IDENTIFICATION OF COTTON FOREIGN MATTER USING LINE SCAN HYPERSPECTRAL TRANSMITTANCE IMAGING

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Abstract

Cotton foreign matter (FM) is detrimental to fiber quality as it may damage cotton fiber during ginning processing or cause flaws in finished textiles. Therefore, detecting and classifying foreign matter are very important steps in the cotton production process. The aim of this study was to identify various types of cotton foreign matter embedded within lint webs using hyperspectral transmittance imaging at the spectral range of 400–1000 nm. A total of 11 types of foreign matter and five cultivars of cotton were collected from the field and the foreign matter was placed between two thin lint webs. A push-broom based hyperspectral imaging system was used to acquire images in transmittance mode. The acquired hyperspectral images were corrected using flat field correction and cropped due to noise at the edges. The foreign matter was observable in grayscale images. The image at 500 nm was chosen to be used for manual region-of-interest (ROI) selection. Mean transmittance spectra were extracted from the ROIs and normalized across all samples. Canonical discriminant analysis (CDA) was used to group FM, and multivariate analysis of variance (MANOVA) was employed to evaluate the differences between each combination of two types of FM using the first three canonical variables. The support vector machine (SVM) classifier was used to classify FM and was verified by 3-fold cross-validation. The classification results indicated that it is feasible to identify FM using this method since plastic package; paper, seed meat, and green leaf were well classified. The accuracies of distinguishing types of FM, which have similar appearance and similar chemical content, were lower but exceeded 60%. The average classification rate of all types of FM and cotton lint was 79.2%.

Introduction

Cotton foreign matter (FM) would damage cotton fibers in lint processing or cause flaws on textile productions, which may lead to low lint quality and economical losses (Himmelsbach et al., 2006). In cotton processing, ginners often enhance the cleaning level to extract more foreign matter and improve the cotton grade. Cleaning cotton causes fiber loss and fiber damage so ginners must balance the effect of trash removal and fiber damage when choosing the operating speed, drying characteristics, pre-cleaning, and lint cleaners (Anthony & Mayfield, 1995; Verschraege & International Cotton Advisory Committee, 1989). Therefore, accurate detection and classification of cotton FM are very important steps for cotton processing. Since ginning procedures and cotton quality assessments are directly affected by the content of FM, it is important to classify cotton FM to improve cotton grading and provide information for processing cotton (C. A. Fortier et al., 2011).

Recently, optical technologies have become very popular for cotton foreign matter identification. Color imaging-based methods are widely used, due to relative ease of use, high speed, and spatial information (Bel et al., 2012; Huang & Xu, 2002). For instance, the high volume instrument (HVI) employs color imaging to obtain trash percent area and trash particle count. Although HVI provides a relative measurement of cotton trash, it cannot give detailed information about the type of cotton trash (Foulk et al., 2006).

Spectroscopy could improve the classification performance by providing more spectral information. Fourier transform near-infrared (FT-NIR) spectroscopy was investigated to distinguish individual types of cotton trash from the fiber and achieved over 98% identification accuracy of cotton trash (C. Fortier et al., 2012; C. A. Fortier et al., 2011). However, the results showed that the spectra of FM had large variance when the sample size was reduced or the sample was heated. In addition, the spectroscopic method does not provide spatial information of the samples, which may limit the industrial application.

During the past several years, our lab tried to combine these two techniques. Firstly, fluorescent spectroscopy was used to find the optimal emission and excitation wavelengths, and then a fluorescent imaging system was built to detect and classify FM based on the wavelengths. It achieved 80% or higher classification accuracies for most FM, but 60%–80% for bark, seed coat, and twine (A. Mustafic & Li, 2015; A. Mustafic et al., 2014). To obtain more information, a hyperspectral imaging system was employed. Hyperspectral fluorescence imaging was used to provide fluorescence information at different wavelengths in the spectral range from 425 to 700 nm. This system has great potential for classifying foreign matter with strong fluorescence, such as paper and transparent plastics, and could be used as a complementary tool for cotton quality assessment (Adnan Mustafic et al., 2016). Using the reflectance modality, the hyperspectral imaging system obtained higher average classification accuracy of 91.25% at the spectral range of 400–1000 nm (Jiang & Li, 2015a, 2015b). At the spectral range of 950–1650 nm, it achieved over 95% for cotton lint and 16 types of foreign matter. However, foreign matter was placed on the surface of cotton lint when reflectance mode was applied. For foreign matter hidden underneath cotton lint, the transmittance modality was applied to the hyperspectral imaging system. At the spectral range of 950–1650 nm, it achieved an average classification rate of 90.91% for lint and 10 types of FM.

