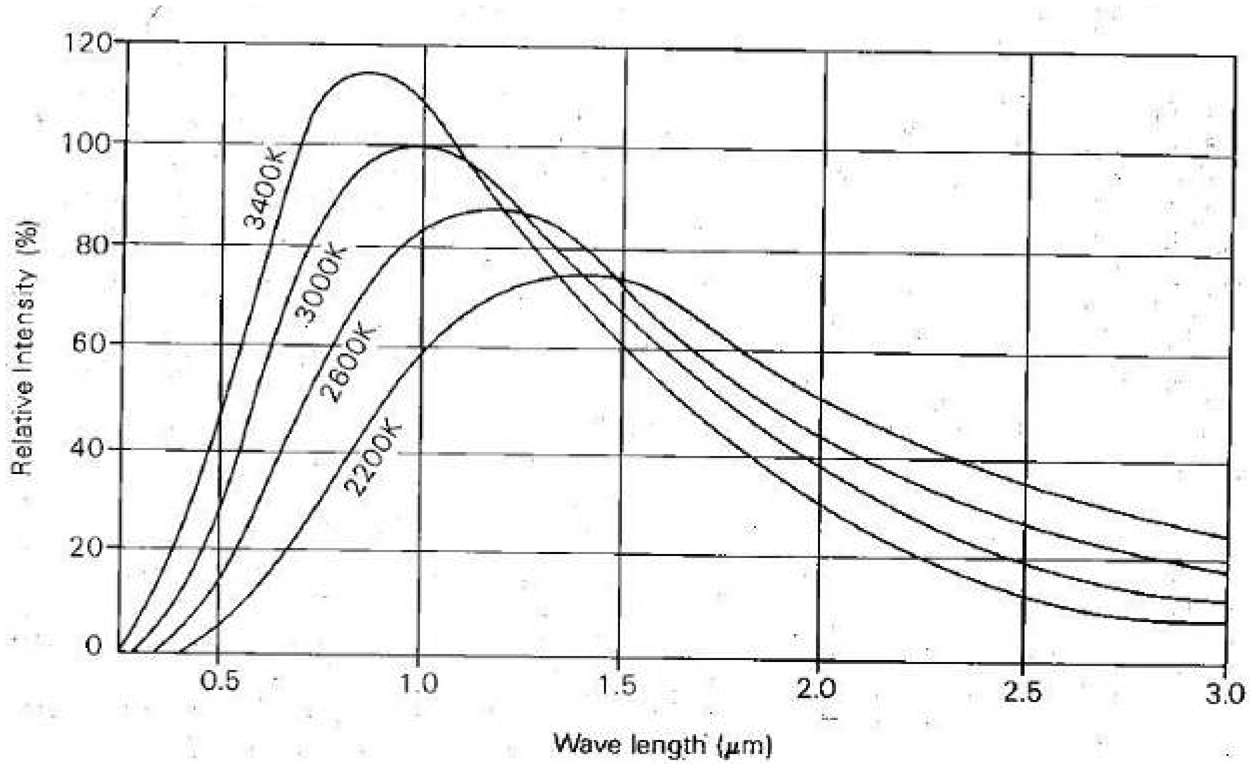

Figure 4: Relative Intensity of QTH Lamp
(S. Burton – USHIO, personal communication. 2 November 2009)

From the lamps (temperature of 3000K), the light must travel through the borofloat glass (91% transmittance) and then be reflected by the cotton (Figure 5 & 6). Once reflected by the cotton, the light travels back through the glass (91% transmittance) and through 1 of 4 selected filters (Figure 7). After the filter, the light passes through the camera lens (92% transmittance), and arrives at the sensor (Figure 8). The VisGaAs sensor also is not uniformly sensitive across the range of wavebands that we are interested in so sensor sensitivity is an attenuation factor here as well (Figure 9).

