CONTINUED WORK TO DEVELOP A LOW-COST SENSOR TO DETECT PLASTIC CONTAMINATION IN SEED COTTON AT THE GIN

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Abstract

Contamination of cotton from plastic trash that collects in cotton fields or introduced at the gin or due to mishandling at the warehouse is one of the most significant threats to US cotton world market share. For US cotton to maintain its status as "contamination-free", the industry must strive to prevent contaminants from entering the cotton stream and to eliminate them when they do slip in. The main objective of this research was to develop an inexpensive and reliable technology to detect cotton contamination at the cotton gin. First, hyperspectral scans of typical cotton contaminants were taken using a spectrophotometer that allowed for scans of contaminants with a seed cotton background. The contaminant samples included conventional module tarps, bale bagging, yellow round module wrap, hay baling twine and netting, plastic mulch, shopping bags, bale strapping, baggies, burlap, grease, and oil. Using spectral bands from the scans that showed distinct differences between cotton and contaminants, statistical analyses correctly classified all of the cotton and contaminant samples as Cotton or Not. Hyperspectral imaging was then conducted using two systems that measured the ultraviolet fluorescence and the visible, near infrared, and short-wave infrared reflectance of the contaminants. Analyses of the images indicated that visible reflectance might be effective in detecting colored plastics in seed cotton. However, detecting contaminants that are white or opaque will likely require using reflectance measured at longer wavelengths. In addition, there were dramatic differences in ultraviolet fluorescence between oil and grease, and seed cotton. These results will lead to design, construction, and testing of a prototype sensor that utilizes ultraviolet light and visible color to detect the contaminants in a bat of seed cotton.

Introduction

Contamination of cotton - from plastic trash that collects in cotton fields, black plastic film used as mulch, plastic twine for baling, and yellow plastic film used for round module wrap; and from oil, grease, and other man-made "trash" introduced during harvesting and ginning - is one of the most significant threats to US cotton world market share. These contaminants are typically introduced prior to ginning, but mechanical gin processes break up and shred them so they become more difficult to detect and remove. Mixed with cotton lint, contaminants slow spinning mill capacity, increase mill waste, and render finished yarns and garments unmarketable. In the past, US cotton has enjoyed its status as "contamination-free". Recently, some foreign mills have considered purchasing cotton from countries other than the US due to the perception that contamination levels in US cotton have risen. Lost markets tied to contamination are difficult to recapture and the textile industry has a long memory. The first line of defense against these contaminants should be in the field before the raw cotton can be introduced into the gin machinery. If contaminants enter the gin, they should be eliminated early in the process. However, current gin machinery does not effectively remove contamination from the cotton stream. For US cotton to maintain its status as "contamination-free" and continue relationships with foreign mills, the industry must strive to prevent contaminants from entering the cotton stream and to eliminate them when they do slip in.

The main objective of this research was to develop an inexpensive and reliable technology to detect cotton contamination at the cotton gin and separate the detected contamination from the cotton flow.

Prior work focused mainly on investigative and exploratory research and proof-of-concept testing of a technique to detect plastic contamination in the flow of cotton at the gin. Initially, experiments were conducted in collaboration with New Mexico State University to test the hypothesis that infrared (IR) reflectance could be used to distinguish contaminating materials from cotton. A bench-top test instrument was constructed and tested. A mathematical algorithm to distinguish contaminant samples from cotton (Cotton/Not cotton) was developed and tests showed that it achieved 100% correct classification with pure samples of cotton and contaminants. Additional testing was done to determine the minimum size of contaminant detectable with the instrument when the contaminant was placed against a cotton background. The minimum size ranged from about 4-mm^2 for black plastic mulch up to 20 mm^2 for bale strapping.

Based on the earlier work using the IR spectrum and previous testing in the near-infrared (NIR) spectrum, a prototype system utilizing short- and mid-wavelength IR LEDs and photodiodes to differentiate between cotton and plastics was constructed and tested. The instrument included:

1. Four high intensity LEDs with peak emissions at 1730, 2350, 2950, and 3400 nm;
2. Two photodiodes with maximum sensitivity ranges of 1100-2300 and 2200-3400 nm;
3. LED driver;
4. Photodiode synchronous detector;
5. Data acquisition module;
6. Power supply; and
7. Computer software.

