# Developing an Agricultural Remote Sensing Program
# at the University of Illinois

## Principal investigator and co-investigators:

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**Donald Bullock** - Crop Sciences, and
**James Westervelt**[1] - Agricultural and Consumer Economics

## Executive summary:

The ability to record and process crop field images from satellites, planes and ground-based vehicles has provided tremendous opportunities to advance precision agriculture. The commercial use of agricultural remote sensing to improve farm management is closer to becoming a reality.

Sponsored by University of Illinois' C-FAR Sentinel Program, this project focused on the applications of remote sensing in agricultural settings. Principal investigators, Lei Tian of the Department of Agricultural & Biological Engineering; Donald Bullock of the Department of Crop Sciences, and James Westervelt of the Department of Agricultural and Consumer Economics[1], work closely with faculty, students, and scientists throughout the U.S. on wide range of remote sensing projects. Emphasis is placed on applied research and engaging U.S. agribusinesses to facilitate the commercialization of new advanced remote sensing technologies. University students also benefit from being exposed to real world, problem-solving situations through partnership projects with companies and grower groups.

Officially opened and dedicated in April 2001, the Illinois Laboratory for Agricultural Remote Sensing (ILARS) located at the University of Illinois at Urbana-Champaign has been a unique infrastructure and brought together research experts from the University of Illinois College of Agricultural, Consumer and Environmental Sciences; National Aeronautics and Space Administration (NASA) Commercial Remote Sensing Program; Institute for Technology Development–Spectral Visions; National Center for Supercomputing Applications (NCSA); and the U.S. Department of Agriculture to develop "real world" applications of remote sensing.

We believe that remote sensing technology will help precision farming reach its full potential, this technology will allow farmers to save herbicide with an intelligent site-specific application system (VRT), identify soil types and problem areas in their fields, and accurately predict in-field yield variability. ILARS has been fusing cutting-edge technologies to develop new product ideas and application prototypes. Research projects include hyperspectral image sensing, the use of dynamic models to monitor agricultural runoff, and the development of data mining and neural network technology to process high resolution spatial and spectral remotely sensed data.

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[1] Dr. Westervelt left UIUC in 2003.

## *Primary objectives and goals:*

The general objective of this project was to establish an interdisciplinary program of remote-sensing-based precision farming technology in the College of ACES. Specific objectives include:

1. Develop and consummate the key technologies needed for NASA remote sensing data applications in precision agriculture settings. These would include: A "ground truth machine" required for the purpose of near-real-time soil and plant sensing. Development of special plant identification algorithms for high-speed crop plant and pest infestation condition sensing, and geo-referencing the image processing results. And the development of a map data processing algorithm and creation of a database of the relationships between remote sensing image patterns and field conditions.
2. To help facilitate the recruitment and training of highly qualified faculty, staff, and students (in the area of agricultural remote sensing). Design new curriculums and/or encourage faculty members to develop new courses in the area of agricultural remote sensing, spatial data management, precision agriculture, etc.
3. To foster cooperation among scientists from universities, government agencies, and industry working in precision agriculture and remote sensing, encourage and facilitate visits and exchange of outstanding scientists and engineers to compliment the talents of existing faculty and staff. Use our existing extension system to bring these new technologies to farmers and assess their needs, target research to address these needs, and maximize the relevancy of our program.

## *Outcomes and impacts:*

### *1. Infrastructure Development*

To setup the infrastructures for agricultural remote sensing study program in Illinois, a total of 1500 $ft^2$ lab space (Figure 1) in College of ACES was remodeled and furnished to house the image/data processing facilities and several key ground data collection instruments for remote sensing related research projects. The Illinois Laboratory for Agricultural Remote Sensing (ILARS) was formally dedicated on April 18, 2001.

Immediately after dedication, the ILARS facility was supporting the collection and processing of data collected on the ground and from aircraft to support precision agriculture, watershed, and Illinois crop yield research. Experiments have been carried out using commercial and University research farms to demonstrate new remote sensing based field operations. The laboratory is being used in support research projects funded by external agencies. For example, we have carried out projects sponsored by the US Department of Agriculture and the Illinois Department of Natural Resources to collaboratively generate annual Illinois agriculture land-use maps.

**Figure 1: The Illinois Laboratory for Agricultural Remote Sensing (ILARS) was formally dedicated on April 18, 2001. The 1500 ft$^2$ lab space in College of ACES houses the image/data processing facilities and several key ground data collection instruments for remote sensing related research projects.**

## *2. Sensing Systems Development*

The goal in our sensor development projects was to create novel ground-based sensing tools to increase data quality and validate remote sensing systems for precision farming. Researchers in ILARS have developed several local-sensor-based sensing systems namely: the “ground truth machine” for ground reference data collections, hybrid positions sensors to increase GPS accuracy, and high-resolution (stationery and UAV mounted) remote sensing system, etc.

