Drones for small-scale agriculture

Digital innovations for inclusive agriculture

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CGIAR - International Potato Center (CIP), Peru
Setting the stage
<table>
<thead>
<tr>
<th><strong>Ag</strong></th>
<th>low-income countries</th>
<th>high-income countries</th>
</tr>
</thead>
</table>
| **farm management** | • *None*, return on investment is too low given local labour costs | • Pod shooting for low-cost planting  
• Spraying campaigns  
Basis is high labour and materials costs that are won back with efficient applications of materials.  
Requires [expensive UAV platforms](#) with substantial payload capabilities. |
| **sensing applications** | • Building the farm cadastre  
• Crop condition monitoring (canopy dems, ndvi, fcover, lai?)  
• Detection of crop stress cause  
• Technology uptake scouting: which crop varieties are grown  
• Contribute to district, national, regional farm statistics (area size per crop, yields, crop calendar), e.g. via smart area sampling frames.  
• Support the planning for emerging irrigation infrastructure. | • Pre-season soil analysis, design of seed planting strategy; design of irrigation systems, planning of nitrogen management  
• Crop condition monitoring (canopy dems, ndvi, fcover, lai?, canopy structure) and early warning (pests, diseases), weeds & irrigation management  
• Detection of crop stress cause  
• Monitoring impact of farm interventions  
UAV platforms can be **relatively lightweight and affordable**. Wall-to-wall surveys are possible but require large UAV systems. |
Rationale for using UAVs

- What they compare against
  1. knowing nothing,
  2. having satellite (or aerial) imageries, or
  3. using UAV images.

- Total field scouting

<table>
<thead>
<tr>
<th>res</th>
<th>cost $/km2</th>
<th>pos-processing $/km2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat-8</td>
<td>30</td>
<td>0 8-band MS</td>
</tr>
<tr>
<td>Sentinel-2</td>
<td>10</td>
<td>0 4 wider bands: 490, 560, 665, 842</td>
</tr>
<tr>
<td>Sentinel-2</td>
<td>20</td>
<td>0 4 narrow bands: 705, 740, 783, 865, 1610, 2190</td>
</tr>
<tr>
<td>RapidEye</td>
<td>5</td>
<td>1.28 5-band MS</td>
</tr>
<tr>
<td>GeoEye-1</td>
<td>0.5</td>
<td>25 4-band MS</td>
</tr>
<tr>
<td>WorldView-2</td>
<td>0.4</td>
<td>29 8-band MS</td>
</tr>
<tr>
<td>Pleiades</td>
<td>0.5</td>
<td>23 4-band MS</td>
</tr>
<tr>
<td>TerrAvion</td>
<td>0.18</td>
<td>188 USA aerial survey</td>
</tr>
<tr>
<td>GeoVantage</td>
<td>0.25</td>
<td>450 USA aerial survey</td>
</tr>
</tbody>
</table>
Cost factors

Cf. Space- and airborne images

- Human capacity
- Platform acquisition
- Flight campaigns
- Data processing
- Platform maintenance & insurance

Comparability in resolutions

**Temporal** space: 4+ d air: 1d UAV: 1d

**Spatial** space: 45+ cm air: 15+ cm UAV: 2+ cm

**Spectral** space: 4-8 b air: 8+ b UAV: 4-200 b
Existing drone technology
Platforms

Fixed-wing
PRO robust, operating range, option to use other fuels
CONS image quality, payload, launch pad

Multi-rotor
PRO image & data quality, multi-sensor, small launch pad
CONS fragile, small operating range, battery-fueled only
Mid-market UAV manufacturers
For monitoring agriculture at landscape scale

- SenseFly/Parrot, Switzerland/France
  - eBee with Sequoia RGB4MS cam

Just one often-used UAV workhorse in agriculture.

Price k$15 – 25, depending on options.

Generally ag-specific UAV prices range from k$ 1.5 – 50, but packages are hard to compare.
On-board commercial sensors

Cameras, Lidar, Positioning, Environmental sensors

Cameras
- RBG + NIR
- Multispectral
- Hyperspectral
- Thermal

Purposes
- **RGB** Visual inspection, terrain elevation, row and plant counting
- **NIR** Soil properties (incl. moisture), plant stress, irrigation management, vegetation indices
- **MS** Plant growth and health
- **HS** Advanced MS, fluorescence
- **Th** Plant health & maturation, irrigation, yield forecasting?

