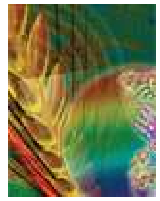
SPIE Professional July 2009

Agri-Photonics

Photonics technologies are helping farmers, food processors, and famine-plagued areas of the world.

By Beth Kelley



Farming strategies and technologies have changed and adapted over the millennia to new environments, new crops, and new needs. Now, optical and photonic technologies are helping to make soil stronger, grapes sweeter, and food safer to eat.

Lasers and imaging sensors mounted on planes, fluorescence spectroscopy, lidar, and energy efficient LEDs are just some of the latest farming and food processing tools in the emerging field of optical farming, or agri-photonics. Photonics technologies can help predict protein levels in wheat harvests, determine when to harvest grapes, map water quality to observe the health of fish stocks, and screen for contaminants in spinach, tomatoes, and other foods.

David Lamb's lab has fiber optic color sensors to measure sugar levels in wine grapes. (Photo courtesy of David Lamb)

Technologies From the Ground Up

Infrared sensing technologies now play key roles in determining the health of soil, nutrient content, and the hydrology of a particular agricultural area.

The U.S. Department of Agriculture is a major player in research and development of techniques to determine soil health and hydrology. Bill Kustas of the USDA Agricultural Research Service, Hydrology & Remote Sensing Lab, says drought information "is being requested at increasingly high spatial resolution to assist in yield forecasting, drought mitigation and crop loss compensation efforts."

The lab uses microwave radiometry to measure surface soil moisture. It also uses thermal infrared remote sensing for mapping evapotranspiration because it does not require ancillary information about rainfall or soil moisture holding capacity. This makes it well-suited for application in areas lacking extensive precipitation monitoring networks and surface characterization.

The USDA-ARS lab also conducts studies on how water moves through soil and what farm contaminants might get carried with it. Remote sensing using narrow spectral bands has produced the best results, Kustas says.

"Estimation of large-scale surface soil moisture has the potential to improve growing season numerical weather prediction accuracy over a broad swath of global agricultural areas," says Kustas. "Such improvements would be of enormous value for agricultural management applications for the farmer."

Lasers and telescopes are used in optical farming to detect evapotranspiration and help farmers decide when to irrigate. (Photo courtesy of Jan Kleissl)

Because water is a particularly important farm commodity in arid areas, whether for large commercial operations in California or small farms in Africa, Jan Kleissl of the University of California, San Diego, developed a method of measuring the sensible heat flux in agricultural fields using laser scintillation. Originally developed for military application, Kleissl's method infers how much heat is emitted from the scintillation observed.

"The sensible heat flux is inversely proportional to evapotranspiration," Kleissl says. "The more available soil moisture, the more evapotranspiration."

This method could be very cost effective for large-scale evapotranspiration monitoring. "Currently the system is best used in conjunction with statewide efforts to calibrate satellite remote sensing maps that then can be used by every farmer in the state," he says. "For this, only about 10 measurement sites in the whole state would be necessary."

Another challenge for agri-photonics is measuring soil health, often indicated by soil bulk density. Soil bulk density is often used as an indication of ease of root growth, water concentration, and overall usability and quality. Ann Rossi at the University of California, Riverside, has developed a 3D laser technique to monitor soil density. Low bulk densities suggest more organic matter and therefore more nutrient-rich soil.

Left: An airplane-mounted passive imaging sensor with four filters allows David Lamb to create composite images using any combination of blue, green, red, and near infrared wavebands. Right: Lamb's team uses an active sensor on a small plane that flies low over the fields. (Photos courtesy of David Lamb)

Previously, soil density was measured by water displacement, weight, and other methods that require destruction of the soil clod. Rossi's scanner automatically rotates the dirt clod sample and assembles the individual scans to create a 3D model.

"The main advantage of the 3D laser scanning method over the 'clod method' is that it is non-destructive," says Rossi. "The same clod can be used for multiple analyses. 3D laser scanning can provide a more precise method of quantifying the size and shape of soil aggregates." The 3D scanner is also more portable than the clod method and can be easily transported and used in the field.