Testing with seed cotton samples and several types of plastics showed detectable differences in reflectance from the LEDs. However, the signal intensity was low and very dependent on the distance between the sensor and samples as well as on sample characteristics (roughness, angle, and size). In addition, resolution (size of plastic piece detectable on a seed cotton background) was low.

Further investigation and discussions led to refocusing of the project to image based spectral reflectance/fluorescence in the ultraviolet (UV), visible, and IR regions. This paper reports on current efforts using hyperspectral-imaging techniques to overcome the issues previously encountered with the prototype LED sensor.

Materials and Methods

Spectrophotometer

Hyperspectral scans of the contaminants were taken using a Foss NIRSystems Model 6500 spectrophotometer with spinning sample module (Figure 1). This device allowed for hyperspectral scans of the contaminants with a seed cotton background, which was more like the cotton stream in the gin. The range of wavelengths measured were 400 to 2500 nm. Two scans per sample were taken. The contaminant samples included:

- new module tarp
- old module tarp blue
- clear bale bagging
- yellow woven PP bale bagging
- white woven PP bale bagging
- experimental green bale bagging
- round module wrap inner layer
- round module wrap middle layer
- round module wrap outer layer
- hay baling twine
- hay bale netting
- black plastic mulch
- clear shopping bag
- gray shopping bag
- white shopping bag
- brown shopping bag
- bale strapping dark
- bale strapping light
- clear sandwich bag
- burlap
- bearing grease
- hydraulic oil
- spindle grease

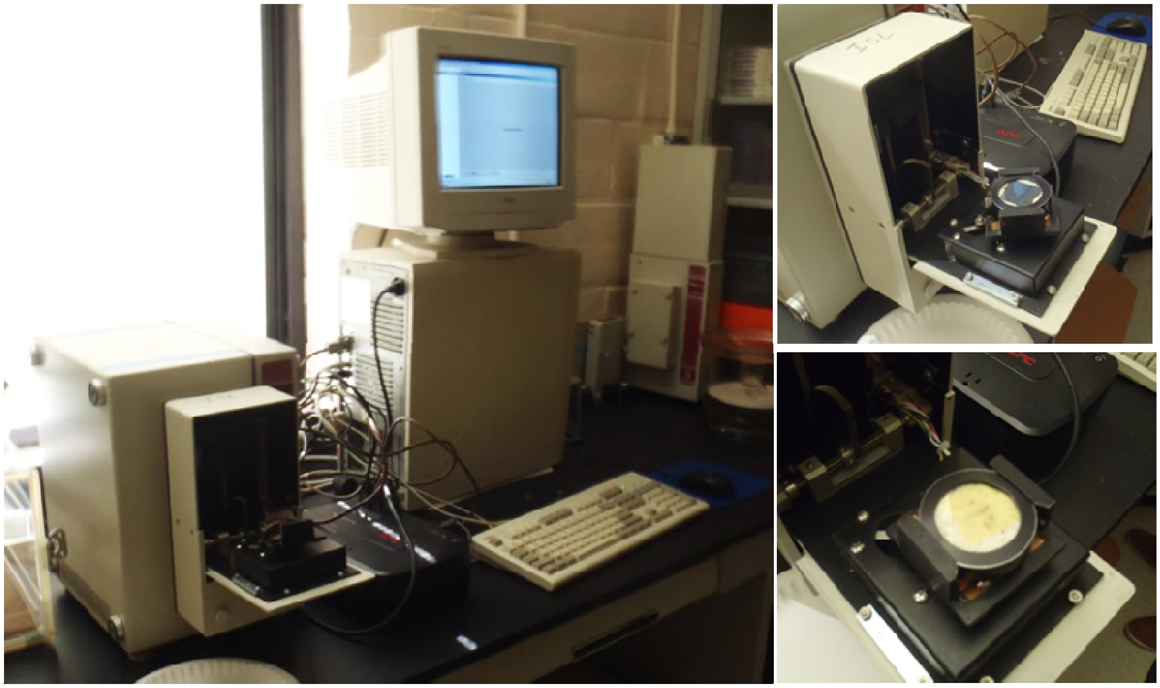

Figure 1. Foss NIRSystems near-infrared spectrophotometer with spinning sample module shown holding a contamination sample on a seed cotton background.

