FOOD AND AGRICULTURE

Evaluating plant and vegetation quality is important for the production of grains, fruits and vegetables in industry, as well as tracking the effects of disease, climate changes, and other factors on natural environments. Similarly, excellent quality control monitoring is crucial in food processing, due to the potential for adverse affects on the health of entire populations. For example, outbreaks of *E. coli* in spinach and salmonella in peppers and peanut butter affected more than 20,000 people in recent years. (Maki, 2009) Hyperspectral imaging provides a means to easily inspect the entire surface of a product, significantly improving upon the random inspections made possible by pull samples and subsequent laboratory tests.

Wheat Kernel Analysis

Insect infestation is a devastating problem for various types of agricultural crops, and is considered one of the most widespread causes of crop degradation in the United States and Canada. Because government policies prohibit live insects, insect fragments, and other insect contaminants in wheat kernels, undetected insect-infested kernels can pose major economic and credibility risks for grain distributors. Hyperspectral imaging technology can be used by grain suppliers and distributors to mitigate risk of contaminated products entering the food chain. In a study conducted at the University of Manitoba, Canada, hyperspectral cameras were used to separate insect-damaged wheat kernels from healthy wheat kernels. Researchers found that scanning wheat kernels in the 1000 - 1600 nm range was an effective way to separate healthy and insect damaged kernels, with success rates between 85-100%. (Singh, 2008)

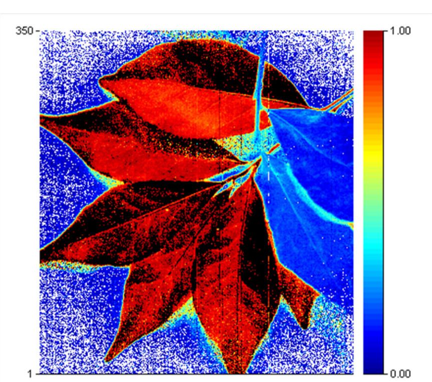
Citrus Ripeness

It is easy to detect citrus fruit ripeness and project yield when the fruit is in its more advanced stages and its color differs from that of the tree. However, it is much more difficult to do the same in earlier stages of fruit maturation. Researchers from Hokkaido University in Japan and the University of Florida used a hyperspectral camera in the 360-1042 nm range to estimate citrus yield from early stage green fruits. The results of pixel-identification tests from hyperspectral images demonstrated that 80-89% of the fruit in the validation sets were identified correctly. This information helped growers to adjust site management practices and other factors. (Okamoto, 2009)

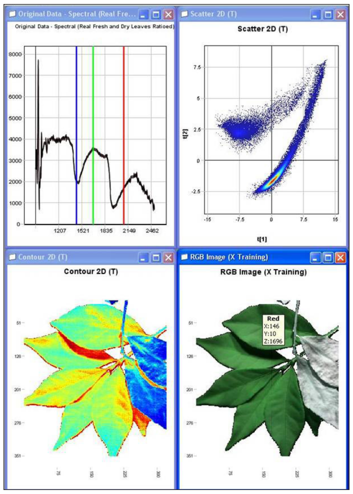
Plant Moisture Content

Fresh leaves and leaves dried to various levels were measured using a SWIR (1000 - 2500 nm range) hyperspectral camera. The samples were placed on a moving tray beneath the camera, and by line-scanning across the samples the camera measured the full spectrum of each individual point of the sample area.

The images to the right show fresh and fully dried leaves analyzed with hyperspectral software programs. From the hypercube of spectral data, the software easily differentiates the fresh and dried leaves and readily identifies not only the degree of drying but also the uneven distribution of the moisture as a consequence of drying. Similarly, plant diseases and other damaged plants can be detected in the laboratory, in a process environment for quality control, or in the field.



