Homeland Security Affairs

Volume II, Issue 1 | 2006 | *Article* 4

Deconvolution of Plant Type(s) for Homeland Security Enforcement Using Remote Sensing on a UAV Collection Platform

James A. Tindall*

*jtindall@uskka.com

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**
4. TITLE AND SUBTITLE **Deconvolution of Plant Type(s) for Homeland Security Enforcement Using Remote Sensing on a UAV Collection Platform**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School ,Center for Homeland Defense and Security,Monterey,CA,93943**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**17**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Deconvolution of Plant Type(s) for Homeland Security Enforcement Using Remote Sensing on a UAV Collection Platform*

James A. Tindall

Abstract

The technological ability to distinguish drug plants from other plant types has important implications for law enforcement (LE), wildfire recovery, reservoir protection, environmental impact, agricultural issues, and military concerns. This ability, termed "deconvolution," can be a valuable technological tool to fight drug trafficking and thus the war on terror. The use of computers and associated hardware, as well as data-base and high-speed computing capabilities, are an integral part of the technological process that will facilitate and make possible plant species identification from airborne sensors. This paper will focus on utilizing Synthetic Aperture Radar (SAR) and/or hyperspectral imagery coupled to a neural network to successfully achieve deconvolution. The proposed approach can be accomplished from (individually or combined) an airborne platform (airplane or satellite) and using a hyperspectral sensor or SAR. To ensure practical use and direct technology transfer for homeland security purposes, for example, the DEA (Drug Enforcement Agency), the technology and methodology is directly applied to a UAV (unmanned aerial vehicle) collection platform.

AUTHOR BIOGRAPHY: The author earned his Ph.D. in 1990 (University of Georgia, Athens) and currently serves as a research scientist for the U.S. DOI – U.S. Geological Survey, National Research Program. Additionally, he serves as adjunct professor at the University of Colorado and is enrolled in the master's degree program within the Center for Homeland Defense and Security, Naval Postgraduate School. His work-related activities involve coupling recent technology discoveries with practical field and scientific application for use in many HLS areas, including toxic chemical dispersal and transport in atmosphere, soil, and water systems; cooperating with local and state agencies on vulnerability analysis and risk assessment for water, agriculture, power & energy, and transportation sectors; and remote sensing technology from UAVs and other platforms that involve many areas within the earth and space sciences. The majority of his work requires technology transfer

*The author would like to thank John Evans of Coventrystudios.com for the illustrations (figures 1 and 2) who volunteered his resources in support of Homeland Security. The mention of specific equipment or brand names does not constitute endorsement by the author, his agency, or *Homeland Security Affairs.*

protocols and policy between U.S. Government agencies and partnering with international partners.

KEYWORDS: Remote sensing, SAR, hyperspectral, drug enforcement, surveillance, UAVs, UASs

INTRODUCTION

The primary reason terrorists have become involved in smuggling drugs is to finance their operations.[1] During the past few years an estimated 500 metric tons of cocaine entered the U.S. each year from countries in Latin America, specifically Bolivia, Columbia, Guyana, and Peru.[2] Marijuana also enters in large quantities and is also grown across the U.S. in hidden fields, mixed with other plants, which makes it difficult to detect. Drug enforcement costs have become overwhelming. To make matters more complex, a new combination of drug and weapons smuggling and links to terrorist groups on both the southern border with Mexico and the northern border with Canada have become serious issues. Towns such as Nuevo Laredo, Mexico, along the Texas border, have erupted in violence, spilling that violence into the U.S. and creating a homeland and national security issue.

News reports are beginning to highlight incidents of terrorists who are reportedly being smuggled into the U.S. accompanied by drugs and explosives. Recently, Mokhtar Haouari, a 31-year-old Algerian, was arrested in Canada and indicted in the U.S. as the central figure in a group of Algerians suspected of planning terrorist attacks in the U.S. He was linked to Ahmed Ressam, who was arrested in Port Angeles, Washington, in December 2005 while trying to smuggle explosives and bomb components from Canada, and to Abdel Ghani Meskini of Brooklyn, who was identified as Ressam's accomplice.[3] Officials are pointing to records in a South Texas drug case with alleged terrorist ties they say underscores the lack of preparedness here. The attorney for a jailed Gulf Cartel member cited in the incident says his client was falsely accused of trying to smuggle Iraqi terrorists into this country and maintains charges were brought to increase the punishment for a drug offense against the accused.[4] More recently, an enormous cache of weapons was seized in Laredo, Texas. U.S. authorities grabbed two completed Improvised Explosive Devices (IEDs), materials for making thirty-three more, military-style grenades, twenty-six grenade triggers, large quantities of AK-47 and AR-15 assault rifles, as well as other weapons and components. The Val Verde County chief deputy warned that drug traffickers are aiding terrorists with possible al Qaeda ties to cross the Texas-Mexico border into the United States. A government spokesman in Houston said "at this point there is no connection with anything in Iraq."[5]

The link between drug smuggling, the financing of terrorist groups from those smuggled drugs, as well as increasing reports of weapons and terrorists being smuggled across U.S. borders, has become obvious. This situation illustrates the need to develop new technologies capable of detecting drugs being grown in the countries of our southern neighbors. Coupled with cooperative agreements between the DEA and other U.S. law enforcement groups and our southern neighbors, this ability would greatly decrease the financing capabilities of the terrorists and cartels (since the plants, even before processing, are the foundation of their capital enterprise) by preventing the processing of those drugs by detecting and destroying them.

