UTILIZATION OF AN AIRBORNE PLANT CHLOROPHYLL IMAGING SYSTEM FOR DETECTION OF SEPTIC SYSTEM MALFUNCTION

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ABSTRACT

Malfunctioning, or leaking, sewer systems increase the supply of water and nutrients to surface vegetation. Excess nutrients and harmful bacteria in the effluent pollute ground water and local water bodies and are dangerous to humans and aquatic ecosystems. An airborne multispectral plant chlorophyll imaging system (PCIS) was used to identify growth patterns in the vegetation covering onsite and public sewer systems. The objective was to evaluate overall performance of the PCIS as well as to determine the best operational configuration for this application. The imaging system was flown in a light aircraft over selected locations in Mobile County, Alabama. Calibration panels were used to help characterize instrument performance. Results demonstrated that the PCIS performed well and was capable of detecting septic leakage patterns from altitudes as high as 915 m. From 915 m, 6 of 18 sites were suspected to have sewage leakage. Subsequent ground inspections confirmed leakage on 3 of the 6 sites. From 610 m, 3 of 8 known leakage sites were detected. Tree cover and shadows near residential structures prevented detection of several known malfunctioning systems. Also, some leakages known to occur in clear areas were not detected. False detections occurred in areas characterized by surface water drainage problems or recent excavation. Further refinement of this approach may provide a useful tool in detecting hazards to public health and the environment.

1.0 INTRODUCTION

More than 25 million homes in the U. S. dispose of domestic wastewater through onsite treatment systems consisting of a septic tank and absorption field (NSFC, 2000). Particulates are trapped in the septic tank while water and dissolved waste products flow out of the tank and into the absorption field through some arrangement of perforated pipe. In such cases, the untreated effluent is absorbed by the soil. In a working system, gravity forces wastewater down through the soil where dissolved waste is broken down through various chemical and biological processes. Inorganic contaminants, harmful bacteria and other microorganisms are trapped in the soil.

There are a number of potential problems with such onsite treatment systems. In coastal areas with sandy soils and high water tables, studies have shown rapid movement of onsite effluent into adjacent canals and bays (Paul et. al, 2000; Corbett et al., 2000). In soils with high clay content, effluent moves too slowly through the soil column, resulting in potential surface contamination (Parkin et al., 2000). Effluent leaving the septic tank may contain a number of potentially toxic or pathogenic pollutants and microorganisms (Canter and Knox, 1985; Peavy et al. 1985; Sawyer et al., 1994). When harmful bacteria and pollutants enter the groundwater supply or rise to the surface they become a danger to public health. In addition, the effluent contains high concentrations of nitrogen and phosphate. If these nutrients reach nearby water bodies, eutrophication can occur (Corbett et al. 2000). This may result in harmful algal blooms, hypoxic or anoxic conditions and loss of higher aquatic organisms.

Because of the potential health hazards and environmental impact, it is important for public health officials to know the status of onsite treatment systems. One possible method of monitoring onsite treatment systems is airborne remote sensing. Remote sensing offers the potential benefits of wide area coverage and repeat acquisition, without expensive site visits or the need to gain permission from property owners. The technique tested in this project was the use of a NASA -developed airborne Plant Chlorophyll Imaging System (PCIS) to detect patterns of enhanced vegetation growth over malfunctioning septic systems. It has been shown that the ratio of reflectance at 700 nm to reflectance at 840 nm is highly correlated to leaf chlorophyll content in a variety of plant species (Carter and Spiering, 2001). Vegetation located above malfunctioning field lines would be expected to contain higher concentrations of chlorophyll than surrounding vegetation. The PCIS implements this band ratio technique and produces images of relative chlorophyll distribution.

A joint project was initiated between the NASA/Stennis Space Center, EPA/Gulf of Mexico Program (GOMP), and the Mobile County Health Department (MCHD) to test the PCIS in this application. Mobile County, Alabama is mostly rural with a metropolitan city surrounded by a suburban area. The city and suburbs are served by a public sewage system. However, onsite septic systems are used outside these areas. PCIS images of areas identified by MCHD were provided by NASA and Associated Technical Management Corp. (ATMC). MCHD performed field observations and evaluated image data. Additional funds were provided by the EPA/GOMP, whose interest was in identifying methods to monitor pollution sources in the Gulf of Mexico.