O($$): 500 (rgb) to 50,000 (HS) or over

$ 3500
## Locally assembled Low-Cost Platforms

<table>
<thead>
<tr>
<th>MikroKopter</th>
<th>3D Robotics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IMAGri Area Covered</strong></td>
<td><strong>IMAGri Area Covered</strong></td>
</tr>
<tr>
<td><strong>Altitude (m)</strong></td>
<td><strong>Altitude (m)</strong></td>
</tr>
<tr>
<td>120</td>
<td>200</td>
</tr>
<tr>
<td><strong>Resolution (cm/px)</strong></td>
<td><strong>Resolution (cm/px)</strong></td>
</tr>
<tr>
<td>11</td>
<td>19</td>
</tr>
<tr>
<td><strong>Area per picture (m²)</strong></td>
<td><strong>Area per picture (m²)</strong></td>
</tr>
<tr>
<td>72x54</td>
<td>120x90</td>
</tr>
<tr>
<td><strong>Flight time (min)</strong></td>
<td><strong>Flight time (min)</strong></td>
</tr>
<tr>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td><strong>Overlap (%)</strong></td>
<td><strong>Overlap (%)</strong></td>
</tr>
<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td><strong>Linear area covered (m²)</strong></td>
<td><strong>Linear area covered (m²)</strong></td>
</tr>
<tr>
<td>1008x54</td>
<td>18060x90</td>
</tr>
</tbody>
</table>
Locally Assembled Multispectral Imaging System

CIP-IMAGri

Description:
The Multispectral Acquisition system IMAGri v2.0 has a resolution of 640 x 480 pixels.

Remarks:
• Blueprints, software, camera and optics selection are open access. Open hardware & software for developers.
• Adaptation for different indexes (e.g. PRI).
• Can be adapted to any UAV that can carry more than 800 g.
• The upcoming version will incorporate correction for light conditions.
Low-cost, hi quality products
Software

OPEN ACCESS:
- e.g. CIP- ISAM V3.0

Remarks:
- Stitch two or more images into one (mosaic)
- Source code, final product, tutorials and sample access in our website.
- GNU GLP License

COMMERCIAL SOFTWARE

Agisoft
3D Modeling and Mapping

Pix4D
MAPPER
Mosaicking using ISAM
Monitoring crops throughout the season

![Graph showing NDVI over days after planting for Sweetpotato, Corn, and Cassava.]
Infrared Thermography

Defining thresholds for water management

Crop Water Stress Index

Stomatal Conductance (mol H2O m^-2 s^-1)

Irrigation threshold

Severity threshold

$y = 0.92 - 2.01x$

$R^2 = 0.76, p<0.01$
Mission planning

- Regulations
- Training
- Flight planning
- Security & crowd management
- Image collection & processing
- Information product derivation & delivery
Regulatory frameworks

• From niche hobby to regulated aviation
• Countries struggle to keep up
• Typical regulation parameters are UAV weight, area/time/altitude of operation, and VLOS vs BVLOS distinction.
• Mission control requirements may include geocage and automatic emergency landing.
• UAV registration, pilot certification are often needed for professional applications. Sometimes one needs mission permits and even government official supervision.
• Insurance conditions may be breached easily. Third party liability often required; total loss is often expensive.
• Privacy legislation may impose additional operating constraints. Data collection & dissemination laws seem to be forthcoming.
UAV regulations worldwide

Stöcker, Bennett, Nex, Gerke & Zevenbergen, Remote Sensing, 2017; Global Drone Regulations Database (www.droneregulations.info)
Use cases
Field Phenotyping

**Purpose** Noninvasive methodologies and protocols generating **quantitative data** on the **dynamic responses** of plants to the environment

**Aim** help breeders accelerate selection of genotypes tolerant to different stress factors

**UAV usage** RGB, Multispectral and thermal cameras, customizable platforms and open access software
Selecting Drought tolerant varieties
Purpose  Irrigation scheduling for low-intensity agriculture areas in winter months. *Maize instead of fallow.*

Clientele  Farmers as irrigation receivers, flow pump owners as irrigation providers. Recommendations to irrigate maize.

