Remote Sensing Using Remote Controlled Airplanes: Monitoring Vegetation near Eddy-Covariance Towers

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Rationale and Objectives

Spatial variation in soils and vegetation can complicate the interpretation of micrometeorological flux measurements. For example, the area sampled by eddy covariance instruments (i.e., footprint) is dependent on wind speed, wind direction, and atmospheric stability. Remote sensing can be used to characterize the leaf area and species composition of the vegetation surrounding flux monitoring sites. These data can be paired with a source area model to match the 30-min flux measurements with the sampled vegetation. These relationships are critical when scaling up tower measurements (Desjardins et al., 1997). Unmanned aerial vehicles (UAVs) as well as relatively low-cost digital near-infrared cameras are well suited for frequent low-altitude imaging of flux monitoring sites. The objective of this research was to examine the feasibility of using a small remote-controlled aircraft to collect images of the source area sampled by eddy covariance towers operating in tallgrass prairie near Manhattan, Kansas.

Design Criteria and Mission Description

The UAV was designed to fly the following mission:

1. The pilot hand launches the aircraft (no runways are available).
2. Flying a circular pattern via radio control, the plane carries a 2.5 lb payload to altitude while transmitting GPS and video information to the pilot.
3. When the video GPS information indicates the plane is at the target altitude (300 to 600 m, 1000 to 2000 ft), the pilot activates altitude hold and wing leveler circuits. The plane automatically maintains the target altitude for the duration of the 8 to 10 minute mission.
4. The pilot flies the plane in a pattern over the study site while viewing the video image from an on-board down-facing camera. When the plane is over the target, the pilot triggers the shutter on the remote sensing camera.
5. After the mission is complete, the plane is landed without power ("deadstick"). Because a landing zone is not usually available, the plane must be able to withstand extremely rough landings (a controlled crash landing).

Aircraft

The main aircraft was a Super Frontier Senior, an almost-ready-to-fly high-wing (ARF) trainer manufactured by World Models (www.theworldmodels.com). The plane had a wingspan of 2.04 m (80.5 in.) and wing area of 79.5 dm^2 (1205 $in.^2$). When fully loaded with the remote sensing gear it weighed 5.7 kg (12.5 lbs.), which was well above the manufacturers recommended flight weight of 3.4 kg. The fuselage and landing gear were heavily modified to accommodate the space and weight requirements of the cameras and avionics. This model has been used for atmospheric research at Oklahoma University (Straka et al., 1996). Other models used for the project were the Big-T and Monster-T manufactured by JK Aerotech (http://www.jkaerotech.com).

Large high-wing trainer aircraft, such as the Super Frontier Senior from World Models, make excellent UAVs. This plane has an 2.05 m wingspan and weighs 5.7 kg when fully loaded. Takeoffs and landings are difficult because runways and landing zones are not available at most research sites. The aircraft is hand launched and landed with no power (deadstick). It often comes to an abrupt stop in tall grass or weeds. A folding propeller is used to avoid damage on impact.

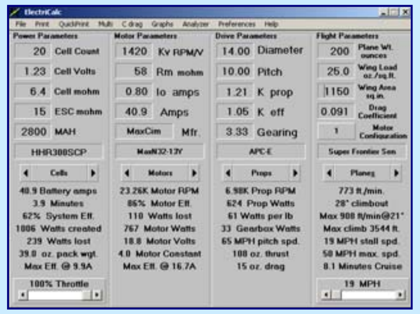
The "Big T" by JK Aerotech is a very simple but durable plane for aerial photography (www.jkaerotech.com). Many photographs were taken using a Canon S110 digital camera mounted on the side of the fuselage.

Power System

The plane was powered by a MaxCim 13Y brushless electric motor (www.maxcim.com) running on 20 Sanyo 2600 mA Nimh batteries. The motor turned a 14x10 folding propeller on a 3.33:1 gearbox. This configuration was capable of taking the aircraft to altitudes of 300 m in less than two minutes. Total flight duration was about 8 min. Lithium polymer (Li-Poly) batteries (e.g., www.thunderpower-batteries.com) would extend flight duration to 24 minutes and reduce weight. However, Li-Poly batteries for this plane are expensive ($450). Some experiments were conducted with internal combustion "glow" engines. However, engine vibration and oil in the exhaust made it difficult to collect quality images.

The UAV is powered by a MaxCim 13Y brushless motor running on 20 Sanyo 2600 mA Nimh batteries (the batteries can be seen protruding through the firewall under the motor). When driving a 14x10 folding propeller on a 3.33:1 gearbox, over 1000 W of power are generated (see ElectriCalc analysis).

After an 8 to 10 min. flight, the batteries can be recharged in 25 minutes. If lithium polymer batteries are used, 24 minute flights are possible.



Analysis of the UAV power system using ElectriCalc 2.01, software for designing electric powered model airplanes (www.slkelectronics.com).