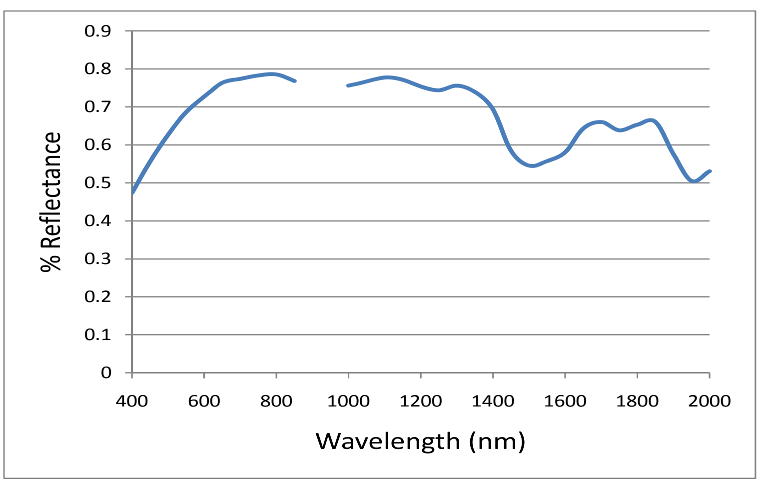

Figure 5: Average % Reflectance of Cotton Lint

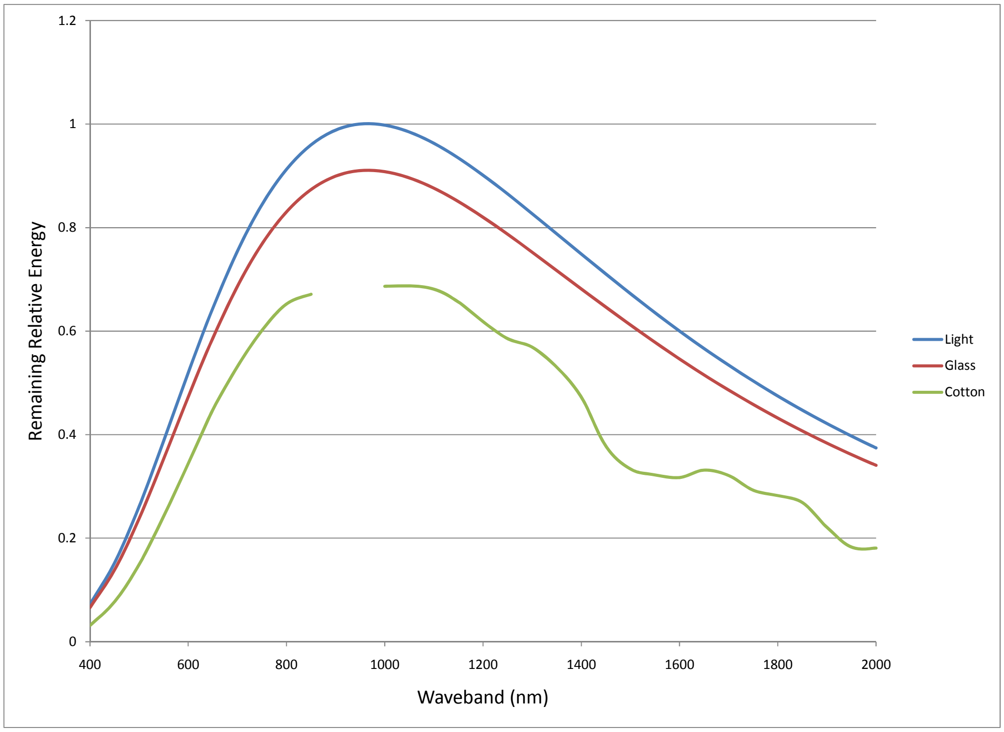

Figure 6: Relative Energy after attenuation up to the cotton surface

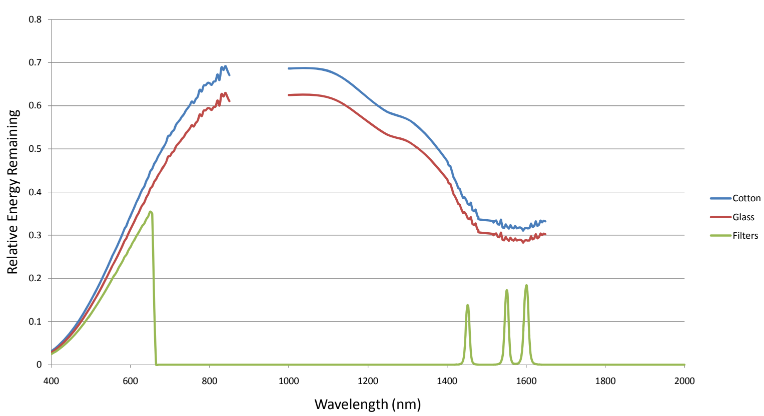

Figure 7: Relative Energy remaining after attenuation up to the optical filters

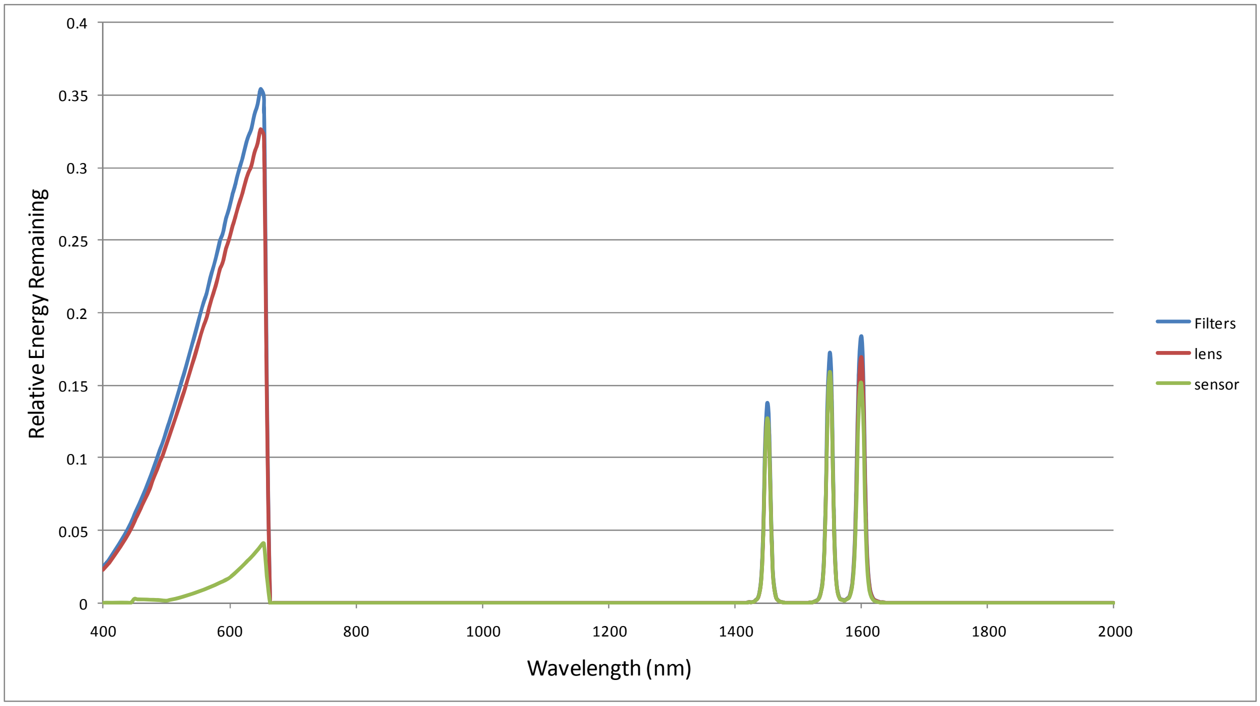

Figure 8: Relative Energy Remaining at the sensor

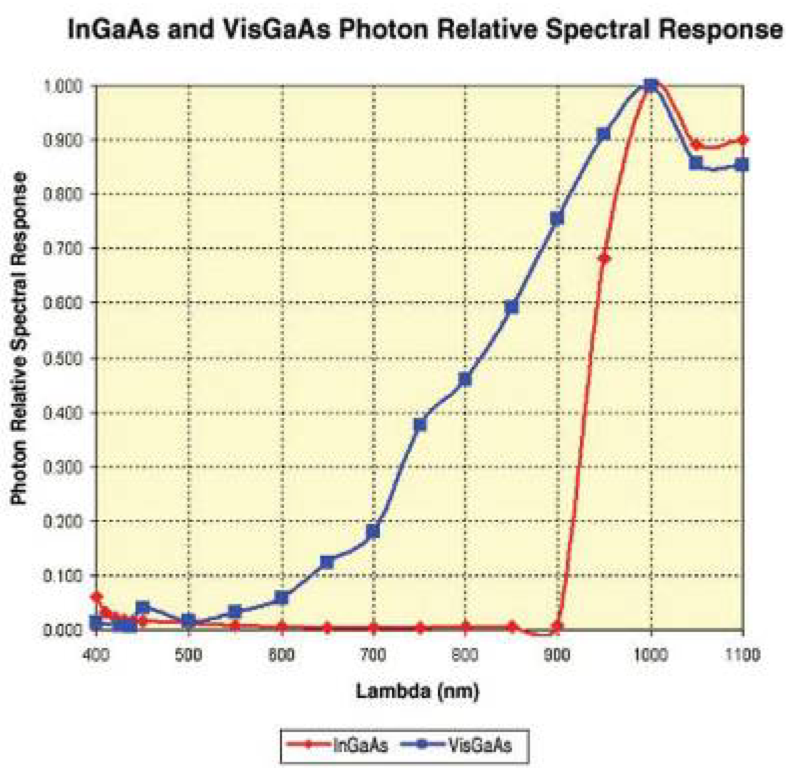

Figure 9: VisGaAs Spectral Response Variation (Walker 2004)

Once the attenuation of each optical component has been factored in, the area under each curve indicates the relative energy at the sensor from that combination of optics (Table 1). Since energy cannot be added to combinations that transmit lower amounts of energy, extra energy must be taken out of the combinations that allow more energy to pass. We would like to do this by incorporating neutral density filters in with the bandpass filters. Since the bandpass filter is the only optical component that changes from combination to combination, and each bandpass filter will require a different neutral density filter, this change of neutral density filters is simplified, and requires no additional equipment.

Table 1: Relative Energy Available at the sensor through four different optical combinations

	Optical Filter Combination			
Filter	750	1450	1550	1600
Energy Sum	2.693	1.565	2.004	2.217
Relative Energy Available	1.72	1.00	1.28	1.42

Trash Identification