UAV usage  RGB, 5bMS, thermal cameras. Precise estimation of ground cover. Thermal images to assess impact of irrigation interventions.
STARS Bangladesh platform

RGB Sony NEX-7

<table>
<thead>
<tr>
<th>Channel</th>
<th>Name</th>
<th>Wavelength (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ILS</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Green</td>
<td>525-535</td>
</tr>
<tr>
<td>3</td>
<td>Red</td>
<td>675-685</td>
</tr>
<tr>
<td>4</td>
<td>Red-edge 1</td>
<td>705-715</td>
</tr>
<tr>
<td>5</td>
<td>Red-edge 2</td>
<td>735-745</td>
</tr>
<tr>
<td>6</td>
<td>NIR</td>
<td>795-805</td>
</tr>
</tbody>
</table>

MiniMCA (Tetracam)

Thermal camera
Optris PI 400

<table>
<thead>
<tr>
<th>Altitude (m)</th>
<th>RGB</th>
<th>MiniMCA</th>
<th>Thermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>65</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Resolution (cm)

15 0.3
65 1.2 12
100 5
STARS experiments as seen from the UAV
Crop Statistics in villages, Kilosa Tanzania

**UAV usage** RGB, Multispectral camera
Land use/cover in Kilosa, Tanzania (sample=100 ha)

<table>
<thead>
<tr>
<th>Class</th>
<th>Area m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana</td>
<td>2246.37</td>
</tr>
<tr>
<td>Bare soil</td>
<td>22418.64</td>
</tr>
<tr>
<td>Bush/Shrub</td>
<td>165016.74</td>
</tr>
<tr>
<td>Cowpeas</td>
<td>10282.3</td>
</tr>
<tr>
<td>Fallow</td>
<td>18552.65</td>
</tr>
<tr>
<td>Flooded land</td>
<td>19001.4</td>
</tr>
<tr>
<td>Paddy Rice</td>
<td>347.93</td>
</tr>
<tr>
<td>Grass</td>
<td>46334.72</td>
</tr>
<tr>
<td>Homestead</td>
<td>7001.58</td>
</tr>
<tr>
<td>Maize and Sesame</td>
<td>1194.4</td>
</tr>
<tr>
<td>Maize</td>
<td>85613.98</td>
</tr>
<tr>
<td>Maize and Beans</td>
<td>1664.7</td>
</tr>
<tr>
<td>Maize and Sunflower</td>
<td>13434.66</td>
</tr>
<tr>
<td>No data</td>
<td>16958.61</td>
</tr>
<tr>
<td>Pigeon Pea</td>
<td>37540.3</td>
</tr>
<tr>
<td>Rice</td>
<td>1270.89</td>
</tr>
<tr>
<td>Road</td>
<td>25954.66</td>
</tr>
<tr>
<td>Sesame</td>
<td>401975.84</td>
</tr>
<tr>
<td>Sesame and Pigeon Peas</td>
<td>2311.95</td>
</tr>
<tr>
<td>Sunflower</td>
<td>189.69</td>
</tr>
<tr>
<td>Recently planted land</td>
<td>51084.71</td>
</tr>
<tr>
<td>Water</td>
<td>2406.1</td>
</tr>
</tbody>
</table>
IMAGE CLASSIFICATION
Kilosa - Tanzania

Total Area: 1 sq.km

Land Cover
- Bushes
- Road
- Sesame
- Water
- Maize
- Grass
- Pigeon Pea
- Shrubs
- Cow Peas
- Bare

Sentinel 2
- Resolution: 10 m
- Spectral Bands: RGB-NIR
- Date: 2016-05-24

UAV RS System
- Resolution: 0.052435 m
- Spectral Bands: RG-NIR
- Date: 2016-04-21
Monitoring Cocoa Plantations, Ecuador

Purpose assess health and pruning quality
Finale
Some Take home messages...