Hyperspectral Imaging

Hyperspectral imaging was conducted using two systems that measured the UV fluorescence, and the visible, near infrared (NIR), and short-wavelength infrared (SWIR) reflectance of the contaminants (Figure 2 and 3). Pieces of the contaminants, approximately 25.4-mm × 25.4-mm square, were placed on a seed cotton background on a black plate (Figure 4). The samples were scanned in both systems and hyperspectral images for UV fluorescence measured in the visible range (400 to 775 nm), visible/NIR (400 to 1000 nm) reflectance, and SWIR (930 to 1650 nm) reflectance were acquired. Unfortunately, the imaging systems were not capable of measurements above 1650 nm. Thus, measurements were not made in the longer IR wavelengths, where some of the distinct differences between seed cotton and contaminants were found with the spectrophotometer. Figure 5 shows images of the plate with samples for three different wavelengths illustrating UV fluorescence, visible reflectance, and SWIR reflectance.

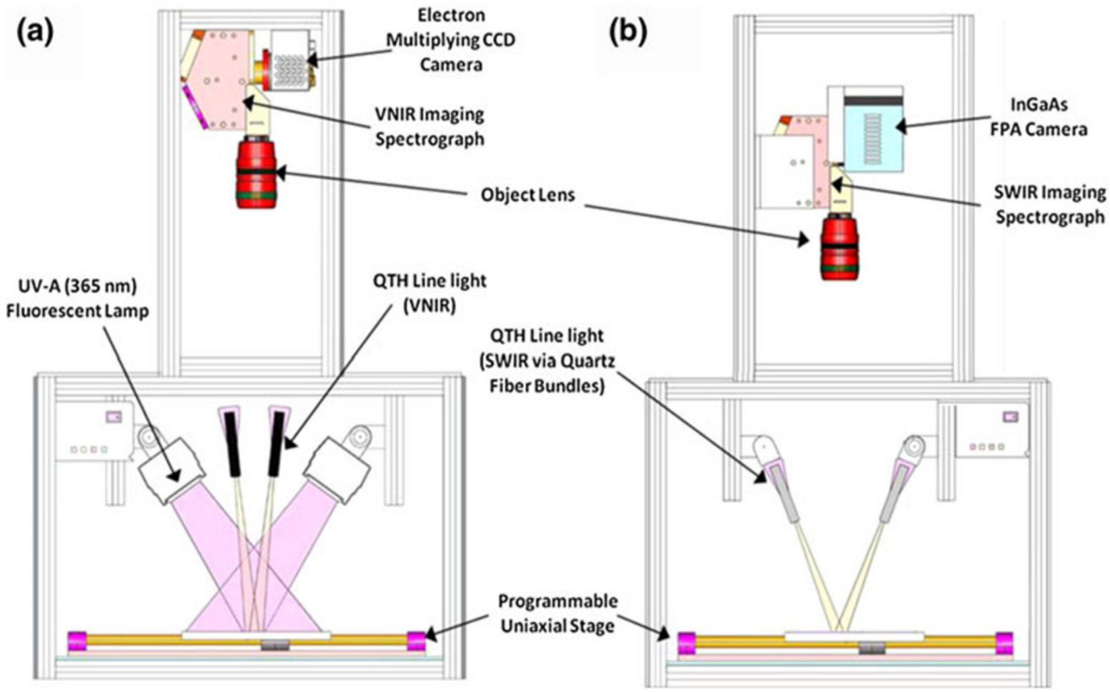

Figure 2. Two systems for hyperspectral imaging analysis: (a) ultraviolet fluorescence & visible/near-infrared reflectance and (b) short-wavelength infrared reflectance (Kim et al., 2012).

