AIRBORNE REMOTE SENSING (ARS) FOR AGRICULTURAL RESEARCH AND COMMERCIALIZATION APPLICATIONS

(White Paper)

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Abstract

Tremendous advances in remote sensing technology and computing power over the last few decades are now providing scientists with the opportunity to investigate, measure, and model environmental patterns and processes with increasing confidence. Such advances are being pursued by the Nebraska Remote Sensing Facility, which consists of approximately 30 faculty members and is very competitive with other institutions in the depth of the work that is accomplished. The development of this facility targeted at applications, commercialization, and education programs in the area of precision agriculture provides a unique opportunity. This critical area is within the scope of NASA goals and objectives of NASA's Applications, Technology Transfer, Commercialization, and Education Division and the Earth Science Enterprise. This innovative integration of Aerospace (Aeronautics) Technology Enterprise applications with other NASA enterprises serves as a model of cross-enterprise transfer of science with specific commercial applications.

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An Overview of Capabilities

Rationale

Tremendous advances in remote sensing technology and computing power over the last few decades are now providing scientists with the opportunity to investigate, measure, and model environmental patterns and processes with increasing confidence. Much of the underpinning data acquisition for such research is multi-disciplinary and synoptic in scale, be it global or local. Airborne remote sensing of the earth is playing an increasing role in the support of fundamental research into the natural environment and its inherent physical, biological, and chemical processes. Furthermore, airborne remote sensing considerably extends the capabilities of traditional satellite remote sensing in terms of resolution and operational planning by providing better spatial accuracies and opportunities for timely monitoring.

The University of Nebraska-Lincoln's (UNL) remote-sensing program and the University of Nebraska at Omaha Aviation Institute (UNOAI) have cooperatively developed the Nebraska Remote Sensing Facility. The remote-sensing program at UNL consists of approximately 30 faculty members and is very competitive with other institutions in the depth of the work that is accomplished. The University of Nebraska at Omaha (UNO) has a strong aviation science and technology program which facilitates the facility air operations for the project. The combined strength of these two institutions creates a unique specialty that will be a resource not only for Nebraska, but also for the entire nation.

The development of an airborne remote sensing facility targeted at applications, commercialization, and education programs in the area of precision agriculture provides a unique opportunity. This critical area is within the scope of NASA goals and objectives of NASA's Applications, Technology Transfer, Commercialization, and Education Division and the Earth Science Enterprise. This innovative integration of Aerospace (Aeronautics) Technology Enterprise applications with other NASA enterprises serves as a model of cross-enterprise transfer of science with specific commercial applications.

Nebraska ARS Collaborative Research Team (CRT)

The Nebraska NASA EPSCoR program at the UNOAI currently provides support for an Airborne Remote Sensing Collaborative Research Team (ARS CRT). This highly skilled team of researchers operates the Nebraska Remote Sensing Facility through which a variety of technological advancements are being made. The ARS CRT is highly productive in its research endeavors, providing multi-institutional and inter-disciplinary research opportunity for Nebraska.

The UNOAI has designated a Flight Operations Coordinator for the ARS facility who oversees administrative operations of the aircraft including flight policy, fiscal issues, dispatching, and personnel. The Flight Operations Coordinator supervises start-up and actual flight operations including daily logistics, all piloting, safety programs, and coordination with the Nebraska Department of Aeronautics, Federal Aviation Administration, other agencies, and maintenance facilities. An air operations research specialist (pilot) conducts the actual research flights in the aircraft. Pilot interns, provided by the UNOAI, serve as co-pilots to assist research operations and provide additional safety. The acquired aircraft is based out of the Omaha Millard Airport where hangar and office facilities are provided to support operations management by the UNOAI. ARS research investigators determine the priority of research mission requests and, in conjunction with the Flight Operations Coordinator, establish the schedule and logistics of the flight. Safety of the mission is the highest priority and is determined by the pilot and the Flight Operations Coordinator.

This facility also fosters close interaction between the university and industry as well as government agencies nationwide. There is currently no university within the United States that operates a full-time airborne remote sensing platform. Since remote sensing technology is poised to enter the commercial market in the near future, the advantage of such a facility will benefit not only the conduct of high-quality research, but also help spawn spin-off companies designing novel low-cost airborne sensor systems. This result provides opportunity for commercialization of research and immediate transfer of technology.

