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Integrating Spray Plane-Based Remote Sensing and Rapid Image Processing with Variable-Rate Aerial Application

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Abstract. *A remote sensing and variable rate application system was configured for agricultural aircraft. This combination system has the potential of providing a completely integrated solution for all aspects of aerial site-specific application and includes remote sensing, image processing and georegistration, prescription generation, and variable-rate application. A missing link has been the ability to rapidly process and georeference images obtained during flight for creation of field prescriptions that can be applied on the next pass of the airplane. Success using the remote sensing system for detection of weeds is described, and evaluation of a variable-rate system indicated fast response to changing flowrates and accurate placement of material in preliminary testing. Evaluation of a scheme for rapid image processing showed that georegistration error could be reduced by accounting for systematic GPS error and improving synchronization of GPS position data with images.*

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Introduction

A fully integrated system incorporating remote sensing, rapid image processing with georegistration, and variable-rate application could be of great benefit to aerial applicators. Presently, remote sensing for variable-rate application is contracted out to agricultural consulting services (In-Time, 2007; John Deere Agri Services, 2007), which also provide the necessary steps to create a field prescription that can be loaded directly into a ground sprayer or an airplane's guidance system. These services have relatively fast turnaround for image production, but total time to create a prescription map from images is variable. In-field scouting is used to specify management zones for prescription application.

Advances in automatic flow control for aerial application have burgeoned during the past few years, and system evaluations have facilitated improvements to flow control systems for variable rate aerial application (Smith and Thomson, 2006). Agricultural aircraft (or spray planes) have also been evaluated for their utility in remote sensing (Thomson et al., 2005a; Core, 2005). These platforms have an advantage of being convenient for frequent imaging since aircraft are in the field for spraying operations anyway. Frequent imaging can be critical for properly timing chemical or water applications to prevent nutrient or water stress.

To provide a completely integrated system for agricultural aircraft, automated image processing would allow remotely sensed images to be processed rapidly, interpreted, and then applied to a variable-rate field prescription. Depending on the variable of interest, different multispectral indices could be generated. This paper summarizes progress in remote sensing from agricultural aircraft, variable rate aerial application, and automated image analysis.

Remote Sensing Applications

Many remote sensing applications using the spray plane as a vehicle for imaging have been published in the literature. These include detection of field weeds and harmful algal components in catfish production ponds (Thomson et al., 2005a), detection of damage caused by spider mites (Thomson and Sudbrink, 2004), and detection of crop response to tillage practices and water stress using thermal imagery (Thomson et al. 2005b). A weed detection example application is illustrated herein.

Weed Detection

Success has been demonstrated using simple digital video from agricultural aircraft to detect and discriminate weeds from crop. Thomson et al. (2005a) described a system that used a Sony Digital 8 video camera and remote pilot controls to image a field of early cotton in rows with a mixture of spotted spurge (*Euphorbia maculata* L.) and hyssop spurge (*Euphorbia hyssopifolia* L.). Patches of Johnsongrass (*Sorghum halepense* (L.) Pers.) were also present in the field. Since camera resolution was limited (500 lines X 580 pixels), the field was flown at a low altitude (54-m) to obtain a clear image. This altitude is much lower than should normally be flown to image a field, but this was adequate to test the concept. Higher resolution video cameras, digital-still cameras, and reasonably priced multispectral cameras have become available, which would allow higher flights. Thomson et al. (2005a) illustrated use of image analysis software and a classification algorithm to separate early cotton, spurges, and Johnsongrass in the RGB (Red Green Blue) image. Cotton, spurges, and Johnsongrass were represented in the classified image with three different colors. If it were desired to apply site specific aerial weed control, this image could be georegistered with GPS coordinates (Thomson et al., 2002) and attitude data (if the airplane is equipped with an attitude sensor) with the

assistance of a Geographic Information System (GIS). In our present system, the airplane's guidance system software converts the GIS shape file to its own data format for generation of aerial prescriptions.