Therefore, the goal of this study was to explore the feasibility of a line-scan based hyperspectral imaging system using transmittance mode to detect and classify common types of foreign matter that were hidden inside cotton lint at the spectral range of 400–1000 nm. The specific objectives of this study were to: (1) extract spectra from the mixed spectra of FM and cotton; and (2) classify cotton FM using spectral information.

Materials and Methods

Cotton Lint and FM samples

The lint from five cotton cultivars and eleven types of foreign matter (Figure 1) were collected from the field during the 2015 harvest season on the Tifton Campus of the University of Georgia. The five cotton cultivars were PhytoGen (PHY) 499, PHY 339, Delta Pine (DP) 1522, DP 1538, and FiberMax 1994. The botanical FM included broken stem, stem, hull, seed coat, seed meat, bark, green leaf, and brown leaf, which were manually selected from the seed cotton and ginned cotton trash. The stem is a crisp and hard material and would be broken during harvesting or ginning. The color of stem and broken are different. Therefore, the stem was divided to two classes (stem and broken stem). The non-botanical FM contained twine, paper, and plastic package (round module), which were mixed with the lint during machine harvesting and packaging process.

When foreign matter was hidden inside the cotton layers, it was difficult to find them with the naked eye, so the size of the FM was purposely prepared larger than typical FM found in lint. Broken stem, stem, bark and twine were clipped to about 10 mm in length, and hull, green leaf, brown leaf, paper and plastic package were cut into a square shape about 10 mm in length. Seed coat and seed meat were kept their original size and shape.

To extract mixed spectra of the FM covered with lint, 30 replicates of FM and 60 replicates of thin lint web (10–12×12–14 cm in shape, 6–10 mm in thickness, 0.5–0.8 g in weight) were made by hand. To avoid the effect of other unknown FM and cotton unevenness, the lint webs were cleaned and disentangled manually. For mixed samples, eleven types of FM were sandwiched between two lint webs.

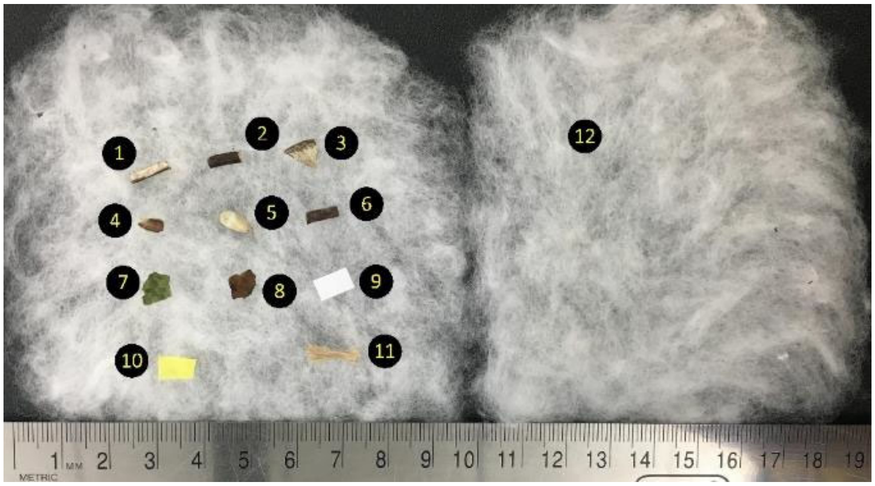

Figure 1. Foreign matter samples and two lint webs: 1. Broken stem, 2. Stem, 3. Hull, 4. Seed coat, 5. Seed meat, 6. Bark, 7. Green leaf, 8. Brown leaf, 9. Paper, 10. Plastic package, 11. Twine, and 12. Lint web.