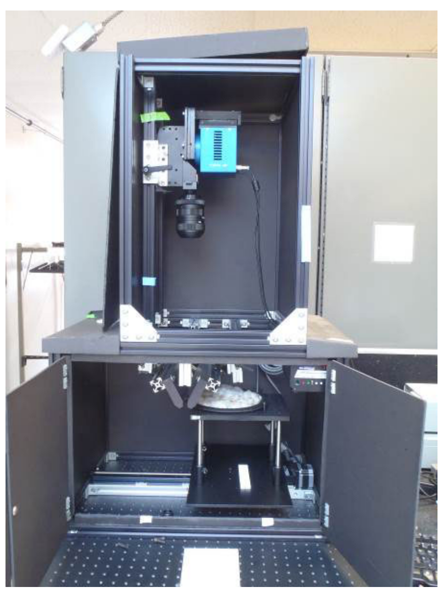

Figure 3. Short-wavelength infrared reflectance spectral imaging system.

Figure 4. Example of contamination samples on seed cotton background prepared for hyperspectral imaging.

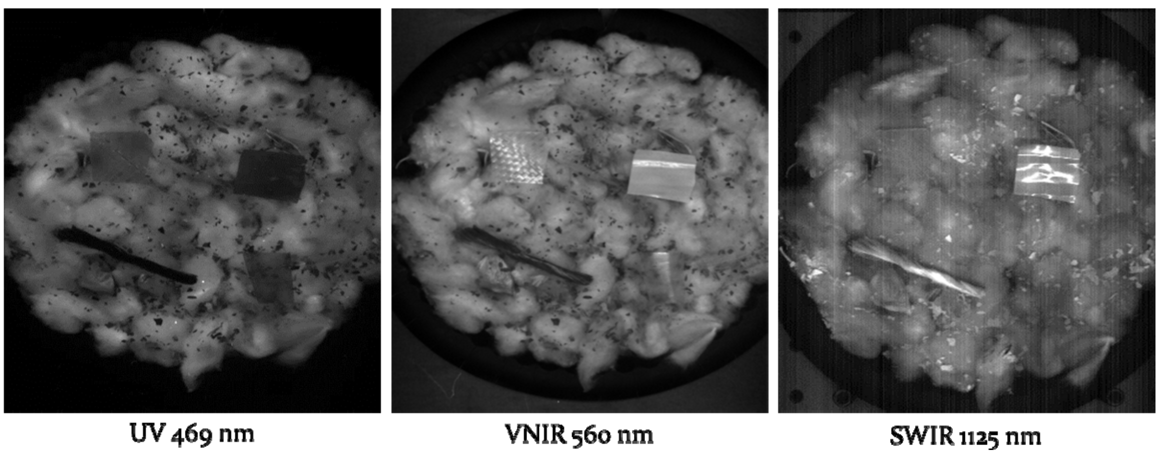

Figure 5. Images from hyperspectral imaging scans of contamination samples on seed cotton background showing ultraviolet fluorescence at 469 nm, visible reflectance at 560 nm, and short-wave infrared reflectance at 1125 nm.

Hyperspectral analysis software developed by scientists at the USDA-ARS Environmental Microbial & Food Safety Laboratory in Beltsville, Maryland was used to select four, 100-square-pixel regions within each contaminant image and obtain four replicate response spectra for each contaminant and type of measurement: UV fluorescence, visible/NIR reflectance, and SWIR reflectance (Figure 6).