The purpose of this project was three-fold. The first objective was to evaluate the performance of the PCIS in an airborne configuration. The second objective was to evaluate the suitability of this detection technique for satisfying the requirements of the MCHD and the EPA/GOMP. The third objective was to identify issues relative to the development of an operational system.

2.0 METHODS

2.1 ONSITE SEPTIC SYSTEM CHARACTERISTICS

Pertinent details of onsite septic system design and layout have been taken from Canter and Knox (1985) as follows. Septic tanks sized for a typical residence can be round or square and 1 to 2 m across. They are typically located a minimum of 2 to 3 m from the structure being served, depending on site conditions and local codes. The absorption field consists of one or more buried, 10 cm diameter, perforated pipes, extending out from the septic tank. The length, number, and arrangement of pipes is site-specific. A typical arrangement is a single length of pipe, or multiple pipes placed parallel to each other and spaced a minimum of 2 m apart. A typical pipe length is 10 m. Pipes are placed in gravel-filled trenches 0.3 to 0.6 m wide, excavated to a specified depth. The gravel prevents clogging by soil covering the trench. Surface vegetation is usually restricted to grass to prevent intrusion of the pipe by root systems of larger plants.

Effluent from the septic tank tends to mound above the pipes in the absorption field (Wilson et al., 1987; Parkin et al., 2000). This implies that the patterns of enhanced vegetation growth will follow the layout of the absorption field pipes resulting in spatial patterns in surface vegetation 1 to 2 m wide and 10 m long. However, these spatial patterns may be disrupted by variability of the soil in the absorption field (Wilson et al., 1987).

2.2 PLANT CHLOROPHYLL IMAGING SYSTEM CONFIGURATION

The NASA PCIS consists of a 3-band, multispectral camera system, solar irradiance sensor and recording system. The camera system, built by Duncan Technologies, Inc., uses a beam-splitter and narrow band filter combination to produce three, co-registered, narrow spectral band images. The filters all have approximately 10 nm bandwidths and are centered at 550, 700 and 840 nm.

The camera was fitted with a 24 mm f-mount lens with an f/8 aperture setting, focused at infinity. This arrangement provides an angular field of view of approximately 19 degrees across track and 14 degrees along track. This results in a pixel ground sample distance (GSD) of approximately 0.16 m per 300 m of altitude. The total ground field of view was approximately 100 x 75 m at 300 m altitude and 300 x 225 m at 915m.

The multispectral camera has an input port that acquires downwelling irradiance in the 700 and 840 nm spectral bands at 20 msec intervals, using an upward looking sensor. The camera also contains a digital processor that converts images to percent reflectance using the downwelling irradiance data. It then computes the ratio of the 700 to 840 nm reflectance images. The result is an image of the relative chlorophyll content of the vegetation on the ground. This image can be output directly from the camera.

A Cessna 172 aircraft was provided by Air-O-Space International, Stennis Space Center, to deploy the PCIS and acquire the image data. The aircraft was outfitted with a pod mounted in the side rear cargo door that allowed an open view of the ground. The irradiance sensor was mounted on a pipe extended above the pod. The camera, multiplexor and recorder were powered by an inverter supplied from a 12V battery. A 35 mm SLR film camera was mounted adjacent to the multispectral camera and was used to collect color photographs of the ground. The pilot used a GPS receiver to navigate to the various targets of interest.

2.3 DATA ACQUISITION MISSIONS

Three data acquisition missions were flown over Mobile County covering locations provided by the MCHD. The first mission was flown at 300 m, the second at 915 m and the third at 610 m on Feb. 22, March 15, and August 17, 2000 respectively.