Current Research

The ARS CRT's current research efforts include a variety of projects. The first involves the current suite of operational instruments. These instruments are being calibrated and validated. Calibration is performed using standard surface targets (with known reflectance characteristics, such as concrete, tarpaulin, etc.) for optical and laser sensors, and active and passive corner reflectors for radar sensors. The calibration is performed under different environmental conditions, with the information being saved for use while analyzing data. The validation procedure is required in order to make sure that the calibrated sensors provide meaningful data when used to measure the reflectance of known terrain and vegetation. Issues such as noise contamination and dynamic range limitations are being studied and methods to overcome these problems are being developed.

The ARS CRT is also performing comprehensive airborne data collection and data analysis. Data is being collected over crops and vegetation at the Mead Test Site in Mead, Nebraska. The team is also taking concurrent ground measurements of vegetation biophysical properties and underlying soil parameters, such as leaf area index (LAI), crown cover, leaf water potential, and soil moisture. ARS is developing forward and inverse models to analyze the data. The forward models are developed first to predict the reflectance from a given set of crop and soil conditions. Using comprehensive simulation, the inversion models are being developed to obtain vegetation and soil properties using remote sensing data. The models will be refined using actual data acquired by the ARS CRT sensors.

Current plans include the development of a detailed study and analysis of various error sources, some unique to airborne remote sensing. This will aid in understanding their impact on the retrieval of biophysical and soil properties using the ARS CRT inversion algorithms. These include instrument noise, aircraft pointing errors, and calibration uncertainty, among others.

Additionally, the ARS CRT has developed microwave scattering models for natural media to analyze scatterometer and SAR measurement data and retrieve target biophysical parameters. This includes the development of a four-component microwave scattering model. First, the generalized Rayleigh-Gans (GRG) approach, the physical optics (PO) approach and the Bridging approach between the quasi-static and physical optics approach (GRG-PO) for disk scattering amplitude formula are compared. Additionally, the PO approach is being extended from a circular disk shape to an elliptic disk shape, which better mimics a natural leaf in the crop. Then, the corrected cylinder scattering amplitude formula and the original formula presented by Karam et al. for the stem are compared and analyzed. Finally, a precise numerical computation algorithm is being developed to combine radiative transfer theory with theoretical simulation of scattering. The model can be applied over a broad frequency range. In other words, the GRG approach is applied at low frequencies, while the PO approach is applied at high frequencies. Furthermore, theoretical simulation based on the improvement mentioned above is conducted for scattering from corn canopies.

Data Acquisition

The collaboration between UNL and UNO, seen through the ARS CRT, provides a unique opportunity to utilize the capabilities of UNOAI's single-engine Piper Saratoga. This aircraft gives UNL's remote-sensing scientists a ready-at-hand airborne platform and provides the UNOAI with advanced aviation technology applications for educational support. University ownership of an aircraft equipped with key sensors allows flexibility in data acquisition and demonstrates significantly enhanced precision.

The Saratoga was modified to accommodate the ARS CRT's remote sensing equipment. The following sensors serve as equipment on the aircraft:

- Kodak DCS-420 color-infrared digital camera
- Analytical Spectral Devices (ASD) spectroradiometer operating in the 350-2500 nm wavelength range
- NASA Goddard Space Flight Center provided and refurbished Airborne Laser Polarimeter System (ALPS) operating at 532 and 1064 nm wavelengths
- UNL developed noise radar scatterometer operating at 1.275 GHz (L-band) and 10 GHz (X-band) frequencies
- Canon 2500 digital video camera

A major goal is to enhance the ways in which airborne remote sensing technology can be utilized in agricultural applications, with special consideration given to applications involving precision agriculture. In order to be used in a practical manner for precision agriculture, remote sensor systems possess the following characteristics:

- spatial resolution (on the ground) of five meters or less

- two- or three-day repeat cycle
- spectral coverage in at least the green, red, near-infrared portions of the spectrum (mid-infrared is desirable), as well as in the microwave regime
- data distribution in near-real time and at low cost

A state-of-the-art AISA hyperspectral imager, operating over the 400-900 nm wavelength range, has been purchased and is being integrated within the Piper Saratoga. This sensor was calibrated at the NASA John C. Stennis Space Center, Mississippi, in February of 2002, and flown over selected sites in Southern Mississippi including the delta region and coastal areas in the Gulf of Mexico.