The combination of drug trafficking and weapons smuggling by illegal immigrants and potential terrorists causes both a law enforcement (LE) and a national security issue, placing an increased financial burden on the U.S. Department of Homeland Security (DHS), LE agencies along the southern border, and other groups comprised of local and federal agencies. The technological ability to distinguish drug plants, especially before processing, from other plant types has important implications, not only for LE, but also wildfire recovery, reservoir protection, environmental aspects, agricultural issues, and military concerns. Thus, plant identification via un-mixing, termed "deconvolution," can be a valuable technological tool in the war on terror. It can also prove to be a valuable tool in identifying other items, including people and weapons.

REMOTE SENSING AND DECONVOLUTION

To appreciate how deconvolution technology works, it is first necessary to understand a few basic principles about remote sensing and how to use commonly applied satellite and airborne sensing techniques to achieve our goal of deconvolution.

Remote sensing is the science of acquiring information about the earth's surface, without actually being in contact with it, through sensing and recording reflected or emitted energy and processing, analyzing, and applying that information. Remote sensing involves the interaction between incident radiation and targets of interest that requires the systems and involvement of seven specific elements. It also involves the sensing of emitted energy and use of non-imaging sensors. The seven elements (see Figure 1) include:

1) **Energy Source or Illumination**: the first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.
2) **Radiation and the Atmosphere**: as the energy travels from its source to the target, it will come in contact and interact with the atmosphere it passes through. This interaction may take place a second time as the energy travels from the target to the sensor.
3) **Interaction with the Target**: once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.
4) **Recording of Energy by the Sensor**: a sensor is required (remote, not in contact with the target) to collect and record the electromagnetic radiation after the energy has been scattered by, or emitted from, the target.
5) **Transmission, Reception, and Processing**: the energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving station where the data are processed by computer software into an image (hardcopy and/or digital).
6) **Interpretation and Analysis**: the processed image is interpreted, visually and/or digitally or electronically, to extract information about the illuminated target.
7) **Application**: the final element of the remote sensing process is achieved when we apply the information we have been able to extract (the data) from the imagery about the target to better understand, reveal some new information about, or assist in solving a specific problem.

The energy that is sensed is electromagnetic radiation. The two characteristics of electromagnetic radiation that are particularly important for understanding remote sensing are wavelength and frequency. The wavelength (λ) is the length (m) of one wave cycle (measured as the distance between successive wave crests).