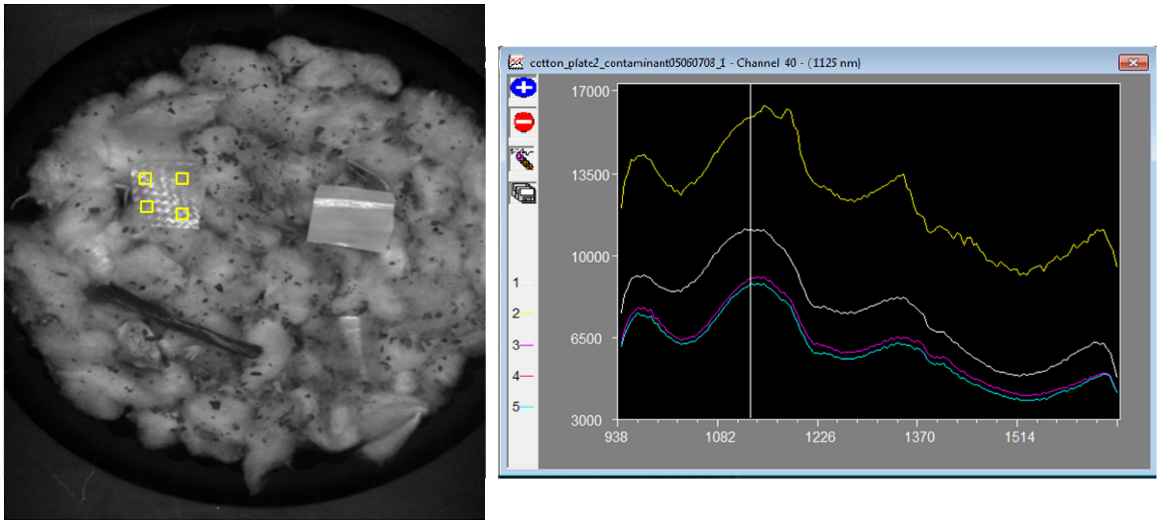

Figure 6. Hyperspectral image with four selected regions in the white bale bag sample and corresponding short-wavelength infrared spectra.

Results

Spectrophotometer

Differentiating the contamination from seed cotton with trash and seed present is a difficult problem. However, data from the spectrophotometer showed several spectral bands at wavelengths 674, 1210, 1730, and 2312 nm where there were distinct differences between cotton and contaminants (Figure 7). Nominal logistic regression analyses for each of these wavelengths to classify samples as either Cotton or not showed that none of wavelengths alone could be used to differentiate seed cotton, lint, or cotton trash from contaminants with 100% accuracy (Figure 8). For the short-wavelength infrared (SWIR) wavelengths (1210, 1730, and 2312 nm), some trash samples and some clear plastic bags were misclassified. All of the cotton samples (seed cotton, lint, and trash) were misclassified by logistic regression using only 674 nm data. However, when two of these wavelengths (674 and 1210) were used together in the logistic regression, all the cotton and contamination samples were classified correctly (Figure 9).

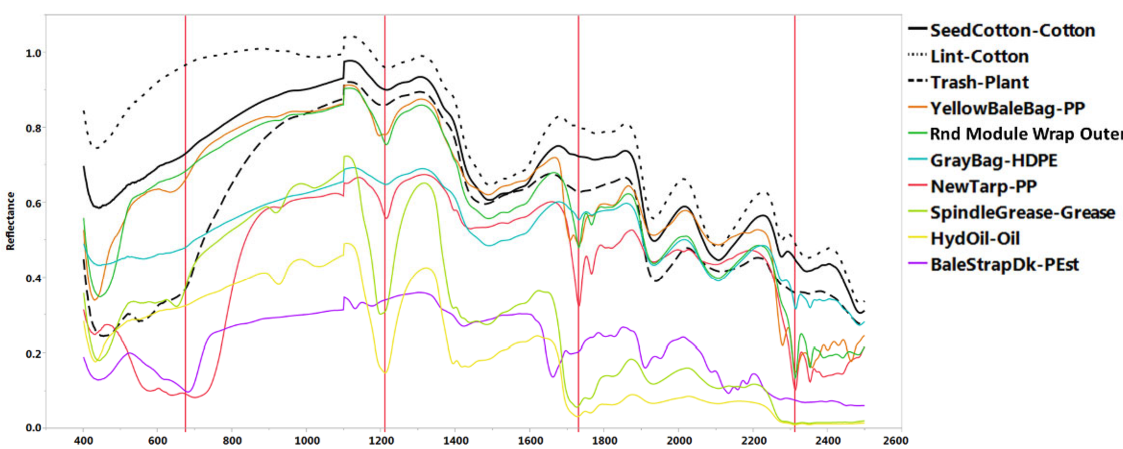

Figure 7. Spectrophotometer measured VIS/NIR/SWIR reflectance for cotton and selected contaminants. Vertical red lines show wavelengths where there were distinct differences between cotton and contaminants.

