UAS: Platforms - picking the right platform for the right application

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- Professor Emeritus, Agronomy, Kansas State University
- Collaborator, Agronomy, Iowa State University

Drone | Small Aircraft | Satellite
Personal and Team Experience

• 33 years teaching graduate and undergraduates in image acquisition and computer processing of satellite imagery

• 35 years using satellite imagery for research on projects throughout the world

• 35 years experience in collecting and analyzing color IR imagery acquired from a small piloted aircraft

• 35 cumulative team years working with unmanned aircraft systems (drones) (Among the first to use drones for ag applications)
Sample Distinctions of our Company Team:

• Scientific Adviser on drone technologies to National Research Council Committee on Agriculture and Natural Resources

• Scientific Adviser to former US Secretary of State as a committee member to the National Research Council, Geographical Foundation for Agenda 21 on Sustainable Development in Africa

• Scientific Adviser to National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA) as committee member of National Research Council, Environmental Satellite Data Utilization (CESDU)

• Testified before US House of Representatives subcommittee on Aeronautics and Space Policy Institute of the Committee on Science.
Our drone specialists have escorted the US Military Predator back into the US.

Dashboard of Kirk Demuth’s airplane

Our pilots are certified flight instructors for single and multi-engine aircraft including jet aircraft.
To best serve our customers, AgPixel processes aerial imagery from all platforms. Our remote-sensing and data services will turn any imagery into an informed farm management decision. However, the most feasible collection platform should be determined by the desired application.

<table>
<thead>
<tr>
<th>Feature</th>
<th>UAS</th>
<th>Manned</th>
<th>Satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical resolution</td>
<td>1 inch</td>
<td>10 inches</td>
<td>200+ inches</td>
</tr>
<tr>
<td>Daily coverage area</td>
<td>&lt; 1,000 acres</td>
<td>&gt; 10,000 acres</td>
<td>&gt; 100,000 acres</td>
</tr>
<tr>
<td>Volume of data</td>
<td>Significant</td>
<td>Moderate</td>
<td>Minimal</td>
</tr>
<tr>
<td>FAA operator policies</td>
<td>Strict</td>
<td>Minimal</td>
<td>N/A</td>
</tr>
<tr>
<td>Required operators</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Specialty training</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Flight schedule flexibility</td>
<td>Minimal</td>
<td>High</td>
<td>None</td>
</tr>
<tr>
<td>Acquisition costs*</td>
<td>High</td>
<td>Low</td>
<td>Low/Moderate</td>
</tr>
</tbody>
</table>

*Includes equipment investment and price per acre calculations

Did You Know?

AgPixel’s standard 10-inch resolution product, collected by manned aircraft, is suitable for many common precision applications.

**Did You Know?**

FAA Section 333 exemptions for commercial use are legally required to operate a UAS. This approval process takes approximately 6 months and initially only allows UAS flight up to 200 feet without a follow on FAA Certificate of Authorization request for an altitude up to 400 feet.

<table>
<thead>
<tr>
<th>Common Applications</th>
<th>UAS</th>
<th>Manned</th>
<th>Satellite*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrient &amp; chemical management</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
</tr>
<tr>
<td>Insect, disease &amp; weed detection</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
</tr>
<tr>
<td>Plant density &amp; stand counts</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Relative yield estimates</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
</tr>
<tr>
<td>Irrigation/equipment checks</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
</tr>
<tr>
<td>Flood &amp; weather damage survey</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
</tr>
<tr>
<td>Phenotype identification</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
</tr>
<tr>
<td>Livestock feedlot monitoring</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Estimating biomass of forage</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
</tr>
<tr>
<td>3-D modeling &amp; elevation</td>
<td>Yes</td>
<td>Maybe</td>
<td>No</td>
</tr>
<tr>
<td>Animal habitat assessment</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Environmental impact studies</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Depends on spatial and temporal resolutions
THERE IS MORE THAN ONE RESOLUTION YOU SHOULD BE CONCERNED ABOUT
There are four resolutions one should be aware of when talking about remote sensing:

1. Spectral
2. Spatial
3. Radiometric
4. Temporal
Satellite Sensor Resolutions Are Inversely Related (Teeter Totter Relationship)

When it comes to satellite imaging systems resolution, one cannot increase one resolution, without decreasing another of the resolutions.

As one goes up, another or other resolution/s has/have to go down.

b. Precise bandpass measurement of a detector based on Full Width at Half Maximum criteria.

1. Blue band (450 – 515 nm)
2. Green band (525 – 605 nm)
3. Red band (640 – 690 nm)
4. Near-infrared band (750 – 900 nm)

100 nm wide band

Spectral Resolution

FWHM = 700 – 800 nm = 100 nm bandwidth

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4. Near-infrared band (750 – 900 nm)
RESOLUTION – PIXEL SIZE

- **Multirotor**: 0.20 inch - 1.0 inch
- **Fixed Wing**: 0.50 inch - 1.0 inch
- **Single Engine**: 1.0 inch - 12.0 inch

- **Rapideye**: 256 inches (21 feet)
- **Landsat 7 and 8**: 1,176 inches (98 feet)
To spatially resolve a feature in an image, such as a plant, one needs a pixel that is at least half the dimension of the object’s narrowest dimension.