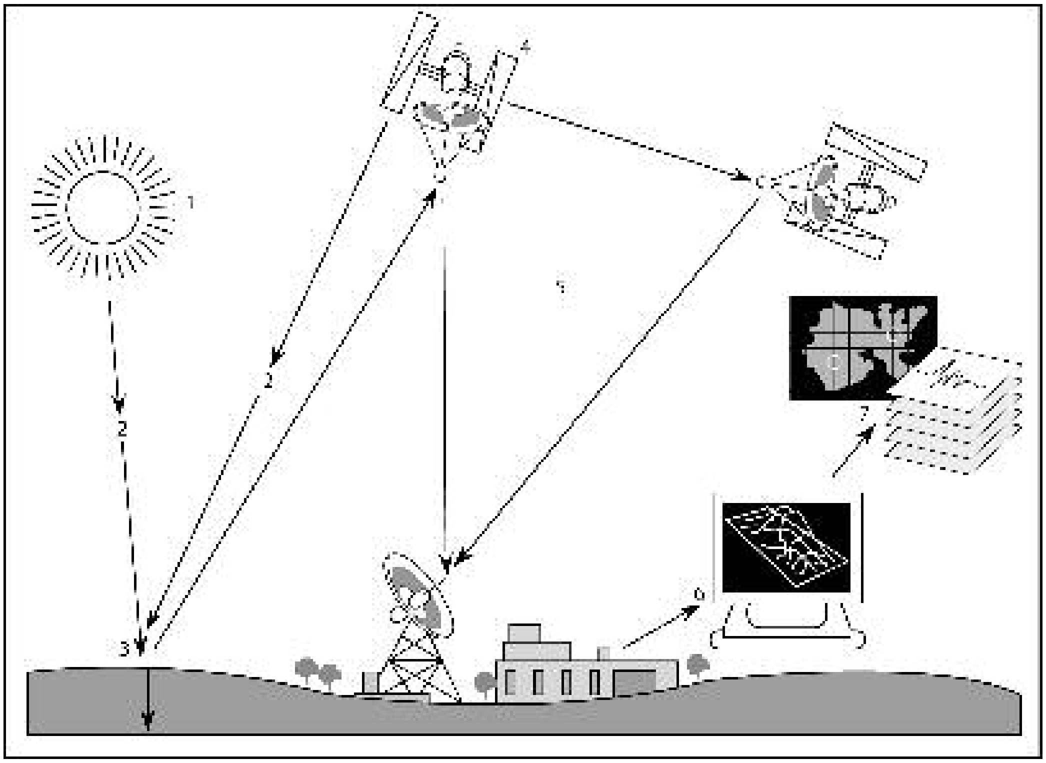


Figure 1: The seven elements of remote sensing: (1) energy source illumination (passive or active – sun or satellite), (2) radiation, (3) interaction, (4) sensor recording, (5) transmission, (6) reception and processing, (7) interpretation and analysis and application.

Frequency (Hz) refers to the number of cycles of a wave passing a fixed point per unit of time, equivalent to one cycle per second. Wavelength and frequency are related by the following formula:

$$c = \lambda \upsilon$$

where, c is speed of light (3x108 m/s) and ν is frequency (cycles per second, Hz). Both λ and ν are inversely related to each other through c. As the wavelength shortens, frequency increases and as the wavelength lengthens, the frequency decreases. Understanding the characteristics of electromagnetic radiation in terms of wavelength and frequency is important in understanding the information that can be extracted from remote sensing data.

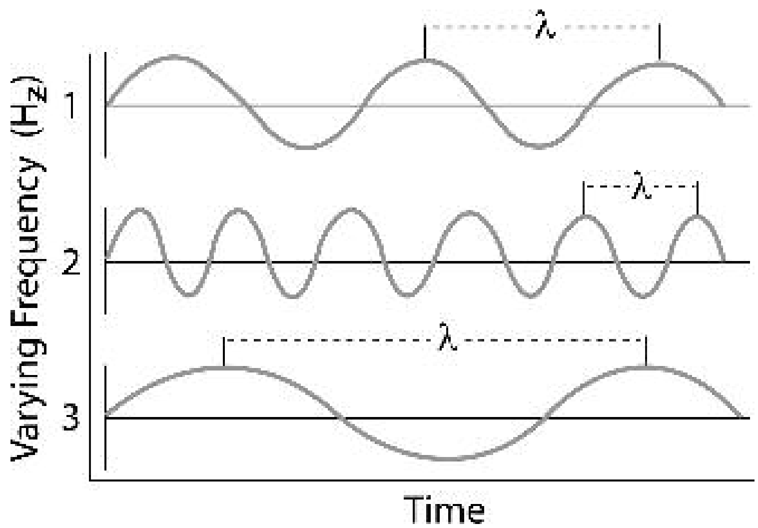


Figure 2: Inverse relationship between wavelength and frequency.

Opportunity for Improvement

As technology has advanced, so have the sensors used on satellites and aircraft to sense the earth's surface. In particular, the deployment of multispectral imagers (commonly called sensors) with a bandwidth of 100 nanometers (nm), has been improved on with the advent of hyperspectral sensors that have bandwidths of 10 nm; this is a significant advance in image resolution. Hyperspectral imagery provides sufficient spectral information to identify and distinguish between spectrally similar (but unique) material, thus more accurate and detailed information extraction from remotely sensed (RS) data is possible than from other types of RS data. Generally, hyperspectral imagery is utilized for target detection, material and mapping details of surface properties. For these specific applications hyperspectral imagery provides details and results not possible with other RS types of imagery. However, while there has been improvement, we are not yet able to distinguish with any degree of certainty the difference between plant types, for example, from an airborne platform.

Information Technology Integral to Improvement

The advent of the computer and associated hardware, as well as data-base and high-speed computing capabilities, has become an integral part of the technological process that will make plant species identification from airborne sensors a reality. The standard multispectral image processing techniques generally developed to classify multispectral images into broad categories of surficial material, or a surface condition, have been inadequate for use in species identification. The advent of hyperspectral imagery improved this in many respects. However, to fulfill the potential for more detailed analysis of images, new image processing techniques were necessary. Development and commercialization was made possible through a sequence of algorithms specifically designed to extract detailed information from hyperspectral imagery in the early to mid-1990s.[6] The ability to further define hyperspectral images has led to four major objectives for this technology: 1) target detection; 2) material mapping; 3) material identification; and 4) mapping surface property details. This research is primarily interested in target detection. In such projects investigators generally attempt to locate known target(s), which means the target must be distinguished from typically similar backgrounds or locating targets that are actually smaller than the nominal pixel size of the sensor. Hyperspectral imagery has been used successfully by the military to detect vehicles under vegetation camouflage and by agronomists to identify vegetation species.[7] Despite this success, imagery details are insufficient for the purposes of deconvolution. Consequently, the technology used must be multifaceted (including the sensor) and must include image analysis and processing techniques, a unique and specific modeling approach, calibration and predictive analysis.