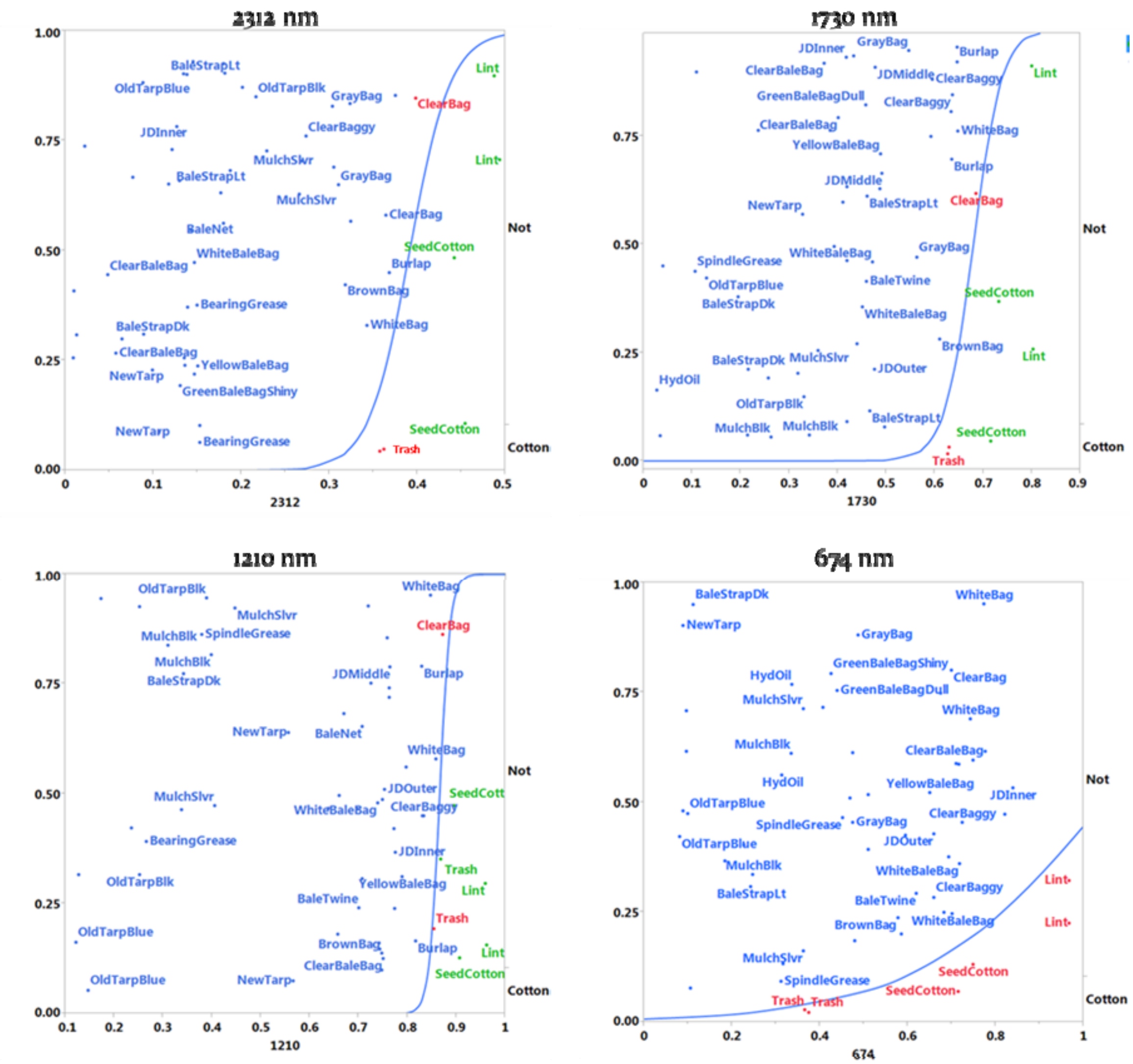

Figure 8. Logistic plots showing Cotton or Not classification results for 2312, 1730, 1210, and 674 nm reflectance data obtained with the spectrophotometer. Green text indicates correctly classified cotton components, blue text indicates correctly classified contaminants, and red text indicates samples incorrectly classified.