SBC prediction of fresh leaves (red) differentiated from the background and dry leaves (blue)



Evince principal component analysis plots of fresh and dried leaves

Production Monitoring

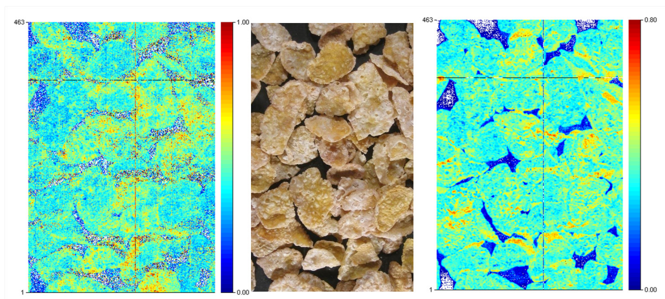
Hyperspectral imaging supports on-line monitoring of food processing by detecting differences in chemical composition, color, or moisture content, as well as recognizing shapes, patterns, defects, contaminants and spatial distribution of other relevant features. By collecting the spectrum of each individual point of the food product, a push-broom hyperspectral camera can be used to monitor the quality of the entire product line as it passes below. In this way, the contaminated or otherwise imperfect food can be easily identified and removed, ensuring better quality products. The SWIR region, capturing important spectral information from 1000 to 2500 nm, is especially powerful for differentiating components of food products, such as seen in the image shown here.

Chocolate pieces in chocolate-chip cookie. Dark chocolate candy on the right side of the image for reference.

The low heat-load from illumination and the high-speed of the push-broom hyperspectral imaging systems are ideal for on-line, non-destructive monitoring. In addition, hyperspectral imaging may be helpful in determining the cause of flawed products. Cameras can be placed over different stages of the moving production line to identify where changes in product quality occur.

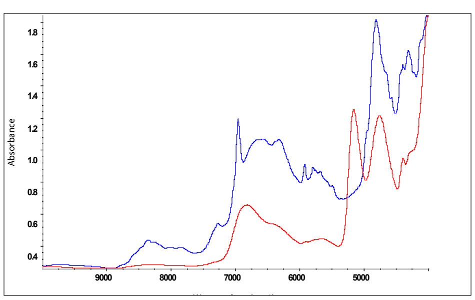
Sugar Coating

It is known that added sugar in foods is somewhat amorphous and partially recrystallizes on the product surfaces. The qualities of different sugars such as nutrition, texture, shelf-life, and dissolution behavior make the determination of amounts and distribution relevant for the manufacturing process. In this example, sugar coated corn flakes were studied. The flakes were illuminated with a halogen line light from about 10 inches, and a Model MRC-303-005-01 SWIR camera scanned the sample at 100 frames per second. The raw data was processed using the SBC algorithm (Marbach, 2002) to produce the sample images shown here.



Crystalline *Cornflakes* *Amorphous*

The algorithm requires use of the pure spectra of the ingredients that are to be predicted. Sucrose, with its characteristic sharp band around 1430 nm was used to predict crystalline sugar, and the spectrum of honey was used as an amorphous sugar model. The model materials were scanned on a FT-NIR instrument using integrating sphere optics and a Middleton Research Model MRC-912-000 Transflectance Liquid Cell accessory was used for the honey sample.



Spectra - red: honey (amorphous), blue: sucrose (crystalline)

The spectral differences between the sugars on the cereal flakes were detectable by the SWIR camera and the composition of the two ingredients predicted online. A complete SWIR camera based process system would therefore be able to determine composition and distribution and report that information to the manufacturing plant process control computer.

Detecting Apple Contamination

A recent food safety example involved visible/near infrared hyperspectral reflectance imaging for the detection of fecal contaminants on apple surfaces. The spectral differences found between the contaminated and uncontaminated surfaces provided the USDA with the basis for creating a universal algorithm to identify fecal matter on apple skins. (Liu, 2007)