One major concern we have was the data quality while doing agricultural remote sensing experiments. The limitation in remote sensing data quality/availability has become a major obstacle in the demonstration and adoption of the technology. The data quality includes two major things we are trying to study: the effects of spatial resolution and the temporal resolution on the precision agricultural applications.

Example sensing systems being developed in ILARS include:

***a) Ground truthing machine used for field mapping*** (Figure 2).

The tractor mounted multiple-sensor mobile data collection system composed of a self-propelled sprayer as the chassis, near-infrared/visible light sensors for canopy morphological property sensing, chroma meter and radiometer for spectral property sensing, and a “sky-meter” for light source temperature monitoring.

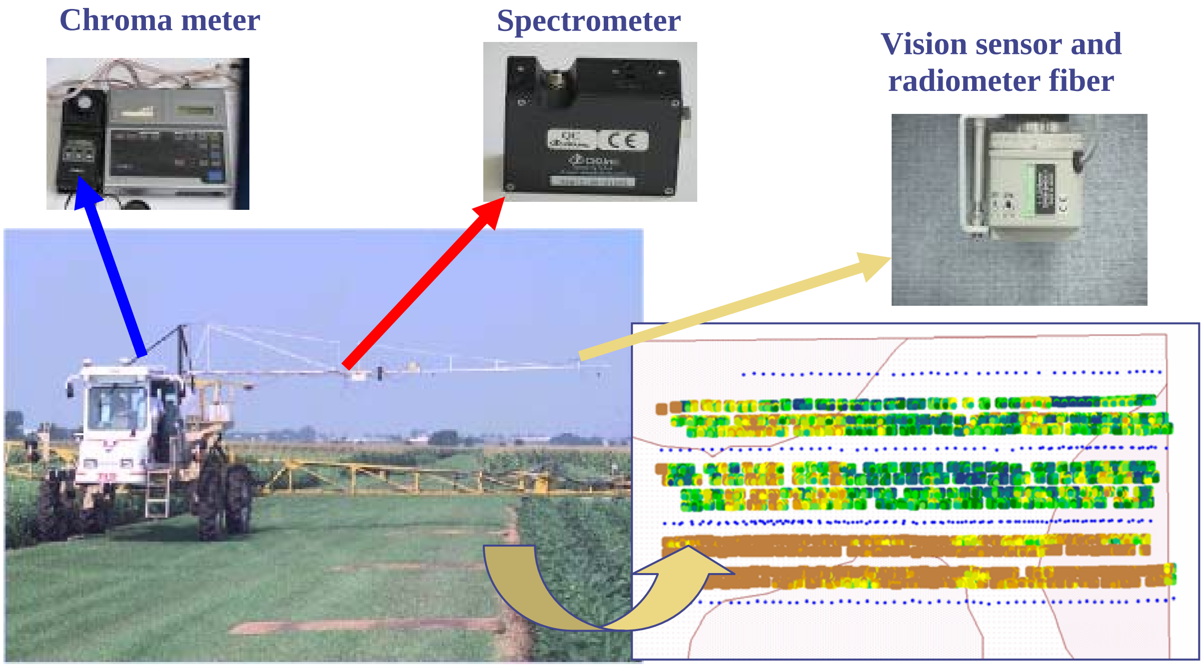


**Figure 2: Ground truth machine for crop field in-season mapping.**

***b) Real-time remote sensing system*** (Figure 3)

This system uses a high-resolution digital camera plus an automatic sensor calibration system to ensure the image data quality in an unstructured outdoor lighting condition. Images are collected every hour during the daytime. Real-time images are posted on a webpage (http://www.age.uiuc.edu/remote-sensing/RealtimeRS.htm). With this sensing system, we have been trying to fine tune a remote sensing system for crop canopy monitoring. Our goal was to eliminate the uncontrollable effects such as timing lighting conditions of the remote sensing images in the in-field variability mapping process.

