An unmanned aerial vehicle (UAV), commonly known as a drone, is an aircraft without a human pilot on board. Its flight is controlled either autonomously by computers in the vehicle, or under the remote control of a pilot on the ground or in another vehicle.

The term unmanned aircraft system (UAS) emphasizes the importance of other elements beyond an aircraft itself. A typical UAS consists of the:
- unmanned aircraft (UA)
- control system, such as Ground Control Station (GCS)
- control link, a specialized datalink
- other related support equipment.

Credit: Wikipedia.org

New emerging technology well suited for geospatial professionals

Complementary to traditional surveying technologies and to traditional photogrammetry

Many UASs, but not many targeting the geospatial industries
How it works

Computer Vision Software:

A. Automatic Aerial triangulation (AAT)
   - Hundreds of feature points per image
   - “Spider web” of connections

B. Robust Optimization Algorithm
   - Bundle block adjustment (BBA)
   - External & internal calibration

C. Point Cloud densification
   - Up to pixel size elevation data

UAS image processing characteristics

Imaging properties
- Unstable camera geometry (initial calibration report not valid over time)
- Small footprint
- High and variable crab angle and constant pitch up around 5°
- Only approximate position and orientation available

Image processing solutions
- Computer vision (SFM) for fully automated feature point (tie point) detection and matching (SIFT related) -> BBA and AT (georeferenced based on camera GPS positions (WGS84) or optimized based on GCPs) -> sparse 3D point cloud
- Densification based on multi-view stereo matching on pixel level (cluster, extend, filter) yielding several M of 3D coordinates with normals
- Images not individually rectified and then mosaiced (seamline editing) but projected on DSM based on probability functions (novel view generation)
**History of Geospatial UAS Aerial Imaging Solutions in Trimble**

- **2013**
  - Trimble Business Center Photogrammetry Module released
  - Trimble UX5 Aerial Imaging Solution released

- **2012**
  - Gatewing acquired by Trimble

- **2011**
  - First desktop image processing software for UAS surveying from Gatewing

- **2010**
  - Gatewing X100 released

- **2009**
  - First Gatewing prototype for surveying

- **2008**
  - Gatewing founded
  - First idea for a surveying UAS within Gatewing

- **2007**
  - Inpho GmbH acquired by Trimble
Applications & Benefits

UAS Aerial Imaging Solutions

Benefits of Aerial Imaging Solutions

- Economic solution – enables aerial mapping technology, once reserved for the largest surveying & engineering firms, to be used by the masses
- Safety – enables surveying of rugged, hazardous, hard-to-reach or unhealthy areas without risking injury (or worse) to them or individuals in the area
- Efficient process – ability to collect and process data faster than often achievable with terrestrial-based survey technology
- Rapid workflow – system is designed to quickly plan a flight and collect data, allowing rapid response to your customer’s needs (traditional photogrammetry processes)
- Versatile – a technology that can be used to serve numerous professional markets and applications

Target Markets

- Engineering & Surveying
- Mining
- Civil & Heavy Earthworks Construction
- Oil & Gas
- Environmental & Landfill
- Public Agencies
- Agriculture & Forestry
System Overview
Trimble UX5 Aerial Imaging Solution

Trimble UX5 Aerial Imaging Solution

Trimble Access Aerial Imaging Application

- Mission planning
  - Create background map and add optional layers
  - Define mission area and avoidance zones
  - Define GSD, height and overlap
    - In the office or in the field
- Flight planning
  - Calculate and plan multiple flights for a mission
  - Define wind direction, takeoff location, and landing location
    - In the field
- Flight monitoring
  - Monitor the flight
  - Trigger emergency actions when needed
    - In the field
- Analysis
  - Check completeness of data
    - In the office or in the field
Flight Checklist

Flight Monitoring

• Flight is controlled by the autopilot system
  - Based on the mission & flight plan from Trimble Access Aerial Imaging application
• Flight parameters & performance displayed
  - Virtual horizon
  - GPS lock
  - Communication link strength
  - Battery level
  - Aircraft height & speed (actual & planned)
  - Aircraft location & flight lines (on map)
• Manual evasive maneuvers available (if necessary)
• Landing confirmation
Safety Maneuvers

- **Land**: Instruct aircraft to follow land circuit before flight path is finished
- **Fly To**: Fly to a user-specified location on map and circle
- **Hold**: Circle at current position
- **Here**: Fly to location of pilot/GCS and circle
- **Right**: Fly 300 m to the right of current heading and circle
- **FTS (Flight Termination System)**: Abort flight immediately and spiral downward
- **Up (not shown)**: Instruct UA to increase altitude by 10 m
- **Down (not shown)**: Instruct UA to decrease altitude by 10 m

Trimble UX5 Aerial Imaging Rover

- **Airframe**
  - Internal carbon frame
  - Expanded polypropylene foam body
  - Engine & propeller
  - Servo-controlled elevons
- **Payload Bay**
  - Battery
  - Camera
  - Tracking beacon
- **eBox**
  - GPS & orientation sensors
  - 2.4 GHz radio
  - Autopilot