Hyperspectral Transmittance Imaging System

A push-broom based hyperspectral imaging system developed by the Bio-Sensing and Instrumentation Lab at the University of Georgia was utilized to acquire images of FM and cotton (Jiang and Li 2015). The spectral range of the spectrograph is from 400 nm to 1035 nm. For transmittance mode, a sample stage was attached to the linear slide (Figure 2). To provide a relatively even light source, a 12 V, 50 W frosted halogen lamp was installed below the sample stage and the light did not move with the slide. To obtain transmittance images, the sample was held by a floated borosilicate glass plate (BOROFLOAT® 33, thickness = 2.00 mm, Home Tech SCHOTT North America, Inc., Louisville, KY, USA) on the sample stage. The glass plate has over 90% transmission in visible and near infrared spectral range. To make the cotton lint web uniform for acquiring better quality images, the sample was pressed by the same type of glass plate and two wood blocks were placed on the edges to increase cotton uniformity. The weight of each glass plate was 200 g and the weight of each wood block was 200 g. The total weight on top of the sample was 600 g.

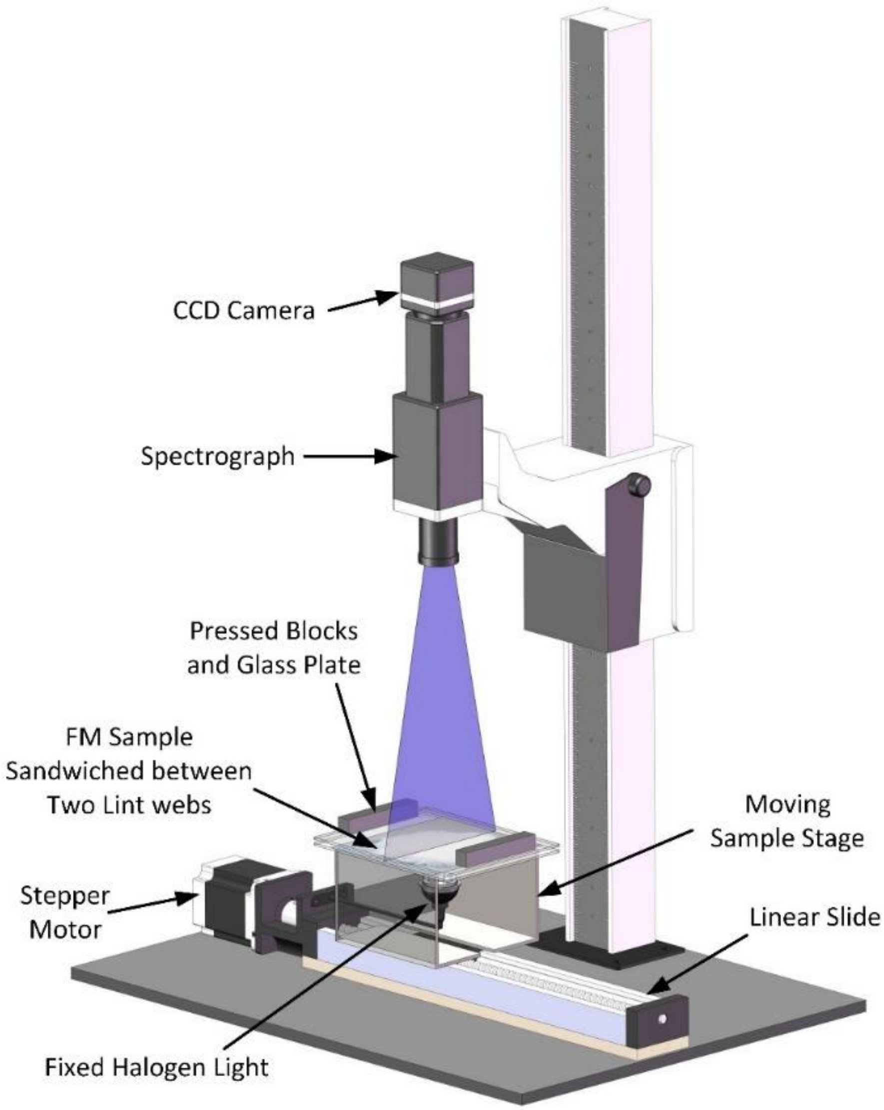

Figure 2. The push-broom based hyperspectral transmittance imaging system and samples