Cameras

The plane is configured to carry three different cameras. The Dycam and Tetracam are multispectral cameras capable of generating NDVI (Normalized Difference Vegetation Index) and other spectral indices.

- Canon S110: 2.1 MB color digital camera
- Dycam Agricultural Digital Camera (ADC): red (635-667 nm) and NIR (835-870 nm), 496 X 365 pixels
- Tetracam ADC: digital red/green and near infrared camera, 1.3 million pixel sensor (www.tetracam.com). The Tetracam is the replacement for the Dycam.

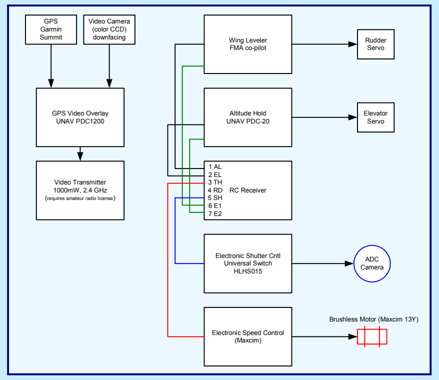
Top view of the fuselage showing the camera (Dycam ADC), GPS, altitude hold, and GPS overlay. The 1000 mW video transmitter is located under the windshield.

The underside of the UAV showing the camera bay opening, the down-facing video camera, and the FMA co-pilot sensor. When activated, the co-pilot module uses infrared transducers to keep the plane flying straight and level (www.fmadirect.com).

Avionics and Flight Controls

In addition to the normal flight controls, the UAV included:

- Altitude Hold Module (U-NAV, PDC-20, www.u-nav.com)
- GPS (Garmin eTrex Summit, www.garmin.com)
- GPS Video Overlay (U-NAV, PDC-1200)
- Wind Leveler Autopilot (FMA Co-Pilot, www.fmadirect.com)
- Remote Electronic Switch for triggering camera
- Video Camera (Panasonic CX-161 color CCD)
- Video Transmitter and antenna (1000 mW, 2.4 GHz, www.blackwidowav.com)



Block diagram of the avionics used in the UAV.

Discussion and Recommendations

Many flights were made using the Super Frontier Senior and the JK Aerotech Big-T equipped with different cameras and avionics. Most of the work during 2003 was aimed at perfecting the hardware and learning to operate the aircraft under various conditions. Many attempts were made to fly the planes on preprogrammed routes using GPS and a U-Nav PDC-10 module (www.u-nav.com). This proved to be quite difficult and research is still underway to obtain this goal. A telemetry-based system, where information is transmitted to and from a laptop computer that "flys" the airplane, may be a more desirable approach. Also, it is clear that slightly larger or more powerful UAVs are needed to carry the desired payload. A new plane is under construction that has 20 percent more power than the existing aircraft.

Results showed that taking repeated images of a small research area was very feasible using remote controlled aircraft. Starting in the spring of 2004, we plan to collect images of our eddy covariance tower sites at two-week intervals throughout the growing season. Leaf area and biomass will be sampled at several points around the towers on the same dates. The post-processed images will be combined with a footprint model to gain a better understanding of the vegetation contributing to the flux measurements.

Images of the Rannells Flint Hills Prairie Preserve taken in October, 2003 at 460 m (1500 ft.) using the Dycam ADC with a wide angle lens. An eddy covariance tower is in the middle image.

Digital photographs of several eddy covariance towers and the headquarters buildings at the Rannells Flint Hill Prairie Preserve near Manhattan, KS.

Photographs of a fence line on the Rannells Prairie. Ungrazed prairie is on the left and grazed prairie is on the right side of each photograph. From left to right, the first image was taken in June, the second during drought in July, and the third in late August when the vegetation had recovered following a 100 mm rain on July 29. Eddy covariance towers were deployed on both pastures during this period.

Historical UAV Flight

"The history of trans-Atlantic aviation reached an unusual milestone Aug. 11, 2003 when a radio-controlled model plane flew from Cape Spear, Newfoundland to Mannin Beach, Ireland. The 11-pound TAM 5 (Trans-Atlantic Model 5) made the 1,888-n.m. flight at an average speed of 49 mph in just over 38.5 hours. Made of balsa wood and Styrofoam covered with red mylar, the plane is four feet long, has a 6.5-foot wingspan and is powered by a 1-hp, 10-cc four-stroke engine.

The project was the brainchild of Maynard Hill of Silver Hill, Md., a retired robotic airplane expert at the Johns Hopkins Applied Physics Laboratory. Though legally blind and partially deaf, Hill, 77, has set many model airplane records over the past 35 years."

From: http://www.landings.com/landings/pacflyer/sep7-2003/Sn-50-r-c-model-flie.html

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An electronic version of this poster is available at:
http://www.oznet.ksu.edu/envphys/Research/researchada.htm

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