Hyperspectral images are produced by instruments called *imaging spectrometers*. The development of these complex sensors has involved the convergence of two related but distinct technologies: *spectroscopy* and the *remote imaging* of Earth and planetary surfaces. Spectroscopy is the study of light emitted by or reflected from materials and its variation in energy with wavelength. Spectroscopy deals with the spectrum of sunlight that is diffusely reflected (scattered) by materials on the earth's surface. Instruments called spectrometers (or spectroradiometers) are used to make ground-based or laboratory measurements of the light reflected from a test material. An optical dispersing element such as a grating or prism in the spectrometer splits this light into many narrow, adjacent wavelength bands and the energy in each band is measured by a separate detector. By using hundreds or even thousands of detectors, spectrometers can make spectral measurements of bands as narrow as 0.01 micrometers over a wide wavelength range, typically at least 0.4 to 2.4 micrometers (visible through middle infrared wavelength ranges).

Remote imagers are designed to focus and measure the light reflected from many adjacent areas on the earth's surface. In many digital imagers, sequential measurements of small areas are made in a consistent geometric pattern as the sensor platform moves and subsequent processing is required to assemble them into an image. Synthetic Aperture Radar (SAR) is a method of microwave remote sensing where the motion of the radar is used to improve image resolution in the direction of the moving radar antenna. SAR imaging instruments support a wide range of commercial applications because of their ability to achieve very fine resolution from great distances. SAR instruments can penetrate through clouds, haze, smoke, and vegetation, while covering large areas of the earth. The active nature of SAR sensors means they can operate equally well in all lighting conditions, i.e., day/night, not requiring the smoothing normally necessary for optical imaging due to sun position or sun glint off reflective surfaces. Until recently, imagers were restricted to one, or a few, relatively broad wavelength bands by limitations of detector designs and the requirements of data storage, transmission, and processing. Recent advances in these areas have allowed the design of imagers that have spectral ranges and resolutions comparable to ground-based spectrometers.

Around 1997, the U.S. Department of Agriculture (USDA) began investigating SAR as a method for regional assessment of soil moisture content (expressed in terms of θ_s on a volumetric content where s is degree of saturation).[8] One of the most important aspects in deconvolution is the ability to minimize the influence of conditions that may hamper accuracy. For example, initial studies are generally carried out on flat, uniformly vegetated sites to monitor the specific parameter of interest such as vegetation cover over time. The advantage of a flat site is that it avoids the complications associated with topography. Choosing one site and monitoring it over time, rather than multiple sites (over space), minimizes the effects of small-scale surface roughness conditions that can result in less accuracy, especially if sensor resolution is low. Measuring through time thus allows quantification of the parameter of interest. In terms of plants, surface roughness is an important parameter, but can be taken into account by SAR backscatter through time; that is, a before and after image of the area. Effects of vegetation influence can then be corrected using empirical relationships, fitted or determined backscatter, and leaf area index (LAI).

Several approaches have been suggested in attempts to identify specific vegetation types by deconvolution. In lay terms, any of these approaches can be thought of as "fancy" pattern recognition processes. However, these approaches have focused on only one plant attribute. This means that the scientists have looked at only a singular methodology in an attempt to accomplish deconvolution instead of coupling a variety of techniques together to develop a more robust, accurate, and reliable solution. A recent approach was to use a nonlinear artificial neural network (pattern recognition through a training set), which achieved about eighty percent accuracy in identifying understorey (a mix of various plants growing beneath a tree canopy), but not plant types.[9] An interesting result from application of a neural network approach is that the influences of understorey vegetation on remotely sensed data are of value to practical approaches to classifying understorey vegetation.

As with all methods used to derive a solution to the deconvolution problem, any approach attempted will be a modeling approach whereby the investigator will test the correspondence between the predicted and surveyed distributions of data. The neural network approach is a spectral deconvolution method that has the ability to parse the proportional effects of individual canopy features from the radiance response of a single heterogeneous pixel.[10] Neural networks are generally non-parametric data transformations that are not restricted by underlying assumptions due to pattern recognition, which means they can distinguish between nonlinear effects if a sufficient complex partitioning of the classification space is accounted for. Additionally, neural networks are termed "learning approaches;" thus they may be more likely to be trained or taught the complex variability in the signature because of varying canopy conditions, at least more so than traditional classifications.

A neural network establishes spatial distribution with significant correspondence to independent data, which makes this a useful approach. However, such a process will not provide conclusive evidence as it typically produces trends or identities in the classification, but generally may lack discernable correlation of overstorey vegetation (the tree canopy that can be comprised of a wide variety of tree and/or shrub types/species) in a forested region to the existence of a specific plant type. The approach of a neural network is more capable of classifying minority features, adapting to the variable influences of changing canopy conditions while accounting for the nonlinear effects of the sub-canopy vegetation, and is thus unable to identify a specific plant type. The general problem with using a neural network approach is that one species will likely be too spectrally similar to another or cause an erroneous time-domain response so as to cause a false positive classification.