The samples were scanned in an enclosed chamber to avoid interference from ambient light. The distance from the lens of the camera to the button glass surface was 280 mm. After scanning a sample, a three-dimensional (x, y, λ) image cube was constructed with both spatial (1392×1440 pixels) and spectral (256 wavelength bands) data. The spatial information of x and y can form an image at a certain wavelength and a pixel in the 3D image cube represents a spectrum.

The acquired transmittance images were calibrated using flat field correction algorithm (Equation 1). The bright images were acquired by replacing the sample with a polytetrafluoroethylene (PTFE) Teflon plate (300×165×13.30 mm) between the two glass plates, and dark images were acquired by covering the lens of the camera. The relative transmittance intensity value IR was calculated by:

$I_R = (I_T\text{-}I_D)/\ (I_B\text{-}I_D)$.   (1)

I_T: pixel intensity of the transmittance image of a sample
I_D: pixel intensity of the dark image
I_B: pixel intensity of the bright image

The bright and dark images were acquired for every five samples.

Spectra Extraction
Before data processing, images were cropped into 900 (width) ×1445 (length) ×217 (wavelength range: 485–1035 nm) pixels, in order to remove the large amount of noise around the border. The regions of interest (ROIs) of FM and lint were extracted manually based on grayscale images and the mean spectra were obtained from the ROIs. After extracting the spectra, normalization was performed to define the relative transmittance in the range of 0–100%. The normalization was done by dividing the original relative intensity at each band by the maximum intensity value found in the whole spectra range.

The software ENVI 4.7 (ITT Visual Information Solutions, Boulder, CO, USA) was employed to conduct image cropping, band removal, ROI selection, and mean spectra extraction from ROIs. For spectra normalization, MATLAB 2016a (The MathWorks Inc., Natick, MA, USA) was utilized to perform the algorithm.

Classification
Given 11 classes of FM mixed with lint as well as lint, and 217 spectral variables (wavelengths), there were a total of 360 spectral samples (12 classes × 30 replicates). Canonical discriminant analysis (CDA) was used to characterize between-class variations of all types of FM and cotton lint using SAS (SAS 9.3, SAS Institute Inc., Cary, NC, USA).

Multivariate analysis of variance (MANOVA) was employed to investigate the differences between each combination of two types of foreign matter using the first three canonical variables in SAS (SAS 9.3, SAS Institute Inc., Cary, NC, USA).

The support vector machine classifier (SVM) was employed to classify FM with cotton lint using mean spectra at full wavelengths for a total of 360 samples (30 replicates of 11 types of FM and cotton lint). SVM was performed in MATLAB 2016a. The quadratic kernel function was selected. The kernel scale was automatically optimized by Matlab 2016a. The classification performance was evaluated by the percentage of samples that were correctly classified using the 3-fold cross-validation.

Results and Discussion

Grayscale Images and Mean Spectra
All types of foreign matter were directly and clearly seen in darker pixels (low pixel intensity) in the grayscale image of 500 nm (Figure 3), including paper which is same color as cotton lint. Plastic package was observed at 500 nm, but became blurred or disappeared at other bands. Except plastic package, all types of FM can be detected at the whole range of wavelengths. The grayscale image of 500 nm was selected to be used for manually designating ROIs.