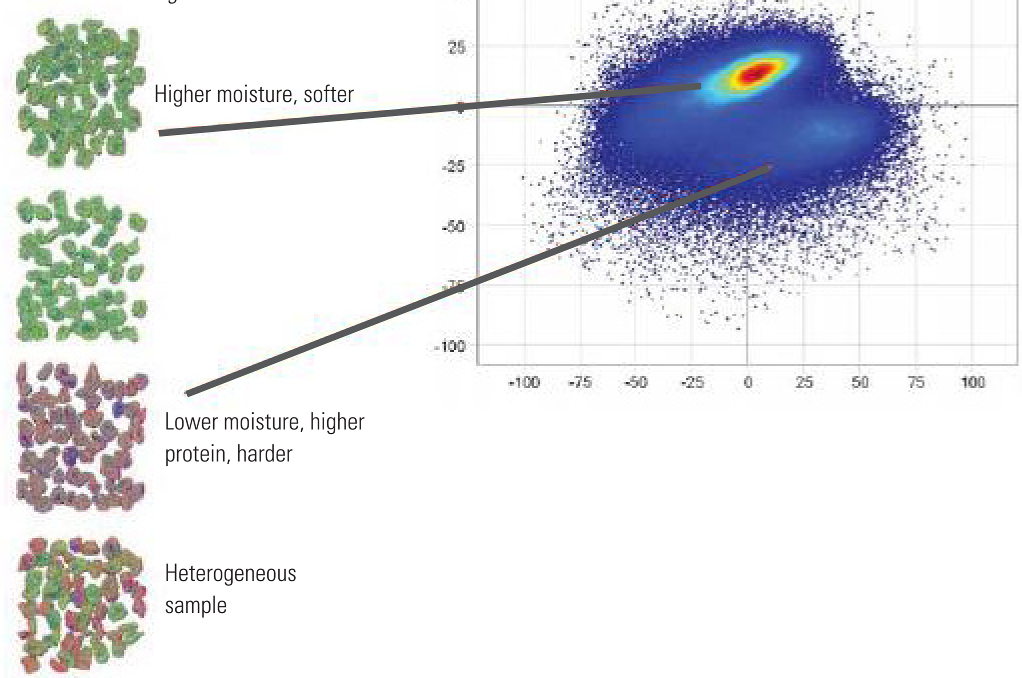
Dairy Applications

Near infrared (NIR) spectroscopy is a technique frequently used to characterize materials and products in the dairy industry. It has proven to be a valuable tool for determining various properties such as solid content, cheese ripeness and milk coagulation. Hyperspectral imaging systems extend the traditional NIR spectroscopy with high resolution imaging by providing detailed, quantifiable information on chemical composition and structural distributions within the sample.

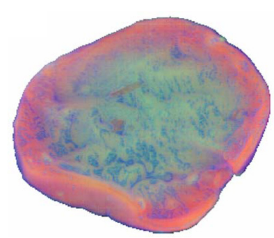
Cheese

The images shown below were collected by a short-wave infrared (SWIR) camera and depict different qualities of cheese granules. A principal component analysis (PCA) was performed on the whole image. As each pixel contains the full NIR spectrum (970-2500 nm), it is possible to distinguish samples of different chemical properties through the use of multivariate methods.

Cheese moisture classification using 1000 - 2500 nm range



The PCA score scatter plot shows two clusters of observations (pixels) separating the two major types of granules. In this case, the granules were analyzed for solid content, moisture and protein. In the picture, the first three principal components were assigned to red-blue-green colors. The greenish granules show low solid content, high moisture and low protein. The reddish granules show higher solid content and more protein.



The image at the right shows a pseudo-colored image of a cross section of a cottage cheese granule created from a NIR image of the first three principal components. The image was created in Evince hyperspectral analysis software and shows the differences in both physical and chemical structure at the surface of the granule.

Predicting Mushroom Quality

Hyperspectral imaging technology was also used by researchers in Dublin, Ireland for quality prediction of white mushroom slices at varying storage temperatures. The mushroom slices were measured with a push-broom line-scanning HSI instrument in the VNIR wavelength range to determine moisture content, color and texture. The results from this study could be used to develop a non-destructive monitoring system for sliced mushrooms in a production setting. (Gowen, 2008)

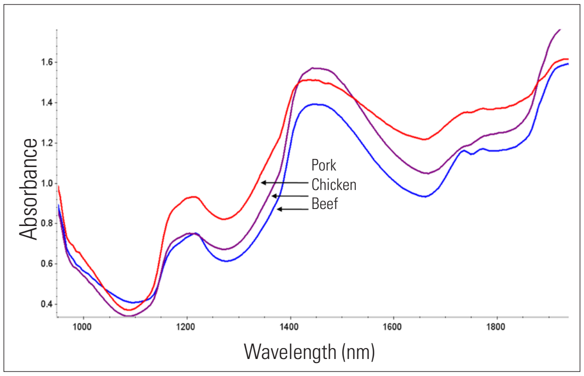
Classifying Grades of Tea

Researchers at Jiangsu University in Zhenjiang, China used hyperspectral imaging to analyze internal and external attributes of tea leaves, such as texture and color. The analysis resulted in a non-destructive tea classification model that differentiates five grades of green tea. (Zhao, 2009)