Construction of the multiwavelength lidar system has also been completed and the ARS CRT is currently performing preliminary field tests and calibration of the system. This multiwavelength lidar system will also be incorporated into the onboard aircraft equipment. This system employs a Nd:YAG laser which emits radiation at two wavelengths: the fundamental at 1064 nm and the frequency-doubled at 532 nm. Both laser beams are highly linearly polarized (100:1 extinction ratio) and have a beam divergence angle of 4 mrad. The receiver consists of four channels: two for each wavelength. Each wavelength contains one channel to measure co-polarized backscatter and one channel to measure cross-polarized backscatter. In addition to the polarimetric information that can be gathered, the lidar system also has ranging capability. Thus, the ARS CRT's lidar system is capable of performing studies of vegetation canopy structure as well as characterization of vegetation depolarization.

The ARS CRT has designed the Synthetic Aperture Radar (SAR), which is currently being tested at the Nebraska Remote Sensing Facility. Additionally, investigations are being conducted regarding the packaging method that will be pursued when the SAR is mounted within the Saratoga's remote sensing equipment. The SAR is one of the main tools for microwave remote sensing because of its multi-dimensional high-resolution imaging capability and its ability to operate in nearly all weather conditions, day and night.

The SAR system is an X-band, stepped-chirp FM, single polarization radar system. One of the unique features of the system is that the signal generation consists of a timing-controlled D/A converter and VCO arrangement to generate the stepped-chirp signal, thereby allowing for less design complexity and lower overall system cost. The individual block segments including waveform generation, transmit and receive hardware, antennas, quadrature detection and image signal processing have been finalized. The microwave system of the SAR has been designed and constructed and is currently under calibration and testing. The system is undergoing field tests from a 10-meter high van-mounted boom on a variety of terrain types. The following experiments have involved use of the SAR:

- Theoretical efforts have been commenced to model the microwave as well as optical scattering from leaves and crop canopies;
- Theoretical explorations have been commenced to understand the limitations of interferometric SAR (InSAR) and various design methodologies; and

- New data has been obtained regarding femtosecond fluorescence characteristics of single leaves, thus, various options for the design of the laser fluorescence sensor for crop stress monitoring are being explored.

In addition to the above, the ARS CRT is investigating new sensor development. This includes the interferometric SAR (InSAR) and the laser fluorescence sensor. This team is working aggressively to develop and test these two sensors. Initial analytical and experimental study has provided us with the necessary information on the major issues involved in the development of these sensor systems. The ARS CRT is exploring various options for the design of the laser fluorescence sensor for crop stress monitoring. Preliminary designs are underway and the development and initial testing of these sensors is expected to be completed within the next year.

Specialized Airborne Capabilities

- Aircraft platforms provide a unique mechanism for obtaining data and images at very high spatial resolution, which is required for site-specific management in agriculture.
- Airborne data can be acquired at precisely specified, often critical, times during the growing season.
- Aircraft platforms provide opportunities to deploy commonly available and widely-used sensors such as multi-spectral digital and video cameras. As a result, these platforms test innovative next-generation sensor technologies that are neither currently available on satellite platforms nor are likely to be available within the upcoming decade (e.g., laser reflectometers, imaging spectrometers, laser fluorescence sensors), and to configure arrays of diverse types of sensors as needed.
- Data acquired by means of airborne sensors for agricultural applications can be delivered to producers and managers in near-real time and at low cost.

It is also anticipated that both satellite and aerial remote sensing information can be used to develop better range management, land management, and water quality.

Collaborative Efforts

The ARS CRT conducts monthly meetings in which all faculty and senior personnel present research results and discuss plans for the future. At times, graduate students also attend to present their progress. These meetings provide an opportunity for all researchers to gain insight on other internal research and give constructive comments and suggestions. Thus, the team is able to ensure that the entire project as well as individual sub-projects are progressing steadily.

The ARS CRT is developing relationships with three NASA institutions. Those include: Goddard Space Center in Green Belt, Maryland; the Jet Propulsion Laboratory in Pasadena, California; and Stennis Space Center in Mississippi. More formal collaborations will be sought with these institutions as concrete research results become available. Active collaboration will commence following airborne remote sensing data collection. Various NASA personnel have expressed interest in this collaboration.

The ARS CRT is actively seeking underrepresented groups to participate in the project. Flyers and announcements are developed to specifically to target these groups and are posted throughout the UNL campus in the near future. Additionally, senior faculty mentor junior faculty and graduate students by discussing research results and providing guidance for research direction. Mentoring also takes place through work on joint research proposals.

