

Developing a Remote Sensor Deployment Testbed

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Abstract—We propose the design and construction of a suite of instrument modules to create a testbed for the deployment of remote sensors. Parameters of the testbed include size, weight and power constraints suitable for small scale aerospace vehicles, anticipating vigorous growth in Unpiloted Aerial Vehicle (UAV) deployment, but the testbed design will allow for deployment on other vehicles including; field towers, tractors, automobiles, and aircraft. The testbed will support a wide range of applications, encouraging remote sensing solutions in new disciplines as well as demonstrating the complete range of engineering knowledge required for successful deployment of remote sensing instruments.

Multi-disciplinary education is a primary component of this proposal where small groups of graduate and undergraduate students will develop components with aspects in sensor fabrication, location and position control, wireless communication, vehicle integration, software development, and applications and field testing. We anticipate participation from students in fields including; mechanical and aerospace engineering, computer science, electrical engineering, environmental science, and biological and agriculture engineering.

This project has the overarching environmental application goals of monitoring properties using remotely sensed imaging data for agricultural applications, natural resource management, urban studies and other projects. The technical focus is on small embedded systems that allow rapid, low cost deployment capability, and real-time or near real-time data analysis and decision making.

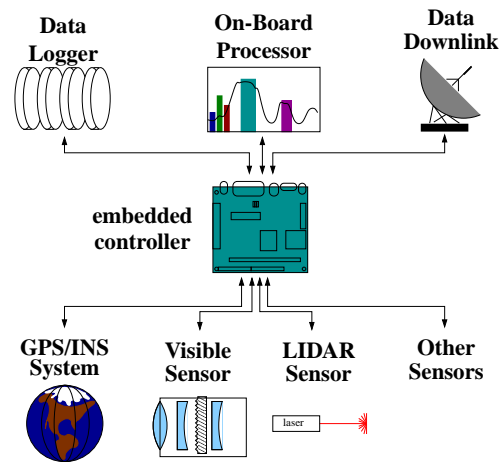


Fig. 1. Remote Sensor Deployment Testbed

To achieve these goals, we propose to develop a remote sensor deployment testbed. This testbed will have a modular approach to the development of new small remote sensing devices. It will include separate components for communication, digital signal processing, and geographic location and sensor position. Software components that expose these capabilities will also be developed. The testbed is notionally described in Figure 1.

This architecture will allow developers to concentrate on the development of new sensors using the existing modules of the testbed for ancillary requirements. The first sensor developed will be a multi-spectral sensor designed for a host of general purpose applications

including spatial machine vision applications; but with spectral capabilities designed to accommodate a wide range of agricultural and natural resource management goals. An active Light emitting Radar (LIDAR) sensor will be designed. The LIDAR will provide range finding, surface topography and water detection capabilities.

Applications will be developed in the project to exercise the testbed and evaluate its general applicability as a general remote sensor testbed. Existing sensors currently being deployed in agricultural engineering projects will be integrated in the testbed as an additional test of the system.

To develop this sensor platform, four main areas need to be addressed; 1) development of adequate sensor technologies, 2) standardized wireless sensor control and communication, 3) standardized GPS derived location awareness and 4) integration of the sensor instruments the communication, location and on-board processing to deliver data products.

I. TESTBED COMPONENTS

A. Sensor Development

The primary sensor design will be a simple imaging system using four separate high sensitivity visible/Near infrared digital cameras. These cameras offer the best scientific applicability, and are relatively inexpensive due to their popularity. The cameras will be sensitive enough to operate with narrow spectral filters, allowing for a wide range of filter choices for different precision agriculture and other natural resource management applications. Table I describes the sensor bands that will be used with this sensor. Not all of the spectral bands in Table I can be operated simultaneously, and the bands used will be based on the particular application for the sensor. Table I also shows a thermal image band. An additional thermal camera will be designed as an additional sensor system.

| Region | Band Center [um]] | FWHM [nm] |
|-----------|--------------------|-----------|
| Blue | .49 | 12 |
| Green | .55 | 12 |
| Red | .67 | 11 |
| Red Edge | .70 | 7 |
| Red Edge | .75 | 7 |
| NIR | .77 | 7 |
| NIR | .80 | 11 |
| NIR (H2O) | .86 | 20 |
| LWIR | 10 | 400 |

TABLE I
SENSOR BANDPASSES

An active LIDAR sensor working in the near infrared range will be designed for this project. Actual construction of the sensor will depend on final costs of the sensor, and the designed size and power requirements. A preliminary study indicates that a small low-power LIDAR is possible within our budget and instrument limitations.