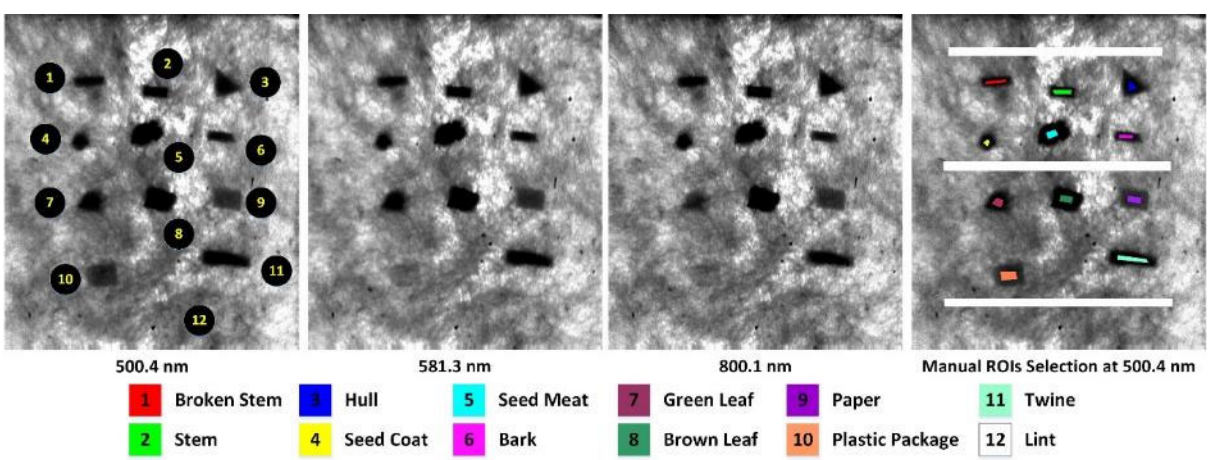

Figure 3. Grayscale images at three single bands and ROIs selection

The mean spectra were extracted from the ROIs and normalized (Figure 4). In Figure 4(a), the spectral intensity of plastic package was lower than that of cotton lint at the range of 480–550 nm, so at this range the plastic package can be clearly observed. After the band of 550 nm, the spectra of plastic package and lint were close to each other, so plastic package was not observed at the range of 550–1035 nm. The intensity of green leaf considerably increased at the range of 680–750 nm and the absorbance at around 660 nm presented chlorophyll (Yang et al., 2012). Seed meat had an absorption at about 640 nm, indicating the phenolic compound called gossypol (Marinan et al., 2010; Neilson, 1999). The spectral intensity of cotton lint and paper decreased at the full wavelengths. In Figure 4(b), the spectra of hull and twine were close to each other; as were brown leaf and seed coat; and bark, broken stem and stem. In Figure 4(c), the seven types of foreign matter have similar appearances and similar chemical components of natural fibers (cellulose), leading to similar spectral shape.