Measuring Crop Health

Crop health and overall production can also be measured by photonics technologies.

Kustas says his teams at the USDA have been using remote sensing data in the visible, near-infrared, and thermal-infrared wavebands to estimate crop yield and soil carbon sequestration. "We have also used NASA's AVIRIS hyperspectral reflectance data (400-2600 nm) for mapping canopy chlorophyll content," Kustas says.

David Lamb and his colleagues at the University of New England, Australia, use remote sensing methods such as spectrum and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imaging to test nitrogen content in soil, and indirectly the protein content of crops like wheat. Nitrogen levels in leaves influence chlorophyll concentration and therefore reflectance, making it easy to take remote sensing measurements of the amounts of nitrogen in plants.

Wheat is a major crop in northern China, and higher crude protein content makes the wheat more valuable, both to consumers and farmers. The ability to forecast grain quality by NRI (nitrogen reflectance index), and thus estimate market potential for winter wheat harvest, allows farmers to make operating decisions and adjustments before the wheat goes to market.

Lamb is also looking at ways to analyze wine grapes, a huge cash crop in Australia and other parts of the world. He uses fiber optics to measure sugar levels in individual grapes. Differences in a grape's sugar concentration create an absorption spectrum that correlates with ripeness. Using fiber optics for measurements is less destructive than creating a grape slurry, he notes, as was done previously. And it can provide crucial information of when to harvest.

Researchers at the Fraunhofer Institutes for Molecular Biology and Applied

Ecology IME in Schmallenberg and for Physical Measurement Techniques IPM in Freiburg have also developed a system that can check the safety and quality of food. The researchers are investigating whether the equipment, based on metal oxide sensors, could be used to test pork, pineapples, and other food.

Ensuring a Safe Harvest
Ensuring that food, drink, and pharmaceuticals are all safe for consumption is another way that photonics plays an important role in enhancing life on the planet.

Recent innovations in spectral imaging sensors have enabled improved food safety and food quality inspections with ruggedized in- or at-line processing monitoring and direct real-time monitoring at a high volume.

"There is a compelling need to improve process capabilities with proven technology advances in order to maintain a safe food supply," says David Bannon, CEO of Headwall Photonics.

Headwall Photonics is working with the USDA, including the USDA-ARS lab, to investigate the spectral characteristics of crops through the utilization of near infrared (900-1700 nm) and short-wave infrared (1000-2500 nm) sensors. A new imaging system, the Hyperspec™ Starter Kit, a device for which Headwall Photonics was a finalist in the 2008 Prism Awards for Photonics Innovation, is customized for agricultural researchers to combine the critical analytical technologies of reflectance and fluorescence spectroscopy.

The kit can be used to identify levels of bruising in fruits and vegetables, pharmaceutical quality, and bacterial contamination, all critically important in the $50 billion market for specialty foods like fresh and dried fruits, vegetables and nuts.

BaySpec debuted its food inspection device, SAFEINSPECT at SPIE Defense, Security, and Sensing in April. This hand-held device is a Volume Phase Grating-based dispersive Raman system with no moving parts that can be easily transported to the field or border inspection point to check authentication, traceability, and quality control. No sample preparation is required.

Eric Bergles, vice president of sales and marketing at BaySpec, says the new device is a non-destructive and affordable way to make spectroscopic measurements compared to mass spectrometer and conventional FTIR approaches.

Ocean Optics has used miniature spectroscopy for applications such as monitoring the sugar content of fruits and vegetables, measuring the color of wines as an indicator of flavor, and analyzing the oxygen content of salad dressings. Its Jaz unit is a modular, handheld spectroscopy platform.

Ocean Optics is also developing a new approach to multispectral imaging that has potential for use in food and drug processing, says Jason Eichenholz, Ocean Optics' CTO.