Although sophisticated classification algorithms were used on these data, good separability between weeds and cotton can also be seen by differences in their raw digital numbers (DNs) that illustrate differences in intensity (Table 1). Image analysis packages like ENVI can extract DN's from images, but graphics packages like Adobe Photoshop can also be used. DN's ranged from zero (black) to 255 (full intensity), and results of Table 1 indicate average DN's across the three colors, averaged over ten pixels per plant. To account for temporal differences in sunlight intensity and provide consistent comparisons, spectral vegetation indices that use waveband combinations have been developed and were successfully used to discriminate weeds from crop and other weed species (Gumz and Weller, 2006).

Table 1. Average values for randomly selected digital numbers (DN's) corresponding to cotton, Johnsongrass, and spurges.

Cotton	Johnsongrass	Spurges	
93	60	104	
85	78	100	
90	75	94	
84	45	115	
89	56	106	
83	88	107	
83	76	106	
80	110	107	
88	68	105	
77	92	113	
85	75	106	Mean
4.8	18.9	5.9	Std. Deviation

Variable Rate Aerial Application

Two components of the variable-rate aerial application system have been evaluated. The GPS in the Satloc guidance system has been evaluated for accuracy against a known ground position (Smith and Thomson, 2005). The flow control portion of the system is continually being improved by comparing measured flowrates and step change responses to desired flowrate response curves (Smith and Thomson, 2006). With these data, the manufacturer of the Autocal II flow controller (Houma Avionics, Houma, LA) then reprograms the system with necessary improvements. The latest test results for both systems are summarized below.

GPS Testing

A ground-based event trigger was used to evaluate accuracy of the Satloc's GPS at a ground position precisely specified using an RTK GPS (Smith and Thomson, 2003, Smith and Thomson, 2005; Thomson et al., 2007). Components of the event triggering system consisted of two mirrors (29 X 120 cm) placed strategically to reflect sunlight vertically to a downward-looking photocell placed in the belly of the aircraft. When the plane passed over the ground reference position, a time record was placed in the Satloc data file, which included location coordinates. One mirror was placed directly over the reference point such that its long dimension was perpendicular to the direction of flight (Fig. 1). The mirror was supported on a stand that provided for full range angle adjustment to achieve a vertical beam of light. A second mirror was placed about 15 m away from the first mirror and was used to reflect sunlight to the reference-point mirror. The second mirror was physically monitored during each test to assure proper attitude as the sun changed position. Both mirrors were positioned and adjusted before initiating data collection by positioning a small horizontal surface on a pole approximately 3 m above the reference point and centering the surface over it using a plumb bob. This was done to assure a vertical beam of light to the airplane. The light beam was centered on the horizontal surface by adjustment of mirror angles while the plumb bob was directly over the reference point (Fig 1).