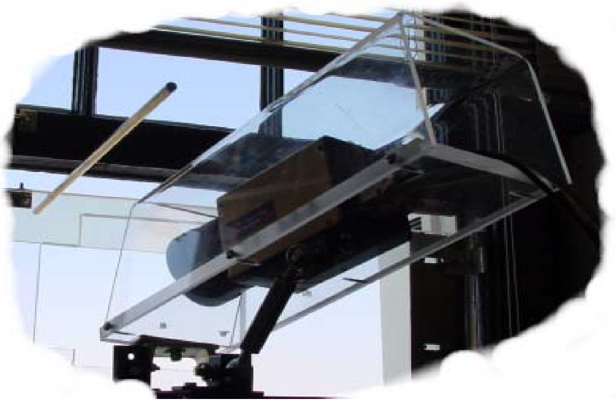


**Figure 3: High-resolution multi-spectral digital camera for real-time crop field sensing.**

***c) Unmanned aerial vehicle remote sensing (UAVRS) data collection system*** (Figure 4)

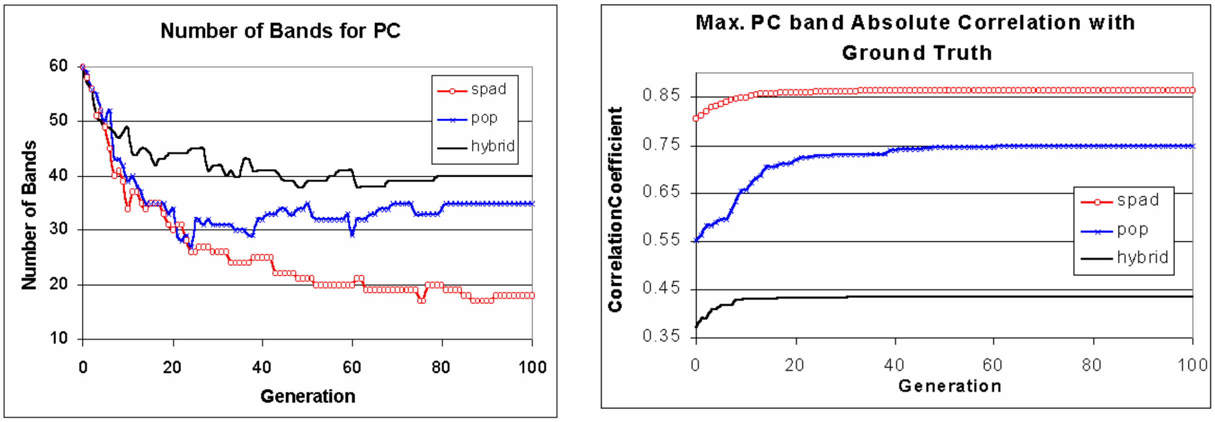
UAVRS uses a state-of-the-art autonomous light-weight helicopter and an auto-pilot system to carry cameras and other sensor to the air for field data collection and mapping. The goal of this project was to eventually develop an affordable and flexible data collection platform for agriculture industry so that people can get their images at the right time right place.

**Figure 4. Unmanned aerial vehicle for agricultural remote sensing and mapping**

### *d) Data processing and management for site-specific farming*

Besides hardware retrofitting, the researchers in ILARS have developed effective software technologies to process and interpret the massive amounts of data generated by precision farming production and research. The objective is to turn the data into useful information that will let the grower make more informed management decisions. Working with NCSA scientists, we have developed agriculture production related remote sensing data processing and data mining tools.

Example project in this area includes automatic remote sensing data pre-processing, new algorithm development for image feature extraction, and data mining. The distortion removal method was a sensor augmentation approach that measured the sensor platform attitude change during image acquisition.



a. Band Reduction with GA-SPCA

b. Maximum Absolute Correlation Coefficient with GA-SPCA

**Figure 5: GA-SPCA performance using maximum absolute correlation coefficient as fitness function. The three ground truth data sets are SPAD readings (indicating corn chlorophyll content), population, and hybrid.**

A genetic algorithm based selective principal component analysis (GA-SPCA) method was developed using the hyperspectral remote sensing data and ground truth dada (yield, nitrogen, plant population, etc.) collected from an agricultural field. This method uses a global optimizer – the genetic algorithm to select a subset of the original image bands, which first reduces the data dimension (Figure 5). A principal component transformation is subsequently applied to the selected bands. Hyperspectral image-feature extraction for precision agricultural soil nutrient classification project deals with the conversion from data to information process. To classify the high dimensionality hyperspectral imagery, techniques for increasing soil nutrient property class reparability, dimension reduction, and feature extraction were used (Figure 6). A procedure (SPCA+ML) was developed to include these techniques prior to apply Maximum Likelihood classifier for soil nutrient classification. The image processing procedure was tested with two US Midwest agriculture fields with four different soil nutrient factors.