Primary Research Applications

One of the ARS CRT's primary foci is the use of airborne remote sensing data for estimating agricultural parameters of interest, such as crop stress and soil moisture. Both these parameters impact the well-being of a large section of the populace and are very relevant to the agriculture-based economy of Nebraska and the Great Plains region. The proposed research and outreach activities are expected to be useful to small farmers as well as large agribusinesses.

Another focus of the team's work is in the area of hail damage to crops. The ability to rapidly monitor hail-damaged areas and estimate the loss would be a tremendous asset to insurance agencies as well as government decision-makers. The ARS CRT is developing the necessary tools using both optical and microwave remote sensing data. In addition, they are exploring ways to estimate the extent of drought and brush-fire hazard regions based upon airborne remote sensing data.

Remotely sensed data hold great potential for use in crop monitoring and diagnostics. In order to analyze and monitor terrestrial vegetation by means of remote sensing, basic research is needed whereby the relationships are unambiguously elucidated between spectral response and biophysical parameters such as vegetation fraction, leaf area index, above-ground biomass, and pigment concentrations. Discovering, identifying, and locating stresses in agricultural crops is a key to both maximizing yield and improving farming efficiency.

The Airborne Remote Sensing Collaborative Research Team project provides an extraordinary opportunity to combine resources through the incorporation of additional aviation-related research. Precise determination of position, velocity and time (PVT) is essential to obtain accurate information about the absolute reflectance characteristics of remote sensing targets. In airborne systems, precision PVT presents a new challenge due to atmospheric conditions, which induce random motion around the aircraft yaw, pitch and roll axes. The precision and reliability of state-of-the-art GPS navigation equipment can be analyzed and enhanced by referencing data acquired from Differential GPS (DGPS) reference stations fixed at precise geodetically surveyed positions. Calibration algorithms can be developed to provide accurate aircraft orientation data to the pilot and allow the airborne sensors to accommodate for the trigonometric errors induced by random motion of the flight. Additionally, the synergism of the remote sensing project and a navigation paradigm incorporating a geographic North versus the traditional magnetic North model will provide both efficient operation and new data to continue research begun by Dr. Mike Larson to study the navigational task performance benefits of using the geographic North model.

Vision, Mission, Objective

Research in remote sensing has already been established as a priority research area at the University of Nebraska. CRT remote sensing research within the University engages numerous units/departments, colleges, and campuses, thus making this a truly multidisciplinary effort. The ARS CRT vision focuses expertise and experience on the technologies of remote sensing, geographic information systems, global positioning systems, real-time aircraft-data reception, and field measurement in agriculture. Although the CRT's primary focus is to conduct basic research, it also emphasizes the practical applications that will or might be linked with private enterprise. In particular, the team is receptive to development of applications in conjunction with associated investigators who represent private companies involved in agricultural applications. This approach seems appropriate given the fact that the economy of the State of Nebraska (and the Great Plains region) is very much oriented to and dependent upon agriculture. The ARS CRT is developing techniques for economic and timely monitoring of the condition of agricultural crops, such as corn and soybean, which form a large portion of the state's economy. A variety of outcomes have resulted from ARS research and can be viewed in Appendix A.

Recent Activities

1. Integration of the following sensors aboard the aircraft and commenced data collection:
    a. Kodak DCS-420 color-infrared digital camera,
    b. Analytical Spectral Devices (ASD) spectroradiometer, and
    c. Canon 2500 digital camera;
2. Purchase of the AISA hyperspectral imager, which has been integrated within the aircraft - data collecting with this sensor has commenced;
3. Construction of the multiwavelength lidar system has been completed and preliminary field tests with this equipment are currently being performed;
4. The synthetic aperture radar (SAR) has been designed and is currently being tested - this system is being packaged to be mounted within the aircraft;
5. Theoretical efforts have commenced to determine microwave and optical scattering from leaves and crop canopies;
6. Theoretical efforts have commenced to understand the limitations of interferometric SAR (InSAR) and various design methodologies are being explored; and
7. New data on femtosecond fluorescence characteristics of single leaves has been obtained, and various designs of the laser fluorescence sensor for crop stress monitoring are being explored.

Further Information

If you would like further information regarding airborne remote sensing, or would like to collaborate with the Nebraska CRT for conducting a mission of your own, please contact:

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Appendix A

Team Outcomes

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