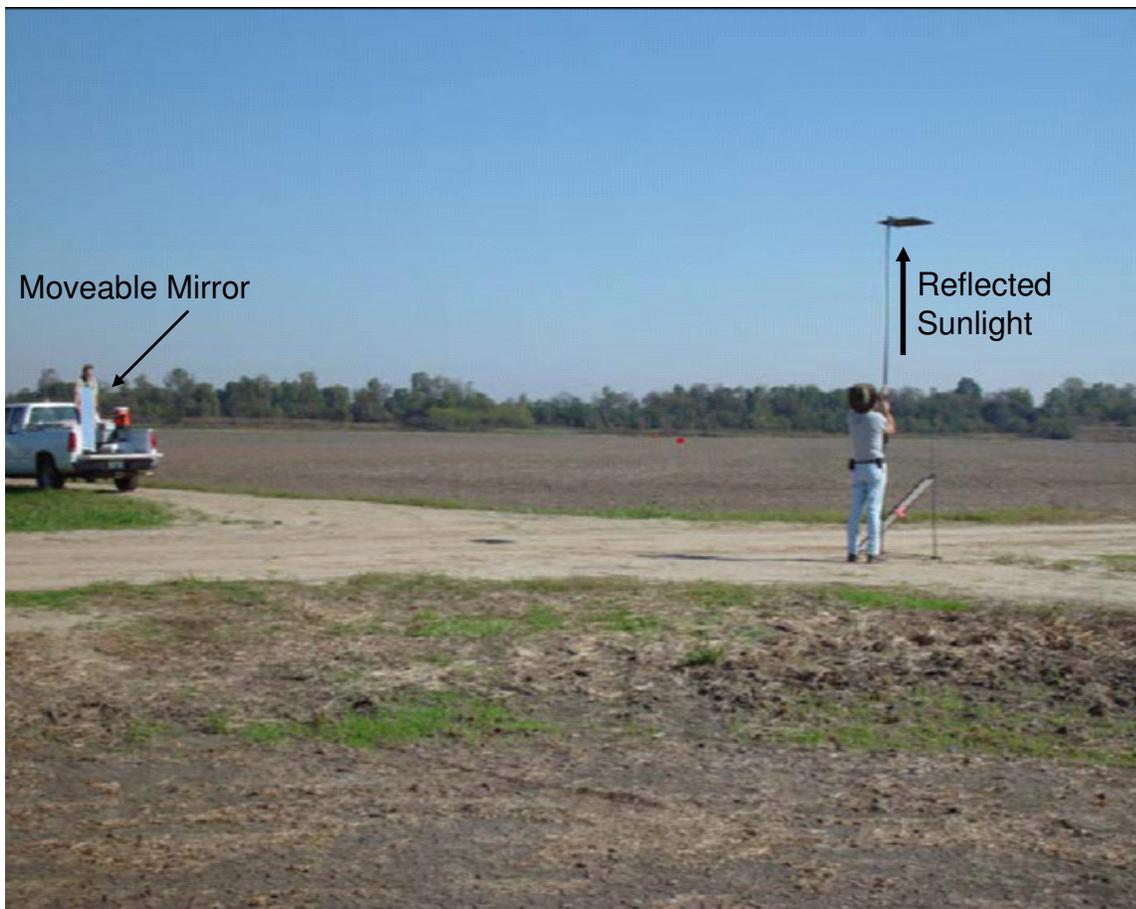


Figure 1. Mirror arrangement for orienting a vertical beam of sunlight to trigger the airplane's on-board GPS.

When the precisely specified ground position was reached by the aircraft, the vertical beam of sunlight was detected by the photocell, causing a solid state relay to close through appropriate circuitry designed by the third author. When the relay closed, a record was placed in the Satloc data file to 0.01s precision (corresponding to about 60 cm at typical airplane speeds), allowing a nearly exact position to be logged. A circuit schematic and pictorial of the mirror-based system can be found in Smith and Thomson (2003).

To determine positioning error for the Satloc, four flights in four directions each (N, S, E, W) were conducted on four different dates in 2003. The airplane was flown at an approximate 3.0-m height, judged by the pilot, directly above a ground target referenced using both a Garmin 76S WAAS-corrected GPS and Rockwell Collins PLGR+. The latter uses the military PPS (Precise Positioning Signal) to obtain a position fix (Sidle, 1999). Locations of ground positions were confirmed using an RTK GPS system based on the Trimble MS750 receiver.

Results indicated for one date (16 October 2003) are typical of the entire study. On this date, the Satloc lagged the ground reference point by an average of -4.53 m (S.D. = 0.68 m) in the east-west direction and led the reference point in the north-south direction by an average of +7.88 m (S.D. = 0.52 m) over 16 total runs (four in each direction). All tests over the five-week period exhibited these consistent, directionally-dependent patterns. A certain amount of negative latency was expected for all directions, but positive latency was not expected.

A comparison of the Northing values for the east and west runs (with the reference point Northing coordinate as indicated by the Rockwell receiver) revealed cross track errors less than 1 m. Likewise, cross-track errors were less than 1 m when traveling in the north or south directions. Low cross-track error is consistent with past evaluations of Satloc swath guidance systems used on agricultural aircraft (Thomson et al., 2002; Smith and Thomson, 2003).