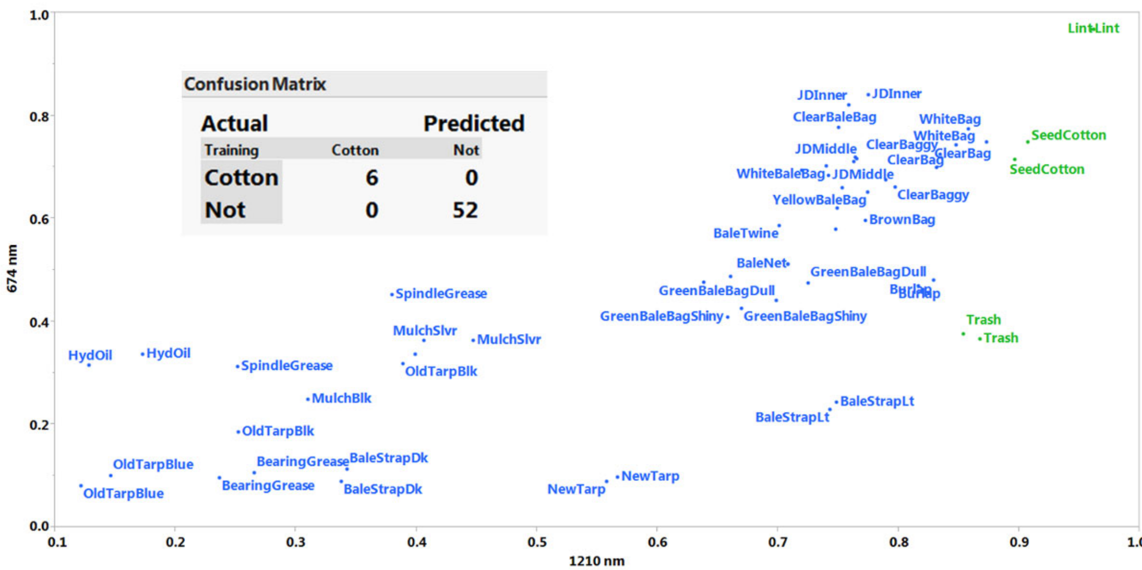

Figure 9. Reflectance measured with the spectrophotometer at 674 nm vs 1210 nm and logistic regression classification indicated. Green text indicates correctly classified cotton components and blue text indicates correctly classified contaminants.

Hyperspectral Imaging

Analyses of the hyperspectral imaging data show some differences in spectral response that could be exploited. For the visible/NIR reflectance measurements, there was a gradual increase in response from the blue (~475 nm) to green (~510 nm) to red (~650 nm) regions for seed cotton (Figure 10). For round module wrap, there was a much greater increase from the blue to the green region. The response for the new module tarp was greater in the blue region than the red and the response was greater in the green region than red for the bale strapping. These results indicate that visible reflectance may be effective in detecting colored plastics in seed cotton. However, detecting contaminants that are white or opaque will likely require using responses measured in longer wavelengths.

Spindle grease also exhibited a different response in the visible range than seed cotton with a sharp increase in reflectance from the green to red regions. However, analyses of the UV fluorescence imaging showed that spindle grease and hydraulic oil had dramatically different responses than seed cotton (Figure 11).