The histogram method used by Schielack et al. (2009) and by Sui et al. (2008) automatically identifies, as trash, anything that does not fit within an expected band. With a true normal distribution within the sample, this method works by removing equal amounts of both high and low reflectance cotton. Once pixels are removed, the reflectance is measured in three predetermined wavebands that are sensitive to the micronaire value of the cotton. It is possible that cotton trash can be identified in a similar manner. If two wavebands within the range of the VisGaAs sensor are identified as sensitive to the trash and debris found in a sample of seed cotton, images can be compared to find the pixels that represent trash. Pixels that represent the extreme high and low reflectance values of the cotton sample can then remain in the calculations for the sample.

Results and Discussion

In an attempt to improve the ability of this system to measure the micronaire value of seed cotton samples using NIR reflectance, we have found a few combinations of changes that will be tested using seed cotton samples. To improve the resolution of the images themselves, a camera lens with a narrower angle will be used in combination with a slightly shorter distance from camera to sample. This configuration will minimize the area of the cotton sample that each pixel represents with the equipment available today. The QTH lamps with aluminized reflectors and axial filaments will be used to get as uniform a lighting distribution as possible. Further testing can include measurements of the reflectance of a white surface to find a flat field correction to adjust for any small variations in illumination around the edges of the image.

The energy balance shows that the 1450nm combination allows the least amount of energy to the sensor (Table 1). The 1550nm combination allows 28% more energy through, the 1600nm combination provides 41% more energy, and the 750 low pass filter used for trash identification allows 72% more energy to the sensor. These filters will be fitted with a corresponding neutral density filter to attenuate extra energy and bring them down to the energy level of the 1450nm combination. By reducing the energy to the sensor in each optical combination, we risk a reduction in our signal-to-noise ratio. In order to improve the ratio and get as much energy to the sensor as possible, the two 20W QTH lamps will be replaced with two 50W QTH lamps. This change alone will increase the energy available to each combination by 133%.

Summary

With improvements in the resolution of the cotton images and lighting distribution, the accuracy of the measurement of micronaire by the system is expected to increase. Lint cotton calibration standards showed a 0.99 R^2 relationship with their micronaire value. We hope that, with these improvements, this system will approach the 0.9 R^2 range measuring the micronaire of seed cotton.

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