### 3. Case Study Examples

Several on going case study research projects used our facilities to collect ground truth data and process remote sensing images. New projects have been initiated in our lab to compete for external funding. The following are some examples:

#### *a) Remote sensing for weed sensing*

In 2001, a case study was initiated to see how remote sensing could be used in the field of weed science. One main objective was on the basis of weed detection and had three parts, which were to determine if remote sensing could be used to distinguish weed species from soybean at various developmental stages, determine if remote sensing can be used to differentiate between several grass and broadleaf weed species, and to see if airborne imagery can be used to create a map based system for a variable rate herbicide application (Figure 8).

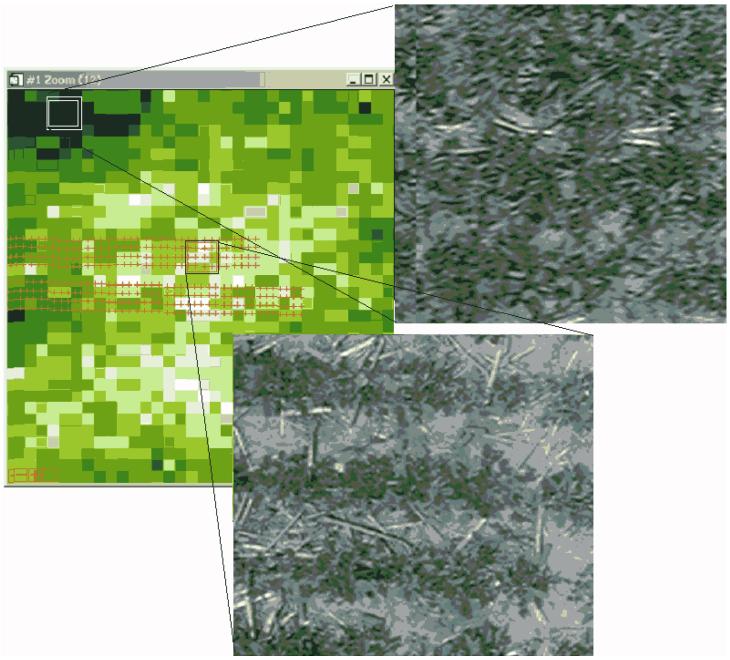


**Figure 8:** This shows different levels of weed infestation after the aerial image was processed and classified. The two photos show a representation of the high and low areas.

Monocultures of both broadleaf grass species were grown in separate plots. Spectral signatures (reflectance values) were collected weekly from an airborne hyperspectral system and a handheld spectral radiometer. Reparability analysis from the radiometer signatures determined that shattercane, common waterhemp, giant foxtail, and common lambsquarters could be delineated from soybeans in most of the visible spectrum (400 to 700 nm). In addition, shattercane and common waterhemp were also separable from soybeans in the near-infrared spectrum. Broadleaf weeds mixed with soybeans could be separated from grasses mixed with soybeans at a number of wavelengths in the visible and near-infrared spectrums collected using a handheld radiometer.

The second main objective was to determine if remote sensing can be used to differentiate levels of herbicide injury in soybean (Figure 9). An experiment was initiated to examine herbicide drift injury on soybean from a new postemergence corn herbicide, Callisto (mesotrione). Greenhouse studies are also being initiated to correlate soybean herbicide injury with soybean reflectance data from a hand held radiometer. Initial results of the field imagery shows that the different levels of soybean injury can be detected.

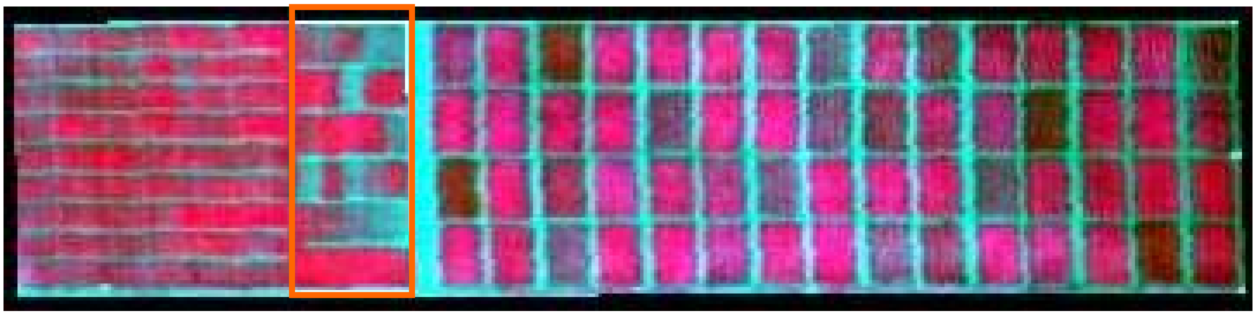


**Figure 9: This is what the aerial image taken 14 days after application looks like. The area inside the orange box is the soybean injury study using the different rates of Calisto. By visually looking at it, injury effects from the different herbicide rates used is noticeable.**

### *b) Remote Sensing Based VRT*

The AG 20/20 initiative project funded by the NASA and United Soybean Board (USB) has been actively support the study of the remote sensing based herbicide application. Field experiments were carried out in both a commercial soybean field and a University research plots.