But there can also be false negatives in which co-occurring species mask understorey features or features of other species. As mentioned earlier, the observation of one basic attribute is not sufficient to address the problem of identifying a specific plant type from among a variety within the target zone. Thus, we should approach the problem from a broader perspective. Correlation among approaches, such as gathering data from other types of sensors and modeling approaches, can contribute to the analyses of any method and make parameterization of vegetation/understorey conditions more applicable. Doing so will infer significant structural information such as biomass and vertical distribution that should differentiate between structurally distinct vegetation types from SAR and/or light detection and ranging (LIDAR).[11] The fusion of increased biomass and structural information with signature information from optical sensor data could allow enhanced classification and biophysical parameterization. Given that this assumption is correct, the use of an artificial neural network in combination with multiple plant attribute data would yield the ability to extract the complex information available from optical remote sensing data, but only if these other procedures are coupled with the neural network.

The methodology in this paper focuses on utilizing SAR/hyperspectral imagery to achieve deconvolution because it presents a unique opportunity for imaging plant types whether or not there is cloud cover, effectually making this process an all-weather one. Utilization of SAR will, at the minimum, identify the difference between trees versus common understorey shrubs and/or agricultural plants. One area that needs to be considered is the temporal and spatial variability (identification and removal) of the plant species being sensed, as well as their mix with other vegetation types. One problem that will arise with the data from SAR/hyperspectral sensor is quantification of the data, since initial estimates of the biomass/species present will generally not be stable due to intrinsic texture, system noise, and other environmental effects. Recent results from NASA's Landsat Pathfinder project indicate that much of the vegetation, especially in areas of reforestation where drug crops are likely, is secondary vegetation (i.e., a wide mix of new growth of many plant species) which would be ideal for trials and tests.[12] Although traditional optical remote sensing techniques have been able to differentiate between cultivated areas, secondary vegetation, and pastures, these methods were limited in terms of mapping various stages of secondary growth and distinguishing separation of species. However, SAR backscatter from a vegetated target is a function of the dielectric properties of the vegetation, soil, surface roughness, and also the size and orientation of the scatterers (composed primarily of the leaves and branches) in relation to the imaging system. Despite this, SAR data lends the capability of charactering changes in vegetation structure and biomass changes, i.e., additional growth. In certain respects, multiple frequency and polarimetric SARs may provide estimates of biomass deconvolutive properties through a combination of higher frequency and shorter wavelength information, which would provide for increased backscatter and thus, better resolution.

IMPROVING MEASUREMENT PROCESSES TO ACHIEVE DECONVOLUTION THROUGH A MULTIPLE ATTRIBUTE APPROACH

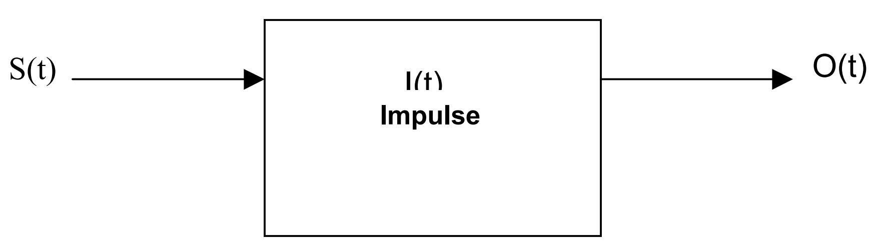
Past efforts at recognizing specific plant types have failed because investigators limited themselves to a simple one-plant attribute, like leaf area index (LAI). The approach used for this paper uses multiple attributes and considers enhancing attributes through deconvolution. The more conditions under which measured attributes can be defined and for which we train the pattern recognition algorithm, e.g. neural network, the higher the probability of success in identifying specific plant species when grouped together in a multiple plant mix. The proposed approach can be accomplished (individually or combined) from an airborne platform (airplane or satellite) and using a hyperspectral imager or SAR. The initial test and calibration phase could be performed from a crane or tower.

The investigative problem is one of pattern recognition for which an algorithm is trained, i.e., learning based on training set. In this case the algorithm would be a neural network and the training set is comprised of various plant attributes: the more information for training the higher likelihood for accuracy. Earlier it was mentioned plants undergo diffusive refraction when energy is reflected, refracted, and diffracted, i.e., bounced from a satellite. During this process, the algorithm will be trained for a hyperbola fit to a quadratic or polynomial equation. The raw data collected will either be from the time domain and/or frequency domain. This will allow transfer of time-space attributes by both frequency number and wave number domains. We can use the amplitude or phase spectrum with the wave number to train the algorithm to identify amplitude and phase. The algorithm can also be trained to identify time and frequency-domain features. By doing so, space can be transformed into a wave number. However, there is a ‘gotcha’ in that this process will work well for only one plant type. For example, a field of corn, wheat, or even an entire field of marijuana may be easily identified using this approach. However, general field conditions are such that there is always more than one type of plant species present. Thus, an enhanced design shift is necessary.