• Must define what the use case will be
• Fine-tuning drone technology for rural development can be done only through use cases
• Rural development interventions can take advantage of the synergies satellite and UAV remote sensing provide – e.g. baselines, monitoring changes and index-based insurance
• Must consult experts for proper project design, selection of platforms, sensors and software to be used and to address budget complexities
INTERNATIONAL POTATO CENTER

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HIGH TECH HUMAN TOUCH
UNIVERSITEIT TWENTE.
Building Local Capacity

Training on:
- UAV assembling
- UAV repairing
- Mission planning
- Data processing
Capacity in UAV Maintenance

3D-printed Quadcopter crashed

Crashed Octocopter

Fixed

Fixed
Chlorophyll Fluorescence and Water Stress in Plants

Jan 10, 2017 @ 9 am
\[ A_n = 24.4 \text{ umol CO}_2/\text{m}^2 \text{ s} \]
\[ g_e = 0.2 \text{ mmol/m}^2 \text{ s} \]

Jan 11, 2017 @ 9 am
\[ A_n = 24.4 \text{ umol CO}_2/\text{m}^2 \text{ s} \]
\[ g_e = 0.2 \text{ mmol/m}^2 \text{ s} \]
Monitoring crop pests

Days after planting

Healthy Plants

Chemical controls

Plants with mites

Greenhouse experiment

Healthy plant

Mite

Plant with mites

RGB

NDVI
**Purpose**  Land tenure innovations in sub-Saharan Africa, (Rwanda, Kenya, Ethiopia) spurring rapid urban, peri-urban and rural land administration.

**Aim**  Make land rights mapping faster, cheaper, easier, and more responsible

**Approach**  3rd gen LA: high tech, human touch, partnerships, innovation and market focused, end-user driven, automation, use of artificial intelligence & robotics.

**Seven tools**  being developed, one is focused on UAV-based solutions. It is called **fly-and-create**. Led by ITC, University of Twente.
Fly-and-create Aims and tasks

T1: UAV regulatory frameworks
T2: UAV workflow scenarios
T3: UAV cost minimization

UAV workflow

Requirements
- UAV
- UAV pilots
- Flight permission

UAV workflow steps:
- Flight planning
- Data acquisition
- Data processing

Orthomosaic DSM Point cloud
Its4Land platform

DelAir-Tech DT-18

• 60min of endurance
• IMU/GNSS Applanix APX-15
• RGB camera, 5 Mpxl
• PPK Solution – cm accuracy
• Area coverage: several sqkm depending on flight speed, strip overlap etc
• First model being allowed to fly BVLOS in France and thereby able to cover large areas
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Information needs around small-scale agriculture

**Information required**
- secure land tenure
- pre-season soil/terrain analysis
- crop status
- pest, disease, stress warning
- farm management monitoring
- agricultural (crop area, crop yield) statistics

**Clientele**
- farming communities
- farmer
- farmer
- farm services aggregators
- extension agencies, farm services, agro-inputs sector
- government, investment agencies, crop insurers
Other on-board sensors
Cameras, Lidar, Positioning, Environmental sensors

- Lidar
- Positioning
  - RTK
  - IMU
- Environmental sensors
  - Incident light
  - Climatic

High precision surface modelling (needs RTK+IMU)

With RTK, UAV position is known with cm accuracy, and this allows for (1) easier image stitching, (2) smaller swath overlaps, thus larger area covered. (+$10k)

Incident light sensor allows to some level image calibration, esp. Needed for image time series.
Ground control and software
On-board sensors
Cameras, Lidar, Positioning, Environmental sensors

• LIDAR
  • Collision avoidance
  • Altimetry and canopy structure

• Positioning
  • GCP vs RTK/GNSS
  • Inertial Measurement Unit (3 gyroscopes, 3 accelerometers)
  • Mission planning and swath overlap
On-board sensors
Cameras, Lidar, Positioning, Environmental sensors

• Environmental sensors
  • Incident light (calibration)
  • Climatic
Mission planning

• Regulations
• Training
• Flight planning
• Security & crowd management
• Image collection & processing
• Information product derivation & delivery
• Practicalities