The calibration mission included deployment of 3 calibration panels. Two green colored panels were deployed, each having spectral reflectance characteristics similar to leaves; one to a dark green leaf and the other to a greenish-yellow leaf. The third panel consisted of 6 spectrally flat gray panels with reflectances of 2, 8, 16, 32, 64 and 88 %. A calibrated spectroradiometer, Model ASD2500, Analytical Spectral Devices, Boulder, CO, was used to measure the radiance reflected from the panels coincident with the time of the flight. Reflected radiance from a Spectralon panel was used to compute percent reflectance for each of the panel radiance measurements. These measurements served as a reference for the relative output of the PCIS. The gray level targets provided a verification of the camera gain, offset, and integration time settings. The spectroradiometer was used to verify the reflectances of each calibration panel. These reflectances were used to determine the linearity of the image sensors.

The two green panels were also used to verify the Ground Sample Distance (GSD) and system noise. The GSD was determined by measuring the number of pixels across known dimensions of the panels. System noise could be determined by computing means and standard deviations of pixel values from each target in the images. Dark images were taken with the lens cap on and uniform brightness images were collected while viewing an integrating sphere. The brightness levels of the integrating sphere were selected to be similar to the expected ground target brightness.

The calibration mission consisted of a single pass over the ground targets at 11:00 AM CST. The sky was clear and the orientation of the flight lines was north to south to minimize the variation in cross track brightness as the sun moved from east to west. The flight was conducted in February to maximize the contrast between effluent enhanced vegetation growth and surrounding vegetation. At this latitude and time of year, most grasses used for residential lawns are in senescence. Effects of effluent percolating to the surface were expected to stimulate growth in various grass and broadleaf weed species. Near- drought conditions during this period were expected to further enhance the contrast between the effluent enhanced vegetation and surrounding vegetation. Ground inspections of the area confirmed these expectations. The PCIS was configured to record the 700 and 840 nm bands as well as the ratio image computed by the camera signal processor.

The second mission was flown by ATMC at 915 m, with a different aircraft. An identical multispectral camera system was used. The 700 and 840 nm band images were digitized and stored directly on a PC. The ratio algorithm was computed on the PC and the ratio images were stored on disk. The MCHD provided the coordinates for a number of specific targets and several complete residential areas. The flights were conducted between approximately 12:00 PM and 2:00 PM CST on March 15, 2000. The sky was partly cloudy, with about 30 % coverage by thin, high altitude clouds. The images were mosaiced and analyzed by ATMC.

The third mission was flown at approximately 610 m over 8 target locations provided by the MCHD. The mission was flown on August 17, 2000 between approximately 11:00 AM and 12:00 PM CDT. The sky was partly cloudy, but ground targets were not obscured. The PCIS was configured to record the 550, 700 and 840 nm bands. The camera-computed ratio was not recorded.

3.0 RESULTS

3.1 CALIBRATION MISSION

The results of the calibration mission are presented in Tables 1 – 3, and Figures 1 and 2. Table 1 contains a comparison of the digital output of the two camera bands and the percent

Table 1 - Linearity Test – Camera Digital Output vs. Gray Panel % Reflectance

Gray Panel Value	Camera Output Digital Numbers		Measured Percent Reflectance	
(% Reflectance)	700 nm (DN)	840 nm (DN)	700 nm (%)	840 nm (%)
2	28	45	3.15	3.17
8	44	55	9.62	8.66
16	74	76	20.22	18.08
32	118	109	35.57	32.87
64	194	173	65.55	63.59