Working with multiple plant species requires designing and applying a deconvolution operator (DO) to remove the effect of noise caused by other plants within a multiple plant mix or enhanced design shift. The DO can be designed in the frequency domain or the time domain (the Kalman Filter is an efficient recursive filter that estimates the state of a dynamic system from a series of incomplete and noisy measurements). Within the frequency domain, time can be divided for enhanced resolution. Since signal bandwidth is limited, the diffraction of the signal off the plant surface attenuates it, changing the signal and the frequency. The overall approach then is termed a linear system approach to designing a DO. This approach can be illustrated by:

$$\mathbf{S(t) \bullet I(t) = O(t) \bullet \text{Convolution Operator}} \tag{1}$$

where S, I, and O refer to signal response in, impulse response, and output response respectively, all as a function of time.[13] Graphically, this process can be visualized as



The impulse response, I(t) or filter, can be thought of as the DO, what some would refer to as a transfer function. Still, others refer to it as a magic black box. From a modeling aspect, although the system is assumed to be linear, i.e., input → impulse → output, what occurs within the impulse box (transfer function) is very complex and generally highly nonlinear. If we wish to convert the system to a frequency approach it can be described as:

$$\mathbf{S(\omega) \bullet I(\omega) = O(\omega)} \qquad \mathbf{2}$$

where the parameters are the same as before, but read in terms of frequency (ω). In simplistic terms the impulse, I(t), can be solved for one plant species type such that

$$I(\omega) = \frac{O(\omega)}{S(\omega)} \qquad \mathbf{3}$$

where I(ω) is the transfer function. However, because there are usually more than one plant species present, using output (O(ω)) as an example, the equation would be written as

$$\mathbf{O(\omega) = O_1(\omega) + O_2(\omega) + O_{n+1}(\omega)} \qquad \mathbf{4}$$

Similarly, to determine the DO for one component we can solve such that

$$O_1 = \frac{O(\omega)}{O_2(\omega)} \qquad \mathbf{5}$$

Once a component is removed, i.e., $O_1(\omega)$, equation 5, it can be transferred back to a time domain function to look for the same attribute, i.e., to place into the algorithm for recognizing/learning the new signal in a different domain. Once the required data are collected from the sensor, the above modeling approach is applied recursively using high-speed computers to deconvolute the plant mix. Although explained in relatively simplistic terms, the process is quite complex. The end result is that one is able to identify the specific plant type within the sensor's resolution area. As an example, DEA agents could identify coca plants (from which cocaine is manufactured) or marijuana plants from a distance without initial personal risk to the agents involved and then proceed per policy mandates.

DATA COLLECTION PLATFORM

Processing collected data and the technology used to do so accurately as described above are only small steps in the process. Ideally, a collection platform for LE or homeland security purposes should be reliable, portable, easy to operate, and functional in any geographic region. There are several methods possible for data acquisition. The preferred choice would be via satellite or fixed-wing aircraft. However, because the goal of this research is to be directly applicable to fighting terrorism and supporting homeland security, it is believed that although less stable, a UAV (unmanned aerial vehicle, sometimes also referred to as an RPV, a remotely piloted vehicle) is the best practical methodology to use this coupled technology. Therefore, this research will focus on mounting either an SAR or hyperspectral sensor aboard a small UAV. A suitable UAV would be the Silver Fox (Figure 3), developed by Advanced Ceramics Research in Arizona, utilizing a hyperspectral sensor developed by Resonon in Bozeman, Montana. A combination of the small UAV and hyperspectral sensor will adequately prove the research hypothesis and set the ground work for a functional system directly deliverable and proven to the DEA, DHS, or related LE group. It should also be noted that the UAV described is not the multi-million dollar "Predator" type used by the military and is much, much less costly.

Figure 3: **UAV (Silver Fox developed by Advanced Ceramics Research – photo used by permission) weighing twenty-seven pounds. This UAV is capable of thirty-five knots average speed, eight hours in flight mission time, 12,000 foot service ceiling, and a five pound payload. The UAV is inaudible at 700 feet and almost undetectable to the naked eye at 1,500 feet. It can also be launched from any site utilizing a portable launcher and requires no runway for recovery.**

Budget

The costs to correctly set up, test, and calibrate such a system (Table 1) are small compared to the potential use and value-added results of the technology and its effect on the drug war; they also include the necessary resources for a required team of three during a six month period. However, once the system is fully tested and calibrated, it could be delivered intact to any LE group, fully operational and functional since it would be software driven.

Table 1: Projected Budget for Technology Development

Description	Quantity	Cost $
Personnel Team[1]	3	165,000
Site Preparation & Agronomic Work	3 sites each unmixed 3 sites each mixed at varying percentage	7,000
Silver Fox UAV[2]	1	103,000
Sensor Equipment[3]	Hyperspectral Sensor	22,000
Miscellaneous Equipment and Supplies		12,500
TOTAL		**309,500**

[1]Includes IT set up (airborne number crunching ability), computer modeling, testing, validation of data, and all personnel time necessary to complete data collection, analysis, and modeling other than equipment uses.
[2]Includes UAV, ground station, GPS navigation, real time video, portable launcher, and pilot training.
[3]Add $38k for SAR.