B. Wireless Communications

One important feature of the testbed will be that it can be quickly deployed in various locations – for example using RC Modelers aircraft or farming machinery – which have limited power and networked capabilities, but still allow for real-time control and data-downlinking. This application requires that a wireless communication system, based on 802.11 or 802.16 standards be included as a component of the testbed.

C. Location and Navigation System

Another component of the testbed is an integrated GPS unit, which will allow for recording of positioning information. This will also require a separate module in the testbed.

D. Module Integration

There exist a number of requirements which are not directly applicable to the sensor itself,

but rather to additional on-board components of the system. These include telemetry capabilities; navigation and Geo-location systems, and on-board Digital Signal Processing (DSP) functionality. A master embedded controller will be developed to integrate these separate systems within the testbed. The controller will also be the unit for programmed operation, and interactive control from the ground station.

II. TESTBED DEPLOYMENT

The application requirements driving the sensor and module integration development imply an additional set of constraints on the sensor vehicle. These constraints closely mirror general requirements for the next generation of rapidly deployable platforms. For example, in a recent NASA workshop on suborbital vehicles, a list of desired “miracles” included: (a) Sensor Web: Suborbitals as leaders in developing a sensor web so scientists, students, the public can get data more easily. (b) “Indy 500” type systems for UAVs. When they come into the “pit”, new instruments are slapped on, and it’s quickly redeployed. (c) Standardized interfaces for data systems and sensors (d) Operation by few crew members (e) Significantly miniaturized instruments (f) Personally designed platforms (g) System-level integration.

One important goal of this project is to encourage development of sensors that can be deployed by these new suborbital UAVs. As such, the primary vehicle used for testing the testbed will be based on an existing unpiloted airplane operated by the UC Davis CalSpace lab. This vehicle, based on a SIG Senior Cadet RC airplane, is a simple and low cost option with limited capabilities in terms of automated control, time aloft, payload capacity, reliability and power availability. However, some of the constraints of this vehicle match or are similar to those of a more fully functional UAV, and offer a good design target for the testbed.

However, deployment of the sensor testbed will not be limited to this vehicle. Other existing sensor systems to be tested are currently deployed on terrestrial vehicles such as trucks and tractors. Also, when appropriate, we will consider deployment of the testbed on more traditional manned aircraft. Reasons for this may be that power constraints are too limiting for an active sensor, or that airspace concerns over an area like urban Santa Barbara preclude UAV operation. The project is committed, however, to developing a testbed which encourages new sensor deployment on aerospace vehicles and unmanned suborbitals in particular.

The UC Davis Mechanical and Aeronautical Engineering Department has an independent CalSpace proposal to build a UAV with extended capabilities as a platform for remote observations. That proposal is to design, fabricate and test fly a UAV, that will be used by researchers at several UC campuses to fulfill their environmental application missions for observation and data collection. Besides UC Davis, interest in this UAV has been acknowledged by faculty at UCLA and UC Merced. Our instrument testbed will facilitate their collaboration.

Our CalSpace proposals have been integrated in the sense that the requirements for a suitable UAV platform to enable advanced sensor development and mission design have been articulated. Especially anticipated are improvements in automated control and increased time aloft. Both features will open many new application scenarios for remote observations in general.