"In both food and drug processing, miniature spectroscopy is especially useful because flexibility in detectors, light sources, and sampling optics allows for rapid implementation of instrumentation into the process, and it makes it much simpler to optimize setups," Eichenholz says.

Future Farming With Optics
Much of the agri-photonics technology is already on the production line or in farmers' hands, and provides information that farmers can apply directly to

their crops.

The National Center for Computational Hydroscience and Engineering (NCCHE) at the University of Mississippi and the USDA-ARS are developing a decision support system for land managers and farmers to help them optimize their conservation practices. Water quality surrounding farms can be degraded by pesticides and livestock waste, and the new system will integrate watershed models with a sophisticated channel erosion model (CCHE1D-3.0).

Many of these optical technologies can also be employed on other applications. Kleissl believes his laser scintillation system would also be useful to monitor urban heat islands, the heat emitted from urban areas into the atmosphere. It could be used to quantify the effect of urban heat island mitigation measures such as tree planting.

"The number and market size of spectroscopy instruments is expected to grow exponentially," says Bergles.

Farming With LEDs

The ability to grow vegetables and fruits indoors using energy-conserving light sources makes it possible to cultivate crops year round in famine-plagued desert regions or the Arctic.

Energy-conserving blue and red LEDs have been used to grow plants indoors all year round. (Photo courtesy of Seoul Semiconductor)

Blue and red LEDs have been found to be extremely effective sources of light for indoor farming and are becoming increasingly popular in Asia.

• Hiroyuke Watanabe of Tamagawa University near Tokyo has reported that red LEDs promote root growth, while blue LEDs promote chlorophyll production and leaf growth.

• In March, Seoul Semiconductor supplied 300,000 blue and red LEDs for the LED Farming Demonstration Project sponsored by the Ministry of Economy, Trade & Industry of Japan. There are currently six operating plant factories in Japan.

• The Rural Development Association of Korea says cultivating crops with supplementary lighting (LEDs) over approximately 3,000 hectares will save 70% of energy use compared to incandescent lamps.

More Information About Agri-Photonics

Learn more about how your food is scanned, poked, squashed, lased, and radiated all before it gets to your plate in the SPIE Newsroom, the SPIE Digital Library, and elsewhere.

- Estimation of winter wheat grain crude protein content from in situ reflectance and advanced spaceborne thermal emission and reflection radiometer image, by Wenjiang Huang, Xiaoyu Song, David W. Lamb, Zhijie Wang, Zheng Niu, Liangyun Liu, and Jihua Wang in J. Appl. Remote Sens. 2, 023530 (2008) DOI:10.1117/1.2968954
- Rice mapping using multi-temporal imagery in Monsoon Asia, by Cuizhen Wang
- A new era in remote sensing of crops with unmanned robots, by Pablo J. Zarco-Tejada, J. A. J. Berni, L. Suárez, and E. Fereres
- Detecting crops and weeds in precision agriculture, by Christelle Gee, Jérémie Bossu, Gawain Jones, and Frédéric Truchetet
- Scintillometer networks for calibration and validation of energy balance and soil moisture remote sensing algorithms by Jan M. H. Hendrickx, Jan Kleissl, Jesús D. Gómez Vélez, Sung-ho Hong, José R. Fábrega Duque, David Vega, Hernán A. Moreno Ramírez, and Fred L. Ogden in Proc. SPIE 6565, 65650W (2007) DOI:10.1117/12.718124
- Rediscovering bamboo: remote sensing and geographic information systems perspective by Amit Kumar in J. Appl. Remote Sens. 2, 022501 (2008) DOI:10.1117/1.3010736
- Spectral imaging solutions for food products, from International Food Safety & Quality Network, June 2009
- Using Lasers in Farming: Twinkle, twinkle, little laser, from *The Economist*, March 2009
- UV LEDs Enrich Lettuce, from photonics.com, May 2009

Beth Kelley is an SPIE editor.

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DOI: 10.1117/2.4200907.08

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