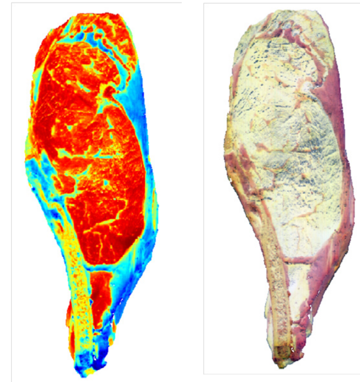
Meat

Hyperspectral imaging can be used to analyze various qualities of meat, such as tenderness, fat, protein and moisture content.

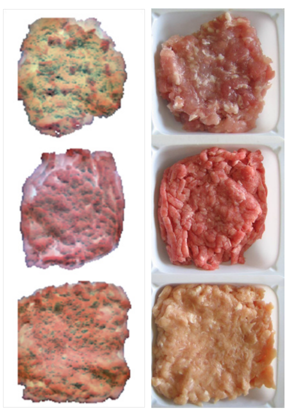
The image to the right was obtained from a SWIR hyperspectral camera in reflectance mode. It shows the spectral variation of different components of a beef steak (fat, muscle, and bone) following a Principal Component Analysis calculation.



SWIR spectra of pork, chicken, and beef



Hyperspectral PCA analysis and pseudo-color RGB image of steak



From top to bottom: Hyperspectral and RGB images of pork, beef, and chicken

Three types of ground meat (pork, beef, and chicken) were also imaged and found to be spectrally distinct. A hyperspectral image of the samples and their average spectra are shown here. From the false-color hyperspectral information in the far left image, clear color differences between the meat types are readily apparent. For some samples, the VNIR and VIS wavelength ranges are also useful for detecting differences in meat characteristics.

Grading Turkey and Ham

Another application of interest is predicting the quality of ham and turkey. Using hyperspectral imaging technology to examine the amount of brine injected in the meat, prediction models were created to accurately and non-invasively estimate ham quality. Researchers at the College of Dublin, Ireland explained that the highest quality ham is cut from a single muscle, which requires less brine injection to produce an acceptable yield. It is known that the more brine meat contains, the lower its quality. The only complication in judging the quality is that despite differing levels of brine content, all grades of ham appear very similar to the naked eye. Using HISI to examine the brine content in the meat slices, researchers were able to classify varying grades of both turkey and ham despite their similar appearance. (Jackman, 2009)

Detecting Diseased Chicken

The USDA has also used hyperspectral imaging to solve meat quality control issues. United States law requires the post-mortem inspection of each chicken by the Food Safety Inspection Service, and the USDA has found that reflectance imaging is a good technique to identify localized diseases/defects. Diseased, bruised or otherwise unwholesome carcasses pose a serious health threat to consumers, so that accurate identification and separation of these carcasses are vital. Hyperspectral imaging in the NIR region has been used to separate good tissue from damaged or tumor-afflicted tissue to ensure that disease carrying poultry carcasses do not reach the processing stage and are subsequently distributed for human consumption. Given such successful results, the USDA is currently investigating other areas in agriculture and food where hyperspectral imaging could be used for grading and inspection. (Park, 2008)

Predicting Meat Tenderness

Researchers at the University of Nebraska, Lincoln used a push-broom hyperspectral imaging system as a non-destructive way to predict the tenderness of cooked beef from the hyperspectral images of uncooked steaks. In this study, a total of sixty-one different beef steaks, in varying cut, were imaged. After imaging and prediction, the steaks were cooked and Warner-Bratzler shear (WBS) force values were gathered as tenderness references. The model predicted each piece of meat according to three tenderness categories: tender, intermediate, or tough. Hyperspectral imaging allowed the researchers to predict the tenderness of meat with 96.4% accuracy. (Naganathan, 2008)

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