III. APPLICATIONS

Figure 2 illustrates the applications that can be supported by integrating different sensor technologies with different testbed component functionalities. Color bars under the UAV represent the four types of remotely sensed data as noted on the upper left. The data type leads to the corresponding data products, identified

along the circles on the right. Data output products are ordered into the approximate time to delivery. Many important parameters are based on image indices, and do not require extensive image calibration. Some products require reflectance (or emittance) retrievals. Data acquired at field sites that contribute to this analysis are in white circles on the left side of the diagram. Following spectral retrieval, additional analysis can be performed. The algorithms near the lower right require GIS inputs to geolocate the image and register it to ground coordinates. We will investigate how much geospatial registration is possible in a real-time environment. Lastly, data is stored in an archive and is accessible for applications and through a web based browser.

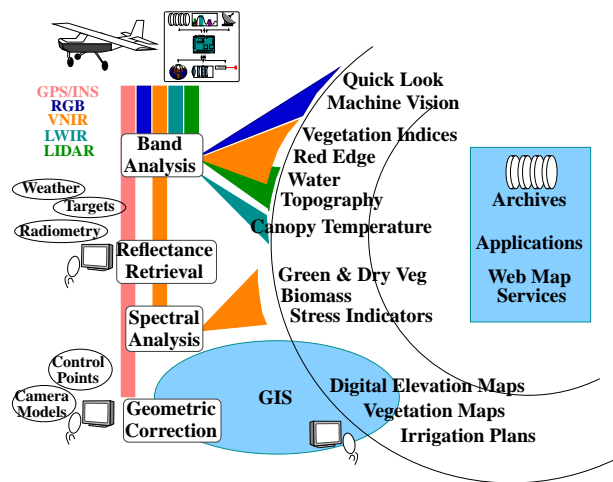


Fig. 2. Applications supported by various combinations of sensors, on-board processing, and command-center data processing

A. Reliable Ad Hoc Networking

While the primary purpose of this testbed is to develop new remote sensing sensors, using it as a bridge for an ad hoc sensor network exercises almost all of the same hardware on the platform, and demonstrates a very useful additional application. The sensor testbed, in particular the wireless communication module can

be used to demonstrate the ability to maintain a reliable ad hoc network between low and mid-bandwidth devices, such as sensor networks, with varying degrees of power consumption over rural and urban settings. The test is to deploy a UAV over an area that is populated with a sensor network. Because of distance and topology, a network developed only with the sensors would be incomplete and would not connect all nodes. Further, there would be no access point to serve as a center for monitoring. The addition of a UAV communication system would allow holes in the sensor network to be connected, and would also provide an access point to the command center.

B. Rapid Remote Sensing Platform Deployment and Data Synthesis

Figure 3 describes the main application scenario for the testbed. This scenario demonstrates a UAV platform, sensor suite and system integration that can be readily deployed with enough processing capability to synthesize data and provide direct outputs to field operatives. Remote sensing offers the best chance of real-time information gathering over large areas. However, remotely sensed imagery are typically difficult to integrate into real-time decision making because of hurdles in machine processing.

In addition to agricultural applications, other examples of real time data needs include; tracking of wildfires, mapping congestion and traffic flow, structure condition, and integrity detection, e.g. levee breaks.

C. Alternate sensor testing

There are multiple existing sensor systems currently developed at UC Davis. These include systems for machine vision algorithms based on simple color imagery, presence/absence monitors of vegetation, and hyperspectral line

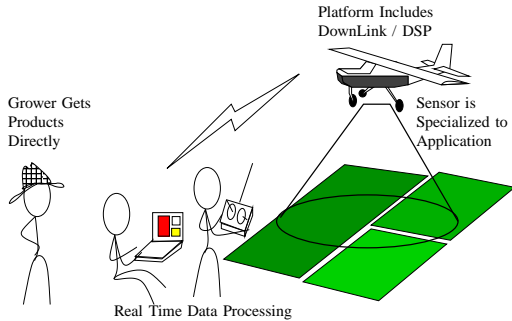


Fig. 3. This deployment shows the testbed fielding a sensor suite designed for agricultural applications. Real time data download and image processing provide the grower immediate information about their crops.

scanning instruments for detecting spectral differences in crops and weeds. Although not all of these instruments are necessarily suitable for aerospace instrumentation, they demonstrate generalities in remote sensing development for field applications. Participants in this project, in particular, Dr. Slaughter, have extensive experience in the design, construction and deployment of sensors in field applications. Many of these instruments are also integrated into real-time decision making applications [1], [2]. These sensors will be investigated as additional targets for the testbed to assess the utility of the other supporting modules.