Flow Control and Placement Accuracy

Field tests on accuracy of the Autocal II flow controller and placement accuracy of spray using spray cards placed in the field have been documented by Smith and Thomson (2006). That paper detailed the latest evaluation to date of the Autocal II flow controller interfaced with the Kawak Aviation hydraulic power pack and boom valve, and Satloc Airstar M3 swath guidance system. A 0.5 second look-ahead was used to trigger a spray event for evaluation of placement accuracy. This look-ahead value was found to be optimal for compensation of delays in GPS response and, more significantly, delays in hydraulic system response.

Figure 2 shows a typical response of flowrate vs. time (Smith and Thomson, 2006). Ground speed during this spray pass was 67.9 m/s (132 knots, 152 mile/h) and the 0.5 s lead time was used. Vertical grid lines represent management zone boundaries based on time required to travel 81 m. Flow controller response to the zero to 28 L/ha (3 gal/acre) rate change was slightly over-damped and can be explained as the combined effect of the control approach used and the type of spray pump.

Spray deposition position error was determined by using spray cards in the field. Twenty one water sensitive cards spaced at 2 m intervals. A single application rate change (from zero flow to 56 L/ha) was made at the mid-point (20-m). The direction of travel for all spray passes was from the 40 m position to the 0 m position (east to west). Overall, observations showed an average spray deposition position error magnitude of 5.0 m when traveling east to west and 5.2 m when traveling north to south. Statistical analysis indicated that direction of travel had a non-significant effect on the magnitude of spray deposition position error.