Advantages

The major advantages of this technology are that it can accurately identify a specific plant type mixed among other plants from a safe distance, e.g. coca or marijuana, through use of multiple plant attributes and improved data modeling capabilities using neural networks and transfer functions to process the data. Utilizing the same modeling approach and delivery platform, an alternate methodology for deconvolution during daylight hours via a combination of the EO 10x camera and IR could be developed concurrently with little added cost; a significant value-added feature. During data acquisition and detection phase a DEA or other LE officer would not be in harm's way. It is significantly cheaper than performing the research via satellite imagery or fixed wing aircraft for multiple date testing and a series of satellite images for each date. The UAV system discussed is more flexible, portable, can be operated from almost any geographic location, and also follow a prearranged flight path due to GPS capabilities. This particular UAV requires no runway for launch or recovery, is inaudible at 700 feet AGL (above ground level), and almost undetectable to the naked eye at 1,500 feet AGL. Data could either be processed in the recovery area or relayed to a ground processing station and processed similarly to that collected via other airborne systems; this technology is easily transferable. Finally, perhaps the greatest advantage is that DEA or LE would get a system that has been proven, is functional, reliable, easy to operate out of the box, and gives the user immediate access and total control of the acquired data. Compared to satellite systems where reliance would be on the DoD and other government or commercial entities to supply necessary information, the latter may well be out of "the window of opportunity" for successful mission fulfillment, which would give this system a value-added benefit to the user.

An alternative for agencies that already possess small manned aircraft is that costs would be limited to the purchase of only the required sensors and processing equipment, such as computers and other peripherals. Another advantage for this group would be that small manned aircraft can carry considerably more weight and a wider variety of sensors, as well as sensors that have much better resolution (that typically weigh more than the suggested UAV can carry) and also give a day/night capability. However, the latter would significantly increase costs, likely equal to or greater than the proposed budget (Table 1).

Limitations

One disadvantage of a sensor/UAV coupled system, at least for the small UAV described and similar UAVs, is that it currently does not offer a SAR capability that would ensure all-weather operation due to the reduced payload capability of the small UAV system, i.e. Silver Fox. Thus, a satellite platform would offer best performance in this regard or a fixed wing aircraft that many DEA groups and other LE groups already possess. However, a suitable SAR unit is scheduled to be available for this UAV in six to eight months. Also, because the UAV system is designed to fly closer to ground level for data acquisition, the enhanced capabilities of an SAR from a satellite are a trade-off with the enhanced resolution of the hyperspectral sensor from the short distances of 500-1200 feet AGL. Perhaps the greatest disadvantage in CONUS is the restriction imposed by the FAA for UAVs, which requires permission to fly any UAV when exceeding 500 feet AGL. The regulations are not yet fully developed, but should be by September 2006.[14] Also, the FAA has granted a national certificate of authorization to the USAF, which implies the USAF may become a necessary partner with DEA or other CONUS LE agencies, as well as foreign LE agencies in Latin America. Altitude level may not be a disadvantage in foreign countries, but is beyond the scope of this paper.

Future Research

Increases in technology, which is easily accessible to criminals and terrorists, will force LE agencies to maintain a technological advantage as drugs, weapons, and terrorist smuggling activities become more prevalent, especially along the southern U.S. border with Mexico. The situation between homeland security agencies and problems along the border will inevitably become increasingly more complex and adversarial. Thus, initial future research should focus on improving current sensor technology so that lighter-weight sensors can be utilized, which will allow additional payload space for other sensors in which the primary mission of the UAV would be surveillance. The focus should also be on enhanced software and systems to develop fully autonomous capabilities. Also, the UAV should be strategically utilized in a multi-layered detection, prevention, and enforcement policy.

APPLICATION TO DEA, BORDER PATROL AND OTHER AGENCIES

For homeland security there are multiple applications for these small UAVs, which are also being developed in rotary-wing form, i.e., small helicopters that weigh about 200 pounds with an approximate length (with rotor) of twelve feet. Unmanned aerial vehicles can serve as the "eyes and ears" along the southern border, which could reduce border enforcement costs. They are almost impossible to see, quiet, and not easily targeted by hostiles. As technology quickly improves, real-time images will help pinpoint smuggling and drug operations that the U.S. Border Patrol, DEA, DHS or another appropriate agency could quickly respond to, whether along the border or with our southern partners, and allow rapid response. Ideally the UAV systems would be synched with current border camera-surveillance systems to gain view distance; because the UAV is at a higher altitude, detection can occur while smugglers or other personnel are far from the border, allowing U.S. Border Patrol agents ample time for a suitable response.