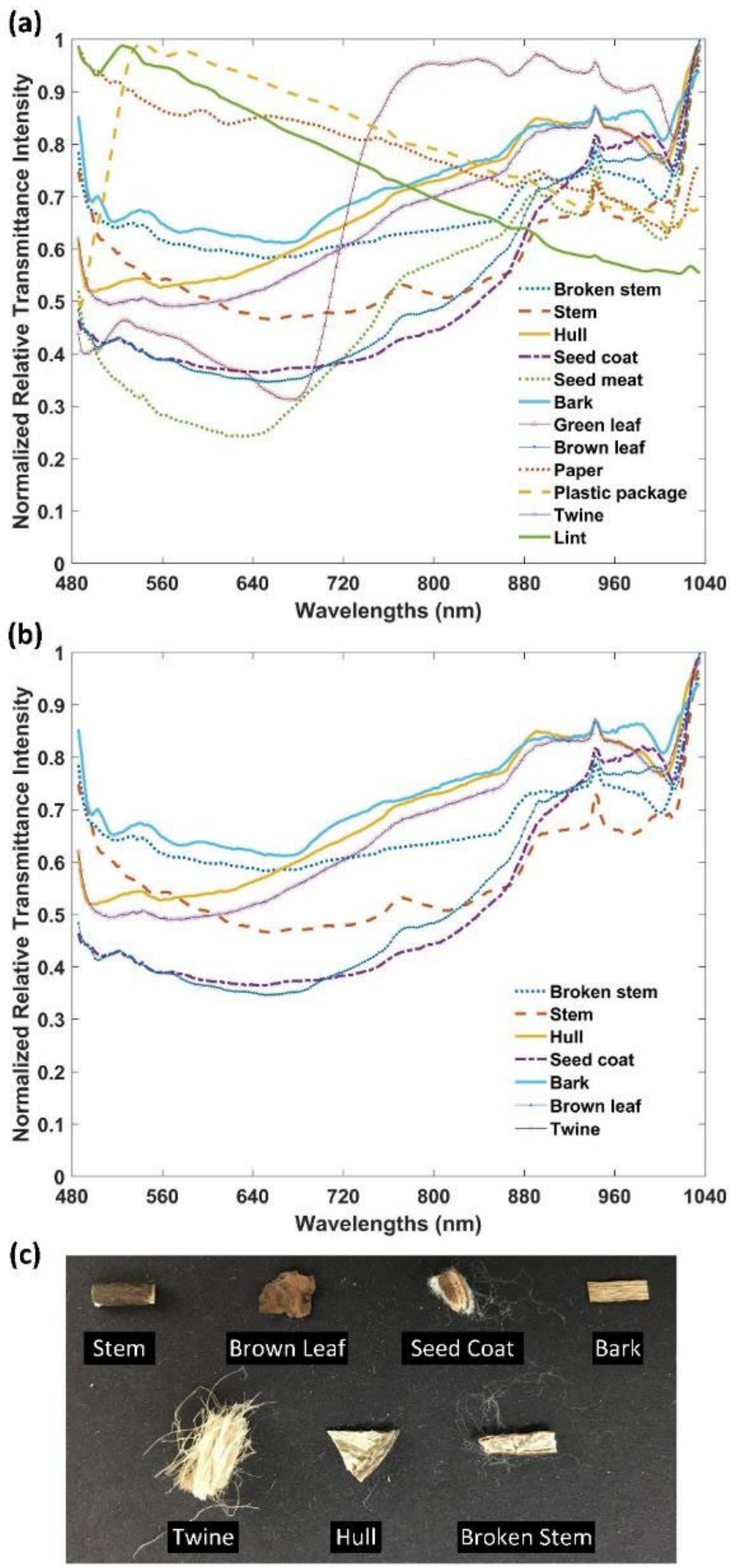

Figure 4. Mean spectra after correction and normalization of (a) 11 types of FM and lint, (b) 7 types of FM in similar appearance, and (c) color image of these 7 types of FM without lint

CDA Clusters and MANOVA Test

In Figure 5(a), the scattering points of cotton lint, plastic package, paper, green leaf, and seed meat were well separated and clustered, indicating that these five types of FM were well classified. In Figure 5(b), removing five types of FM, the clusters of seed coat, brown leaf, and bark were clearly formed. Yet, the clusters of broken stem, stem, hull, and twine overlapped and they were not clearly differentiated, implying that broken stem, stem, hull, and twine may have high misclassification accuracies.

To better understand the difference between samples, MANOVA test was applied to all types of FM using the first three canonical variables. The results were displayed in Table 1 (P-value < 0.01 indicated that the two types of FM had significant difference).