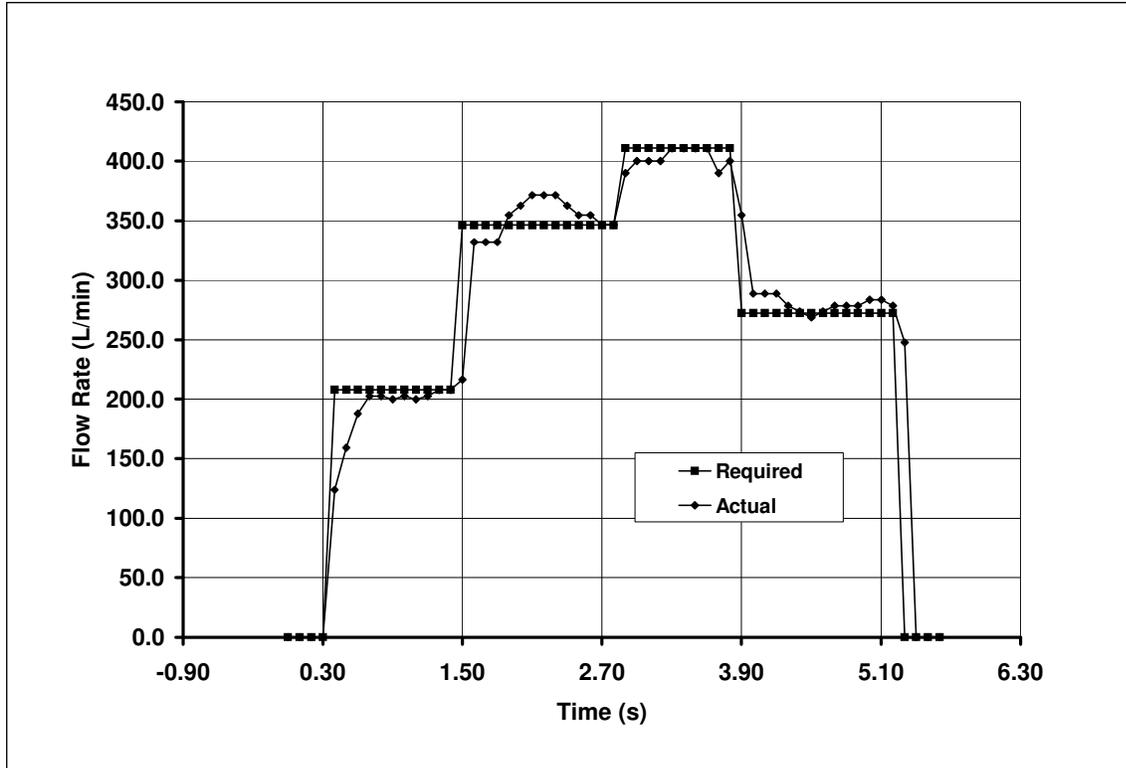


Figure 2. A typical response of actual boom flow rate to step changes in the required flow rate

Automated Image Processing and Georegistration

A system has been documented by which remote sensing images can be automatically georegistered and transferred into a site specific farming program using special hardware and software (Price and Alli, 2005). Special electronics were designed to perform all control functions for the camera system. Color-infrared images were processed into the Normalized Difference Vegetation Index (NDVI) and were automatically georeferenced using both an on-board GPS and plane attitude sensor.

A single board computer (BasicAtom Pro, Basic Micro Inc., Murrieta, CA) controlled image acquisition and acquisition of data from the sensors, which were passed to the flight computer through the Microsoft Windows Hyperterminal data communications program. The software determined the correct time between photos, and to produce a percent overlap in the images (20% in this case). Conversion software, programmed in Visual Basic, used standard trigonometry and plane attitude data to determine a center coordinate in the image (assuming a flat field). The program then stepped across the image using a moving box that determined an average NDVI value and GPS coordinate for each box. This box could be any size selected, or desired, by the user (i.e., 1.5, 3, 6 m., etc.). The average NDVI value and GPS coordinates were saved into a separate text file. This file format was used since it could be imported into most farm management software programs including graphically-based programs. The process was repeated until the entire image was transformed. Processing times were typically less than 30 seconds for each photo using a 2 Ghz computer.

The integrated system was evaluated for georeferencing accuracy. Initially, average Root Mean Square (RMS) error for all images was 56 meters. This value was not acceptable for prescription map generation and was no better than initial experiments on video-based image georeferencing with one-second GPS updating (Thomson et al. 2002). GPS errors were seen to be caused by latencies in the direction of flight and the time required for the GPS to output the coordinate, which was simultaneously used to trigger the camera. When consistent GPS errors were accounted for, about half the RMS error was removed leaving 27m of error. Further analysis of error indicated that synchronization problems still existed between GPS data arriving from the satellite and camera triggering. Another problem was that attitude data were not synchronized, explaining why accuracy of the GPS data with attitude adjustment fared worse than the GPS data alone. A partial solution to the camera synchronization problem was to use the PPS line from the Garmin GPS to trigger the camera so output would correspond more closely to the GPS time clock. When this was done, RMS errors were reduced to 10-m (GPS only - no attitude adjustment).

Discussion

Flow Control

Over-damped system responses observed from zero flow to high flowrates (Fig. 2) has caused the manufacturer to consider a revised approach for flow control that keeps the pump operating and closes the boom valve to achieve zero-flow requirements. Presently, the pump is turned off at zero flow, and rate changes to a non-zero value require the spray pump to overcome the static condition of the spray mix and get it moving through the plumbing. With the new proposed system, flow to the boom is shut off at zero output and the pump output re-circulates to the hopper. Thus, fluid momentum through the pump is maintained for initiating spray when the boom valve is opened.

Automated Image Processing for Variable-Rate Application

The study presented herein indicates that georeferencing errors were systematically reduced by accounting for synchronization and timing issues. In order for the automated image processing system to be useful for use on agricultural aircraft, output file formats will ultimately need to be compatible with the Mapstar prescription generation software that is part of the Satloc guidance system package. It is our feeling that Arcview (or ArcGIS) will still be needed as intermediate software before conversion to the Mapstar data format. This would allow other guidance systems besides the Satloc to be compatible with the automated image analysis system.

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