D. Urban Deployment

Dr. Roberts has developed remote sensing applications in the Santa Barbara area for many years. In terms of test areas, the Santa Barbara urban area is an ideal test zone, with information on building materials as well as road quality and condition, with about 300 reference points on roof types, roads, etc., plus a full spectral library [3]. Xiao et al. [4] have developed a library for identifying and mapping trees in urban settings. This is an application domain well suited to the sensor testbed.

E. Canopy characteristics and irrigation monitoring with LIDAR

Another sensor identified is a scanning LIDAR to measure canopy and ground height. The combination of spectral images with LIDAR open new possibilities for environmental applications [5], [6]. In addition, the wavelength of some range finding LIDAR instruments is sensitive to the presence of water, and can be used to plot surface water amounts, for example to monitor irrigation patterns in agricultural fields.

IV. EDUCATION, TEACHING, AND OUTREACH

The proposed research is inherently multidisciplinary, addressing fundamental methods, techniques, and applications in Computer Science, Mechanical Engineering, Electrical Engineering, Remote Sensing, and Environmental Sciences. Most of the research described in the previous sections will be conducted in collaboration with graduate students pursuing advanced degrees in the above areas. We will involve undergraduate students and encourage them to pursue advanced degrees by participating in advanced research projects based in this program.

We are mindful of the shortage of skills in the applications communities that are required to design, build, and use sophisticated instrumentation and data management infrastructures for remotely sensed data. The special status of CalSpace in accessing undergraduates, graduates and post-graduates will facilitate developing a true interdisciplinary program on remote sensing research in agriculture, natural resources and environment.

Our education and teaching efforts will be complemented by a project Web site through which we disseminate not only software components and technical papers but also provide users and communities interested in this

project with various means to directly utilize our results, including detailed descriptions of the various modules in the testbed, so that other researchers can replicate successful developments of this project, and hopefully contribute new modules, software, and application development.

There is a strong commitment in including students from under-represented groups in our research. Departments at the UC campuses have ongoing recruiting efforts to attract graduate students from under-represented groups. Given the inherent excitement and appealing nature of the research topic, we are optimistic that we will be able to attract good students from diverse backgrounds; thus, we hope to increase, in the long-term, the diversity of the faculty applicant pool to U.S. universities.

V. PARTICIPANTS

The PI for this proposal is Dr. Susan Ustin. Dr. Susan Ustin's Center for Spatial Technologies And Remote Sensing deals primarily with interpretation of remote sensing imagery, applications of geographic information systems, and landscape modeling of vegetation, hydrology, and climatology. CSTARS is proud to be a California Space Institute Center of Excellence. The Davis campus is home to the CalSpace Center of Excellence for Agriculture, Natural Resources and Environment. The UC Davis CalSpace Center leads in remote sensing R&D with applications in agriculture and resource management. One of its major priorities is advancing precision agriculture and workforce training in remote sensing through public outreach.

Mr. Hart currently has a Space Grant fellowship to investigate using a UAV – a simple RC modeler based system – as a platform for embedded systems and field deployable sensors. The vehicle from this project will be available for the testbed developed for this application.

Dr. Slaughter has extensive experience in precision Agriculture, including the use of remote sensing instruments deployed on farming machinery to provide real-time feedback, for example pinpoint weed control application. This is a good potential platform and application for deployment of the testbed sensor system.

Dr. Roberts, from UCSB, has interests in remote sensing of vegetation, geology, and ecophysiology. Dar is a collaborative partner in Terrestrial Plant and Ecosystem Ecology at UCSB. Dr. Roberts' experience in urban remote sensing also provide opportunities for applications outside precision agriculture and natural resource management.

Additional collaborators include; Dr. Raju Pangey, Computer Science, sensor network and networking specialist at the University of California, Davis. and Dr. Michael Gertz, Computer Science, streaming remote sensing imagery.

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