Minimum pixel size needed to resolve the card or kale plant leaf.
Image over croplands (6.5 m resampled to 5.0 m)

Average repeat coverage is 5.5 days at nadir, 1 day at off-nadir assuming no cloud cover.

Source: © BlackBridge

http://www.aamgroup.com/_blog/News/post/rapideye-archive-imagery/
Landsat 8 multispectral image over croplands

- Pixel size = 30 m pixel size (98 feet)
- Repeat coverage = 16 days, assuming no cloud cover
- Radiometric resolution (energy levels) = 12 bit (4096)
- 9 multispectral bands (1 panchromatic) 2 thermal bands
Orthomosaic of a section of a 51,000 acre overflight acquired at 12 inch resolution.

If one flew for 6 hours over contiguous area, they could acquire 12 inch resolution imagery for over 300,000 acres in a Cessna type aircraft.

Zoom in on a section of Burlington, Colorado
Natural Color Cessna Acquired Imagery 0.36 m (~12 in) spatial resolution
Natural Color Imagery resampled to 2.5 m (~8 ft) spatial resolution (comparable to some commercially available satellite imagery)
Natural Color Imagery resampled to 6.5 m (~21 ft) spatial resolution (comparable to actual resolution of higher resolution satellite imagery)
Natural Color Imagery resampled to 30 m (~98 ft) spatial resolution (comparable to Landsat satellite imagery)
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Natural Color Imagery resampled to 30 m (~98 ft) spatial resolution (comparable to Landsat satellite imagery)
Drone imagery at approximately ¼ inch spatial resolution
AGPIXEL COLLECTS AND PROCESSES MULTISPECTRAL IMAGERY FROM THE PLANT LEAF TO THE GLOBAL SCALES

leaf level < 1.0 inch

Field level (3 inch – 40 inch)

County/State Level 15 (acre)

Continental/Global Level (15 acre or 250 acre depending on satellite)
The Canon 6D has a radiometric resolution of 14 bits = 16,384 intensities of energy in RAW mode and 256 in JPEG mode.
Examples of 16 gray levels or 4-bit radiometric resolution, which is about equal to human resolution.

Could you tell which is grayer A or B if I mixed them up behind my back and held them in front of you? Now let's increase this to 256 gray levels or more. Do you see why the sensors detect stress in the field before we do with our unaided eye?
Winter Wheat
With satellites, the smaller the pixel size, the lower the temporal resolution. In the summer of 2014, regions of the US never acquired a non-cloud covered image the entire growing season. With **drones and piloted aircraft**, one can fly **under the clouds** or as often as the area is free of cloud cover.
First MODIS Satellite Image over the Eastern Half of the US and Meso-America.

Clouds cover most of the area.
Data Collection

• This imagery was collected using a small aircraft under dense cloud cover during **Tropical Storm Colin**.
• Despite the poor conditions during data collection, the imagery proved very useful during a time when satellite imagery would not have been able to penetrate the clouds.
Data Collection

- Photographs taken by our pilot during the overflights, showing the dense cloud layer under which the imagery was collected.
Contrast Imagery Acquired under Cloud vs Clear Sky Conditions

Orthomosaic of Sorghum Breeding Plots
October 6, 2015
High Cloud Cover Conditions

Orthomosaic of Sorghum Breeding Plots
October 9, 2015
Sunny Condition
October 6, 2015
High, uniform clouds
Notice subdued shadow conditions

October 9, 2015
Sunny skies
Notice darker, harsher shadow conditions
A CHALLENGE WITH DRONE AND LOW ALTITUDE AIRCRAFT IMAGERY

WHY CREATE ORTHOMOSAIC?
How does viewing the same location from varying viewing angles impact pixel brightness values?

Images were collected by Canon T4i NDVI camera over the same sampling frame at nine different viewing angles: N, S, W, E, NW, NE, SW, SE and Nadir. (Carter Wang)
Camera’s viewing angle does have an effect on raw image brightness values. This effect, however, is not very obvious for NDVI values. Normalized data will eventually eliminate the negative effect of viewing angle on image brightness values.
Notice as you move away from the Principal Point, the trees seem to be leaning over away from the center of the image. Notice also, that at the center of the image, the ground can be seen, but as you move outward, one views mostly the sides of the trees.
ELECTROMAGNETIC ENERGY AND ITS INTERACTION WITH MATTER
Soybean Leaf Phenology States

- VISIBLE
- NEAR INFRARED (NIR)
- MIDDLE INFRARED (MIR)

Pigmentation
Cell or Canopy Structure
Water Content
Carotenoid (yellow) pigment masks chlorophyll pigment.

Plants adaptive strategy in using antioxidants to combat “free radicals” that destroy plant cells during times of plant stress.

Natural color image of soybean plant in the greenhouse.
Redder = Greener

LOW NDVI

Unhealthy

Healthy

HIGH NDVI
Sudden Death Syndrome
infected – Lower Chlorophyll Density

Uninfected Higher - Chlorophyll Density

Lower NDVI area

Higher NDVI area
NDVI is like a thermometer. It tells you something may be wrong, but often cannot tell you what is wrong.