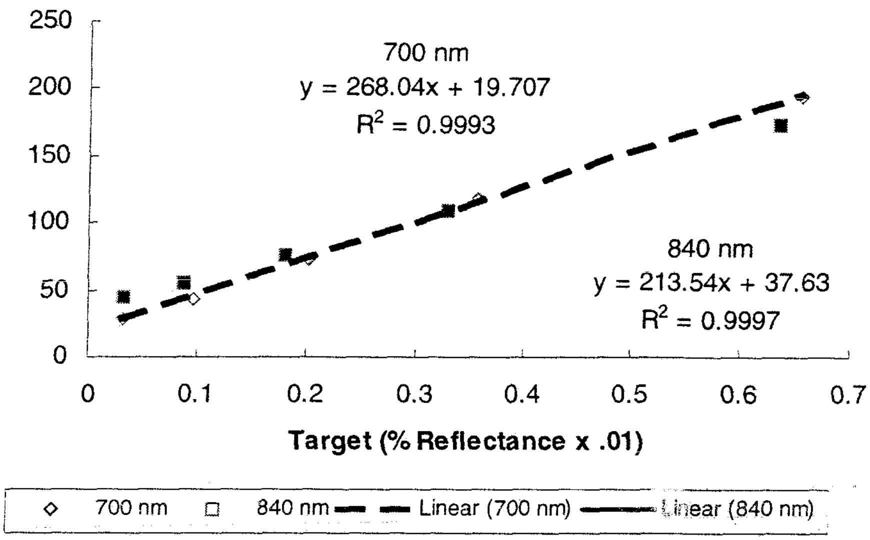

Figure 1 - Least Squares Linear Regression of Camera Output vs. Measured Panel % Reflectance

reflectance of the gray scale panels as measured with the field spectroradiometer at the time of the overflight. It can be seen in Table 1 that the panel reflectances were close, but not identical, to the values provided by the manufacturer. Also, the reflectances at 700 and 840 nm were close to each other but not identical, indicating a slight spectral variation of panel reflectance. Figure 1 shows the results of a least-squares linear regression between the camera digital output and the measured panel reflectance. The r^2 of the regressions for both the 700 and 840 nm bands were > 0.999, indicating that the camera output is a linear response to the reflected radiance.

Table 2 contains the 700 to 840 nm ratio output from the camera and the ratio computed from the spectroradiometer data. For comparison, the ratios from each instrument have been presented in both digital number format and decimal format. For the camera output, the means and standard deviations of the target ratios were computed from all the pixels within the dark and light green targets. The ratios for grass areas 1 – 3 were computed from transects surrounding the two green targets and the grayscale target, respectively. For the spectroradiometer output, the means and standard deviations of the ratios were computed from 5 discrete points on each green target and 8 discrete points in the grass surrounding each green and grayscale target. The camera output ratios were not corrected for offsets identified by the regressions in Figure 1. This resulted in a slight difference in the range of the ratios when compared to the spectroradiometer output. However, the least squares linear regression result shown in Figure 2 indicates that the

Table 2 - Ratio Comparison between camera and spectroradiometer

	Camera		Spectroradiometer	
Target	**Ratio**	**Ratio DN**	**Ratio**	**Ratio DN**
Dark Green	0.25 ± 0.02	31 ± 2	0.15 ± 0.01	19 ± 1
Light Green	0.50 ± 0.02	64 ± 3	0.40 ± 0.01	52 ± 1
Grass 1	0.64 ± 0.04	83 ± 5	0.64 ± 0.04	83 ± 5
Grass 2	0.64 ± 0.04	82 ± 5	0.63 ± 0.04	81 ± 5
Grass 3	0.63 ± 0.04	81 ± 5	0.64 ± 0.04	81 ± 5

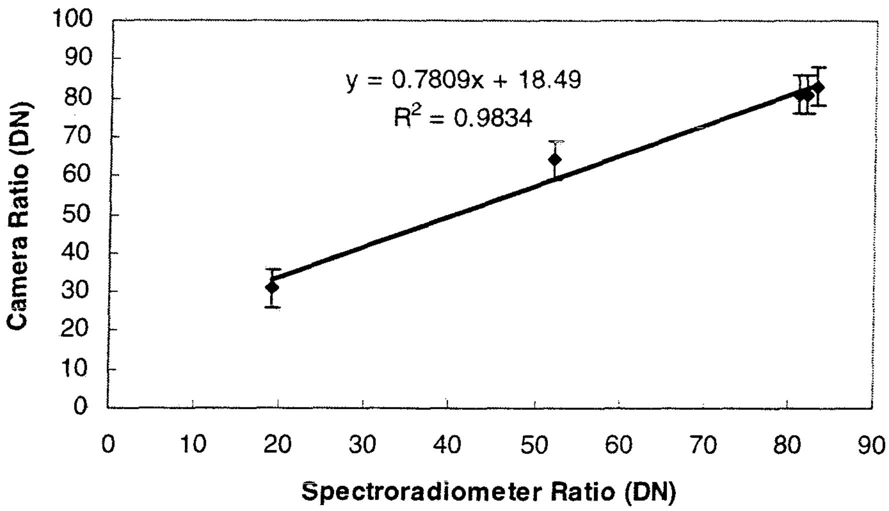

Figure 2 - Camera ratio vs. ratio computed from spectroradiometer data (% reflectance at 700 nm / % reflectance at 840 nm)

response of the camera was nearly linear ($r^2 > 0.98$) with respect to the spectroradiometer. It can be seen from the standard deviations in Table 2 that the camera results were only slightly more noisy than those from the spectroradiometer.