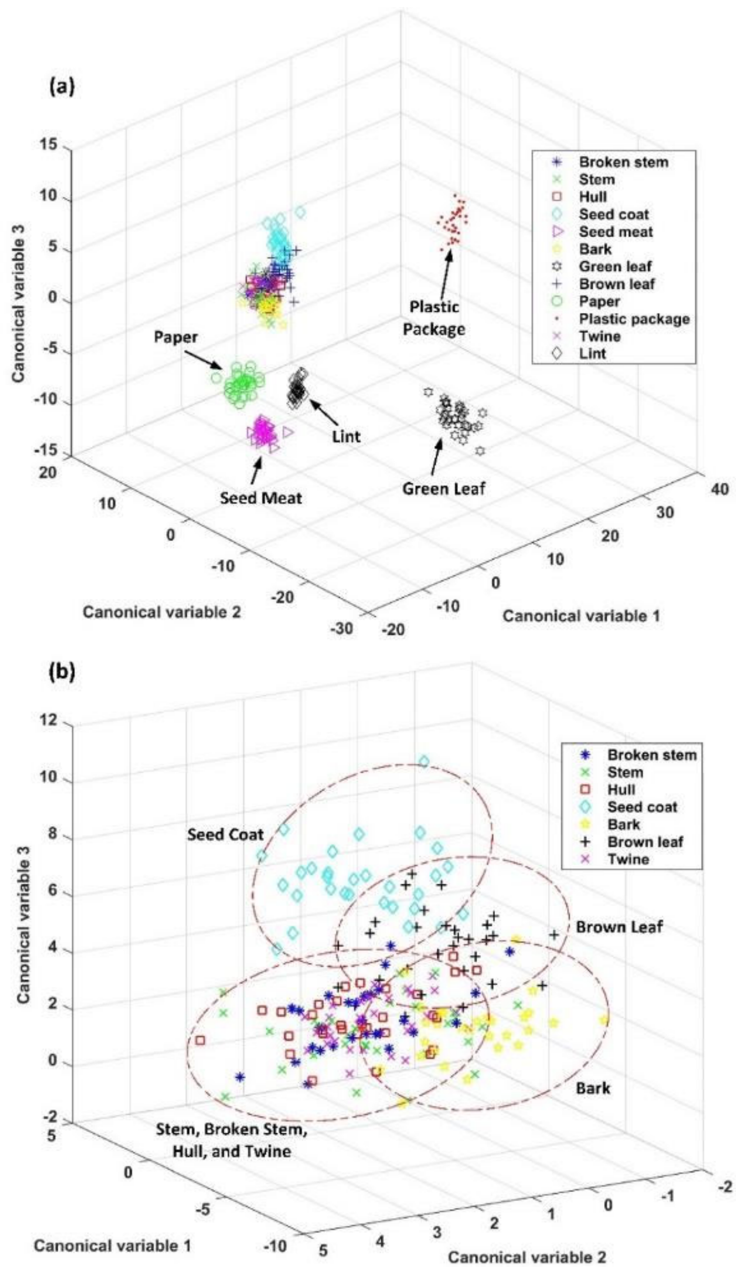

Figure 5. Scattering clusters of the first three canonical variables for FM and cotton lint based on canonical discriminant analysis (CDA) using full wavelengths: (a) 12 types of FM and cotton, (b) 7 types of FM (excluding plastic package, seed meat, green leaf, paper, and cotton lint)

Table 1 MANOVA test results ($p \geq 0.01$) for the first three canonical variables

Between Types	p-Value
Broken Stem vs. Stem	0.039
Broken Stem vs. Hull	0.344
Broken Stem vs. Twine	0.125
Stem vs. Twine	0.596

The accuracy for separating cotton lint and foreign matter was 100%. The accuracies for classifying green leaf, seed meat, paper, and plastic package were 90% or more. The other types of foreign matter exceeded 60% classification accuracies. The highest misclassification was between hull and stem, as well as brown leaf and seed coat. Because they have similar appearance and similar chemical content, their spectra were similar to each other, resulting in high misclassification results.