That said, how many doctors do you know who consider a thermometer to be of little value?

Making farm management prescriptions from NDVI values alone is not something I would recommend.
Correlation curve showing the $r^2$ values between 2,151 bands (350 nm – 2,500 nm) and tallgrass prairie biomass.

How many bands would one need to predict tallgrass biomass?
3D modeling and elevation mapping is better with drone and Cessna acquired imagery.
AGRICULTURAL APPLICATIONS

- Weed Detection
Canada Thistle (Cirsium arvense)
Canada Thistle Mapping
1.0 inch pixel sizes
Canadian Thistle Study: Herbicide Application

- Cost for single rate treatment: $3,931.13
- Estimated cost for data collection, processing, and spot treatment: $506.63
- Total herbicide savings: $3,424.50

Only 0.6 acres affected of 120 acre pivot
Green Snap of corn (stock broken off)
Lost 55 acres of corn due to green snap

At 200 bushels/acre: 10,960 bushels lost

At 2014 price of $3.50 per bushel: Loss = $38,360

**Total loss due to herbicide overuse, green snap – cost of overflight**

$38,360 + $3,425 = $41,784

Does not include equipment use and labor to spray entire field
NDVI of Corn Field with Thistle

1.5 inch pixels

1.0 m pixels

5.0 m pixels

Weeds

Weeds?

Weeds?
AGRICULTURAL APPLICATIONS

• Crop Damage Assessment
Root-Lodged Corn With Range of Severity for Root Damage

Corn root lodging caused by wind at Iowa State University Genetic Breeding Plots (Picture taken Sept. 3, 2014)
Corn Root Lodging in University Genetic Breeding Plots

Color Infrared (Cessna 2.5 inch pixel resolution)

Natural Color Oblique

NDVI

50,000 seeds/acre

32,000 seeds/acre

Severe

Less Severe

Severe

Less Severe

Severe

Less Severe

Severe

Less Severe

32,000 seeds/acre
Corn Root Lodging comparison between 2.5 inch and 5.0 m resolution

Cessna Color IR Imagery
2.5 inch pixels

Corn root lodging
50,000 seed/acre
32,000 seeds/acre

Same image resampled to 5.0 meter. Where is the root lodging?

If one is missing something as obvious as the root lodging above, what else is being missed using satellite imagery?
AGRICULTURAL APPLICATIONS

• Crop Breeding (High Throughput Phenotyping)
Sorghum Biomass Study Rep 1
1.0 cm (0.4 inch) sUAS Image Data

Multi-temporal color infrared (CIR) image data

Rep 1: biomass study

Jul 14  Aug 06  Sep 01  Oct 06
4. Extract data to calculate crop percent cover subject to high, medium, and low light exposure

All dates: 80 cm wide polygons

Level of Light Exposure
- High
- Medium
- Low
Cluster analysis based on crop percent cover subject to high, medium, and low light exposure.
AGRICULTURAL APPLICATIONS

• Irrigation
Pivot irrigated corn in Chile. The imagery reveals irrigation system adjustment problems. The concentric rings of red and green indicate either improper nozzle head adjustments or drop hoses that are too low.

The red and green lines radiating out from the center to the center indicate uneven pivot arm rotation speed.

- Not enough water
- More water
- Uneven sprinkler arm rotation speed (faster then slower)
Multitemporal Dataset showing crops greening up and browning down in Stevens County, Kansas

Winter Wheat

Irrigated corn and alfalfa

Lower Plant Chlorophyll Density

Higher Plant Chlorophyll Density

Lower NDVI (bare ground and plant dormancy)

High NDVI
Multitemporal Dataset showing crops greening up and browning down in Stevens County, Kansas.

Weekly datasets provide 52 maps per year, so a graph as seen on the right can be created for each pixel on the map.
Using just the NDVI map for each period tells one very little about the current conditions relative to normal or the previous year. NOTICE that the End of July NDVI maps for 2016, 2015, and 2014 look nearly identical.
ENHANCED VEGETATION INDEX (EVI) VALUES FOR THE LATE JULY COMPARED TO 16-YEAR AVERAGE

- Decreased Biomass
- Increased Biomass
- No Change
Late July 2016 Vegetation Index map compared to 16-year average.
O’Brien County, Iowa
2015 Record Corn Yield Year vs. 2012 Lowes Corn Yield in Decades

2015 Record Yield Year
2012 Poor Yield Year
15-Year Average

2015 Record Yield Year
Late June, 2016
15-Year Average

O’Brien County, Iowa
2015 Record Corn Yield Year vs. 2016 (January - May)
Global image coverage
- Tracks plant response to its growing conditions
- Plants integrates year-to-year and within year weather variation, so it works in areas where weather data are not available
- Interactive maps
- Interactive graphics
- Customized crop yield forecasts
- Data output to spreadsheets for further analyses
- 780+ data layers
- Nearly 3 trillion bits of data in the database
- Updated weekly for most of the world
- User defined areas of interest for weekly tracking and customized reports
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