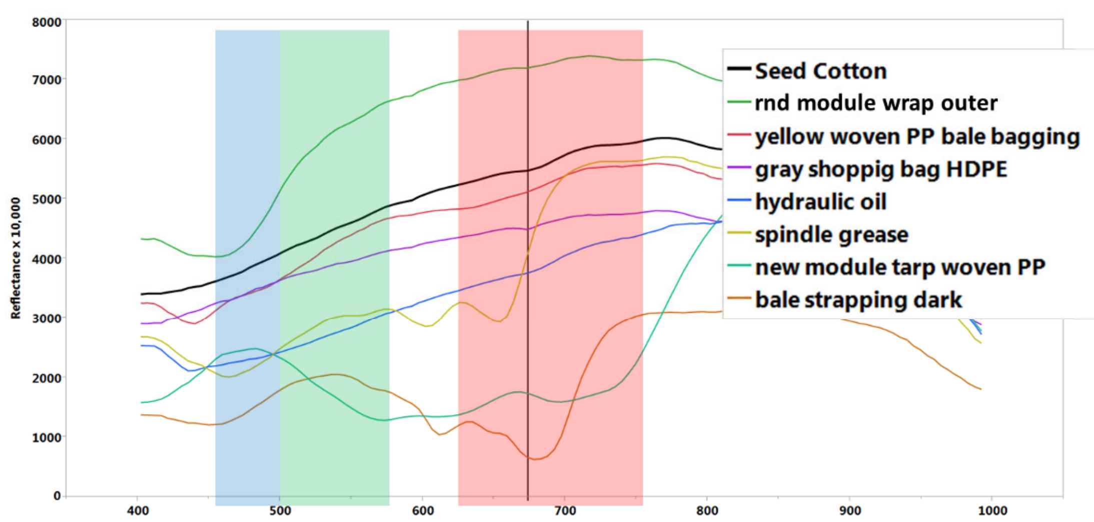

Figure 10. Resulting average visible/near-infrared reflectance spectra from hyperspectral imaging of seed cotton and select contaminants. Blue (~450 nm), green (~510 nm), and red (~650 nm) shaded regions indicate corresponding wavelengths for those colors.

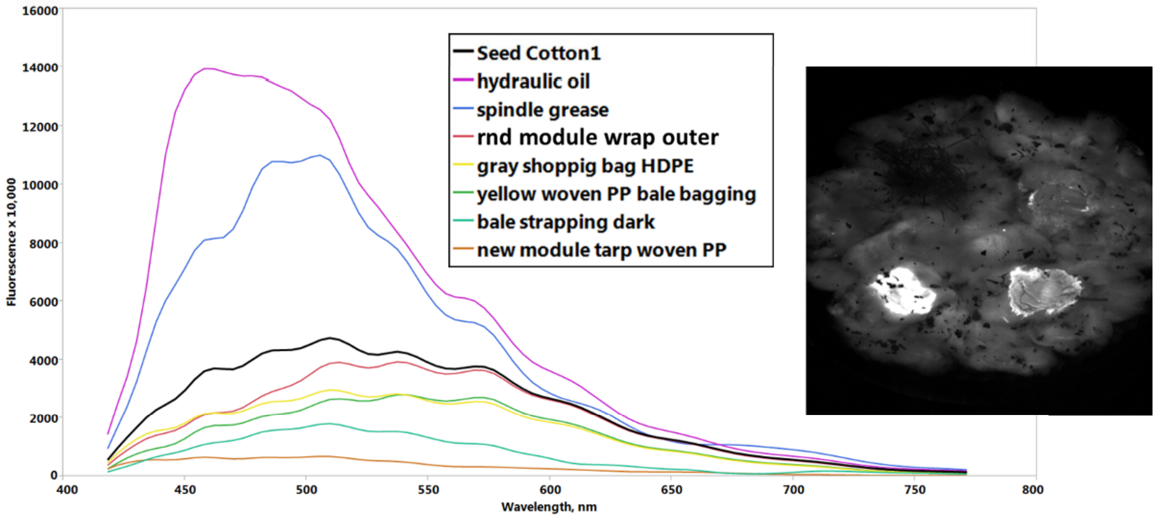

Figure 11. Average ultraviolet fluorescence spectra for seed cotton, hydraulic oil, spindle grease and other select contaminants. Image shows hydraulic oil and spindle grease fluorescence on a seed cotton background measured at 465 nm.

These results will lead to future work on better quantification of the differences between seed cotton and the contaminants. In particular, further analyses will follow with the goal to design, construct, and test a prototype sensor that utilizes UV fluorescence and visible color to detect the contaminants in a bat of seed cotton.

Summary

Spectral responses of seed cotton and common contaminants are known for some regions of the visible to IR spectra. Hyperspectral imaging was used to measure ultraviolet fluorescence and visible/near-infrared/short-wave infrared reflectance of different contamination samples with a seed cotton background. Data analyses to date show some differences in spectral response that could be exploited. Specifically, round module wrap, module tarp, and bale twine exhibit distinct differences from seed cotton in the VIS/NIR spectra due mainly to visible color. In addition, greases and oils have very different UV fluorescence responses than seed cotton.

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