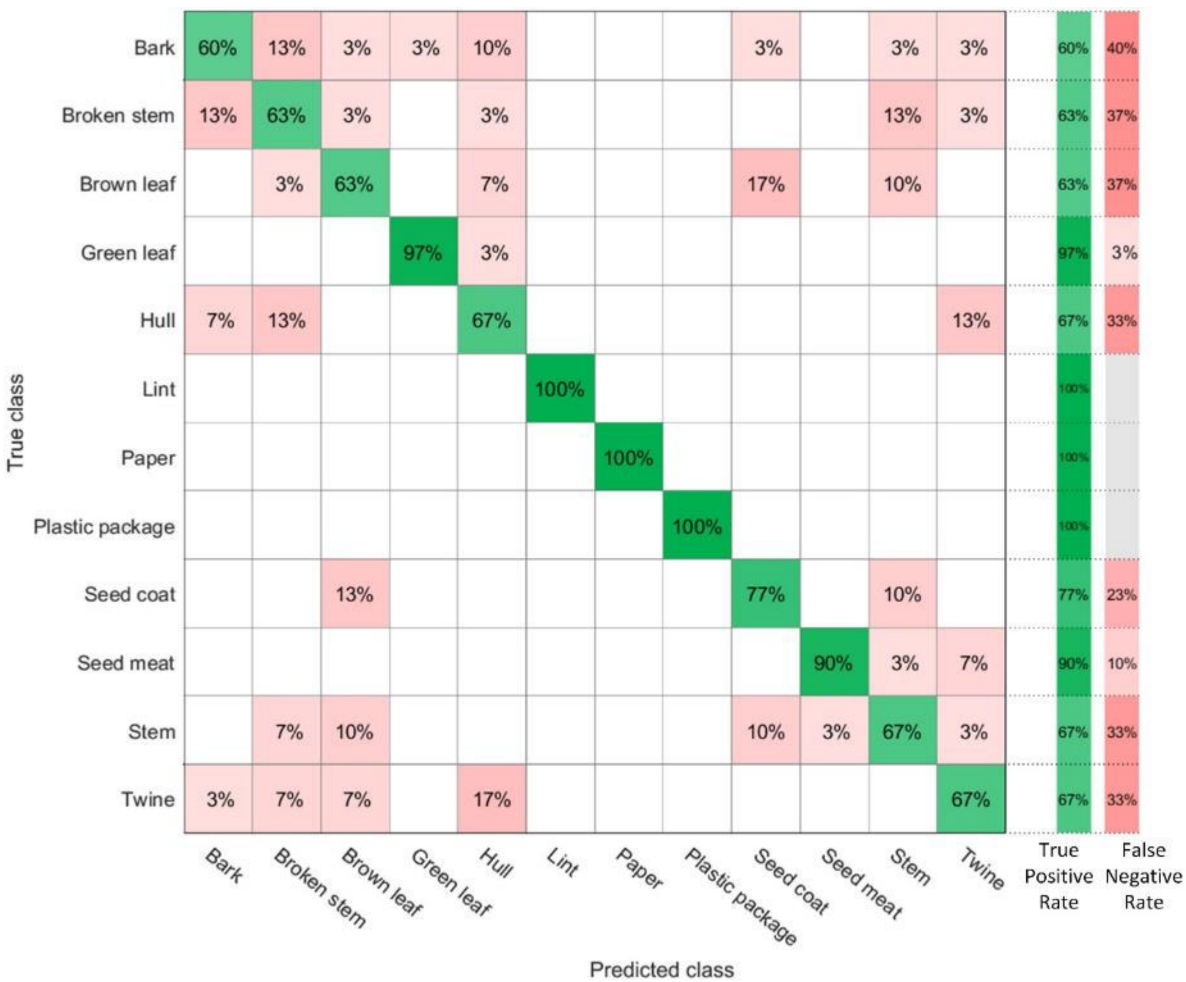

Figure 6. Average SVM classification accuracies for 3-fold cross-validation using full wavelength

Conclusions

This study explored the feasibility of hyperspectral transmittance imaging at the spectral range of 400–1000 nm to detect and classify cotton foreign matter that was hidden in lint webs. The preliminary results indicated that a total of eleven types of FM (broken stem, stem, hull, seed coat, seed meat, bark, green leaf, brown leaf, plastic package, twine, and paper) were presented in lower pixel intensity and can be detected in grayscale images of the range 480–550 nm. Except for plastic package, all types of FM can be observed in grayscale images of the full wavelengths. CDA scattering and SVM classification results indicated that cotton lint, plastic package, paper, green leaf, and seed meat were well identified, with higher than 90% classification accuracies. Other types of FM (seed coat, bark, hull, brown leaf, broken stem, stem, and twine) which have similar appearance and similar chemical content were misclassified with each other and the classification accuracies exceeded 60%. The average classification rate was 79.2%.

In this study, due to space issues, the small halogen bulb used as light source did not provide uniform lighting. In future work, the platform will be improved with a line light to supply more uniform light. Also, the size of the pieces of FM was relatively larger than those found in ginned lint. In addition, the spectra of FM were affected by lint webs when FM were sandwiched in lint webs. The lint webs were cleaned and carded by hand which might produce errors to the spectra. Feature wavelengths selection will be investigated to improve the classification. The imaging and FM classification process will be optimized for industrial applications.

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