Table 3 contains a comparison of the noise between camera bands. The mean and standard deviations of the outputs of the 700 and 840 nm bands were computed from several images as described in section 2.0 above. The noise increased with camera response to an input greater than zero, but there was little change in noise between brightness levels.

Table 3 - Camera Noise Performance

	Camera Output Digital Numbers (DN)	
Target	**700 nm**	**840 nm**
Dark Image	3 ± 1	7 ± 2
Uniform Bright Image	99 ± 3	160 ± 4
Light Green Target	93 ± 4	173 ± 4
Dark Green Target	39 ± 3	146 ± 4

3.2 FLIGHT TEST DETECTION RESULTS

Ratios were compared between calibration flights 1 and 2 (Table 4). A sample ratio image was taken from the site of a positive detection flown at an altitude of 610 m. A septic system absorption field line was clearly visible in the image. The means and standard deviations were computed from transects along the center of the absorption line and immediately adjacent to it. These ratios were compared to those computed from the calibration panels. It can be seen from Table 4 that there was much greater variability in the data from the septic system site than from the calibration panels. However there was an almost 3 to 1 difference in the magnitude of the ratios of each transect, indicating that detection is possible, even in the presence of high noise values.

Table 4 - Flight Test Ratio Comparison

Target	Ratio (DN)
Dark Green	31 ± 2
Light Green	64 ± 3
Grass 1	83 ± 5
Field Line Transect	17 ± 10
Adjacent Transect	63 ± 27

The results of flights 2 and 3 are shown in Table 5. The potential sites identified from the images taken during flight 2 were selected through visual evaluation of all the images collected during the flight. There was no *a priori* knowledge of the conditions at these sites. Because of this selection method, these results represent a comparison between actual and false detections. The potential sites identified for flight 3 were known to have problems. The results from this flight represent actual detections of real problems.

Table 5 - Flight Test Detection Results

Flight	Altitude	GSD	Potential Sites	Confirmed Sites	Percent Correct
2	610 m	0.32 m	8	3	37.5 %
3	914 m	0.48 m	18	3	16.7 %

4.0 ANALYSIS AND CONCLUSIONS

It has been shown through this evaluation that the PCIS camera performs well and can provide results similar to a calibrated field spectroradiometer in computing ratios of ground targets. The noise in the camera output was slightly greater than that of the spectroradiometer indicating a decrease in the number of discrete detection levels available from the camera. The linear regression between the camera output and spectroradiometer output (Fig. 2) indicated that the output of the camera was nearly as accurate as the calibrated instrument. It was also shown that the spatial resolution of the camera was sufficient to match the expected size constraints of the onsite treatment systems.

The detection of malfunctioning onsite treatment systems does appear possible. Though the detection rate of 16.7 % for flight 2 is low, these detections may not have been possible at all unless reported by property owners. It is likely that this rate would have gone up if the GSD had been reduced from 0.48 m to 0.32 m. The detection rate of 37.5 % for sites with known problems is more indicative of a maximum detection limit and provides some insight as to the types of operational problems that will be encountered. Detection at several of the known sites was prevented by shadows cast by adjacent structures or vegetation. Obscuration by overhanging vegetation canopies also prevented detections at some sites. Shadows and obscuration are more significant problems in older residential areas and appear to be the major operational problem with this application.

Overall, the PCIS performed well and appears well suited to this application. Field testing produced positive results and provided insight to operational issues. Due to the significance of problems created by malfunctioning onsite treatment systems, any improvement in the ability to correct such problems will be useful in protecting public health. Further efforts in cost benefit analysis and system improvements could result in the development of a cost-effective implementation of this system.

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