A preliminary economic model of variable rate herbicide application has been developed. This model has been applied preliminarily applied to a comparison of variably applying Roundup to Roundup Ready soybeans.

### *c) Soybean Quality*

The spatial variation of soybean seed oil and protein concentration has been demonstrated at a field scale. We hypothesize that aerial images of crops during the late growing season, in combination with site property maps, can be used to delineate areas of similar seed oil and protein concentration within a given field. Relationship between site properties, hyperspectral vegetation indices and soybean seed protein, oil concentration were found with an $R^2$ of 0.67 and 0.49, for the 2000 and 2001 seasons respectively. The regression analysis indicated that PCs of vegetation indices predicted soybean seed protein and oil concentration more consistently than did site properties.

### *d) Prediction of Yield Zones*

Crop performance is often shown as areas of differing grain yield. Many producers utilize simple GIS color ramping techniques to produce visual yield maps with delineated clusters. However, a more quantitative approach such as an unsupervised clustering procedure is generally used by scientists since it is much less arbitrary. Intuitively the yield clusters are due to soil and terrain properties, but there is no clear criterion for the delineation. We compared the effectiveness of two delineation or classification procedures: quadratic discriminant analysis (QDA) and k-nearest neighbor discriminant analysis (k-NN) for the study of how yield temporal patterns relate to site properties. The k-NN had greater and more consistent successful classification rates than did QDA. Classification success rate varied from 0.465 to 0.790 for QDA while the k-NN classification rate varied from 0.794 to 0.874. This shows that areas of certain temporal yield patterns correspond to areas of specific site properties. Although profiles of site properties differ by crop and production field, areas of consistent low maize yield had greater shallow electrical conductivity ($EC_{shallow}$), than those of consistent high maize yield. Furthermore, areas of consistent high soybean yield had lower soil reflectance than those areas of consistent low yields.

### *4. Teaching*

One new course, AG E 396 Precision Agricultural Remote Sensing, was developed and taught in the Fall Semester of 2000. The course was designed for students in College of ACES; it covers major techniques and applications of digital remote sensing systems in precision agriculture. Using examples to teach students how to work with airborne and ground–based remote sensing data. Multiple existing courses used our facilities to teach students precision farming remote sensing techniques.

All together, six graduate students (4 in Ag E, 2 Crop Sci.) are supported by the remote sensing projects from ILARS. Three Ph.D. student and two M.S. students finished their degrees. The lab continues the support for classes that teach students remote sensing techniques as they relate to precision farming.

### *5. Outreach*

We hosted several local, domestic, and international visiting scholars. Researches from ILARS have made presentations and exhibitions on major conference like ASAE, ASPRS, and InfoAg 2001. All together, more than 100 technical papers were published and 6 dissertations finished. Also, new findings were broadcasted through local and national news agencies. Experiments were carried out in commercial farms to demonstrate new remote sensing based field operations.

With newly developed equipment, we provided unique remote sensing data collection and data processing services to researcher and the producers. Researchers from ILARS presented papers and held displays in national and international conferences like ASAE, ASPRS, ASA, Precision Ag, and ECPA. We are working closely with similar research labs at other universities and also with government agencies such as NASA and USDA. ILARS has also developed a very good co-operative relationship with other research institutes and private companies in Asia, Europe, and South America. We have been hosting several local, domestic, and international visiting scholars in ILARS.

Working closely with NASA contractors, we have also provided remote sensing data collection and data processing service to the local agricultural industry. For example, we helped University extension service in the study of remote sensing tile line identification project.

## *Beneficiaries:*

From the current results we can see that the remote sensing application is a promising approach for crop production. Even with a relatively conservative experiment design, we have got impressive performance. From these results, practical procedures can be developed to realize remote sensing based precision applications with appropriate image processing tools. In addition, field-scouting system can be eventually implemented to monitor crop growth and pest infestation conditions in the crop field.

The infrastructure developed with the program has been the valuable resources for researchers and the industry in their study and production.

## *Leveraged funding:*

All together, more than 17 major co-operative proposals were developed using ILARS resources and have been submitted to different agencies.

External funding for “AG 20/20 initiative research project” from NASA/USB ($250,000.00) has been received and project study and experiments have been carried out. More than $500,000 external funding has been received from different sponsors (Deere, NCRARE, USDA SBIR).