With the development of small rotor (small helicopter) UAVs, the ability to hover over a given area for several hours without being seen would be of enormous benefit for detecting not only vegetation, but also personnel and tactical operations. Other uses would be for the U.S. Coast Guard in ship inspections at sea, tracking/following ships into harbor, and search and rescue operations that cover a localized area, since the UAVs can fly a specific pattern and even a small vessel could carry and launch them. There are also a variety of classified uses, as well as uses by other agencies, including fire fighting observation, reservoir protection, power grid distribution surveillance, and others. The primary advantage for all these uses is cost, since the cost to fly a UAV of the type explained in this report is approximately ninety percent less per hour than a full-sized fixed or rotary-wing aircraft.

CONCLUSION

This paper focused on utilizing SAR and/or hyperspectral imagery to achieve deconvolution of plant species coupled with a neural network and a modeling approach to separately identify individual plant species and utilizing a UAV airborne platform to collect the necessary data. The more conditions under which measured attributes can be defined and for which we train the pattern-recognition algorithm, e.g. neural network, the higher the probability of success for identifying specific plant species when grouped together in a multiple plant mix. The proposed approach can be accomplished from (individually or combined) an airborne platform (airplane or satellite) and using a hyperspectral imager or SAR. The initial test and calibration phase could be performed from a crane or tower. During the data collection and analysis process, the algorithm will be trained for a hyperbola fit to a quadratic or polynomial equation. The raw data collected will either be from the time domain and/or frequency domain. This will allow transfer of time-space attributes by both frequency number and wave number domains. Either the amplitude or phase spectrum with the wave number can be used to train the algorithm to identify amplitude and phase. To make this approach a reality requires setting up a variety of field plots with specific plant types and plant ratios and the design of a deconvolution operator (DO) to remove the effect of noise caused by other plants in a multiple plant mix. This deconvolution methodology is not only useful for LE purposes, but also has applications to wildfire recovery, reservoir protection, environmental aspects, agricultural issues, and militarily.

---

[1]Committee on the Judiciary, U.S. Senate, "Report Number: J-108-12" (Washington, D.C., 2005).

[2] Maritime Administration, ed.,"Cocaine Smuggling from South America to Europe and the United States Increased in 2000 Via Commercial Maritime and Other Modes of Transport," *Maritime Security Report* (Washington, D.C.: U.S. Department of Transportation, Office of Ports and Domestic Shipping, 2001).

[3]Benjamin Weiser and Craig Pyes, "U.S., in Pursuit of Bomb Plot, Indicts Man Held in Canada," *New York Times*, January 19, 2000 [cited March 4 2006]); available at

http://select.nytimes.com/gst/abstract.html?res=F10D17F93C590C7A8DDDA80894D8404482&n=Top%2fReference%2fTimes%20Topics%2fPeople%2fR%2fRessam%2c%20Ahmed.

[4]Roger L. Simon, "Osama's People Crossing into U.S. from Mexico?" *Internet News*, January 15, 2006 [cited March 4 2006]; available from http://www.jihadwatch.org/archives/009807.php. http://www.jihadwatch.org/archives/009807.php

[5]Phyllis Schlafly, "Is a War Going on in Texas?," *American Renaissance,* February 5, 2006. Available at http://www.amren.com/mtnews/archives/2006/02/is_a_war_going_on_in_texas.php.

[6]J.W. Boardman, "Automated Spectral Deconvolutive of Aviris Data Using Convex Geometry Concepts," Paper presented at the In Summaries, Fourth JPL Airborne Geosicence Workshop (JPL Publication, 1993); J.W. Boardman, F.A. Kruse, and R.O. Green, "Mapping Target Signatures Via Partial Deconvolution of Aviris Data, " review of Reviewed Item, *JPL Publication 95-1*, no. 1 (1995).

[7] M.A. Cochrane, "Using Vegetation Reflectance Variability for Species Level Classification of Hyperspectral Data," *International Journal of Remote Sensing* 21, no. 10 (2000).

[8] Susan M. Moran, et al., "Soil Moisture Evaluation Using Radar and Optical Remote Sensing in Semiarid Rangeland," *American Meteorological Society* (1998).

[9] M. Linderman, et al., "Using Artificial Neural Networks to Map the Spatial Distribution of Understorey Bamboo from Remote Sensing Data," *International Journal of Remote Sensing* 25, no. 9 (2004).

[10] G.A. Carpenter, et al., "A Neural Network Method for Mixture Estimation for Vegetation Mapping," *Remote Sensing of Environment* 70 (1999).

[11] R.N. Treuhaft and P.R. Siqueira, "Vertical Structure of Vegetated Land Surfaces from Interferometric and Polarimetric Radar," *Radio Science* 35 (2000).; M.A. Lefsky, et al., "Lidar Remote Sensing of the Canopy Structure and Biophysical Properties of Douglas-Fir Western Hemlock Forests," *Remote Sensing of Environment* 70 (1999): 399-361.

[12] Ibid, 340.

[13]Charles S. Williams and Orville A. Becklund, "Introduction to the Optical Transfer Function," in *Spie Press Monogragh* (Seattle, WA: SPIE International Society of Optical Engineers, 2002).

[14] "Regulation and Certification: Federal Aviation Administration, Fiscal Year 2005 Business Plan" (Federal Aviation Aministration, 2005).