UX5 Top

- **Winglets**
- **Payload Bay**
- **eBox**
- **Servos**
- **Engine**
UX5 Belly

- Camera Lens
- Belly Plate
- Leading Edge
- Launcher Slats
- Propeller
- Elevon

UX5 Airframe

- Internal carbon frame
- Expanded polypropylene foam
- Impact resistant plastics
  - Motor assembly
  - eBox
  - Servos
- Composite fiber parts
  - Elevons
  - Vertical winglets
  - Belly plate

UX5 Payload Bay

- Battery
- Tracking Beacon Clamp
- Camera
UX5 Camera

- Sony NEX-5T digital SLR
- 16.1 MP (APS-C) sensor
- Custom mounted Voigtlander fixed-optics lens
- Increases the stability of the camera internal geometry
- Image size 4912 x 3261 px (156.67 x 104.67 m @ 100 m flight height)
- RGB & NIR (Near Infra-Red) versions

UX5 Camera Sensor Size

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>1/2.3&quot;</th>
<th>1/3.1&quot;</th>
<th>2/3&quot;</th>
<th>4/3</th>
<th>APS-C</th>
<th>35mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect Ratio</td>
<td>4:3</td>
<td>4:3</td>
<td>4:3</td>
<td>4:3</td>
<td>3:2</td>
<td>2:3</td>
</tr>
<tr>
<td>Diagonal (in)</td>
<td>7.3</td>
<td>8.9</td>
<td>11.3</td>
<td>12.3</td>
<td>22.9</td>
<td>43.3</td>
</tr>
<tr>
<td>Width (mm)</td>
<td>3.8</td>
<td>7.2</td>
<td>8.8</td>
<td>18</td>
<td>22.7</td>
<td>56</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>4.3</td>
<td>5.3</td>
<td>6.6</td>
<td>13.5</td>
<td>15.1</td>
<td>24</td>
</tr>
</tbody>
</table>

UX5 eBox

- GPS Antenna
- Power Button & Status LEDs
- Pitot Tube
- Radio antenna
- Download Port
Trimble UX5 Specifications

- Weight: 2.5 kg
- Wingspan: 100 cm
- Launch Type: Catapult
- Cruise Speed: 80 km/h
- Endurance (flight time): 50 min
- Flight Height (AGL): 75-750 m
- GSD: 2.4-24 cm
- Coverage (@ 5 cm GSD): 2.19 km²
- Coverage (@ 10 cm GSD): 4.94 km²
- Flight Ceiling: 5000 m
- Wind Speed: 65 km/h
- Landing Type: Belly
- Camera: Sony NEX5R (16.1 MP)

Launcher Components

- Ramp
  - Bungee
  - Winching tool
  - Release handle
  - Safety pin
- Launcher Dock
- Support

Launcher Benefits

- Consistent launch
  - Speed
  - Launch angle
  - No risk of stall
  - Short learning curve for operator
  - Less stressful (user has to control speed & angle with a hand launch)
- Safety
  - Consistent & controlled launch sequence
  - User not exposed to running motor
  - Complies with Machinery Directive 2006/42/EC
Ground Control Station

- Rugged Tablet
- Flight Planning & Control Software
- Communications Link
- Download Connector

Trimble Business Center Photogrammetry Module

- Office application for processing traditional and Trimble UAS survey data
- 64-bit processor / operating system requirement
- Photogrammetry processing using technology from Inpho
- Simple workflows for importing flight data, stitching images, identifying ground control points, producing deliverables, and measuring features

Visualize the Flight
Create Orthomosaics

Create Digital Surface Models

Create Point Clouds
Topographic Survey Example

<table>
<thead>
<tr>
<th>Time</th>
<th>UAS</th>
<th>GNSS</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground control</td>
<td>1 ½ hr</td>
<td>—</td>
<td>Ground control not</td>
</tr>
<tr>
<td>Ground control</td>
<td></td>
<td></td>
<td>required for all</td>
</tr>
<tr>
<td>measurement</td>
<td></td>
<td></td>
<td>applications</td>
</tr>
<tr>
<td>Setup time</td>
<td>15 min</td>
<td>15 min (per day)</td>
<td></td>
</tr>
<tr>
<td>Survey time</td>
<td>4½ hr</td>
<td>30½ hr (4 days)</td>
<td></td>
</tr>
<tr>
<td>Tear-down time</td>
<td>15 min</td>
<td>15 min (per day)</td>
<td></td>
</tr>
<tr>
<td>Data processing</td>
<td>4 hrs</td>
<td>—</td>
<td>Data can be processed</td>
</tr>
<tr>
<td>time</td>
<td>(2.80 GHz Intel Core i7,</td>
<td></td>
<td>overnight</td>
</tr>
<tr>
<td></td>
<td>16 GB RAM)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total time</td>
<td>38½ hr (60 mins)</td>
<td>38½ hr (60 mins)</td>
<td>6½ faster than GNSS</td>
</tr>
<tr>
<td>Measurement</td>
<td>3.6 cm (at 120 m flight</td>
<td>15 m</td>
<td>Minimum sampling size</td>
</tr>
<tr>
<td>sampling</td>
<td>altitude)</td>
<td></td>
<td>is 2.4 cm</td>
</tr>
<tr>
<td>Horizontal accuracy</td>
<td>2 cm</td>
<td>1 cm</td>
<td></td>
</tr>
<tr>
<td>Vertical accuracy</td>
<td>4 cm</td>
<td>2 cm</td>
<td></td>
</tr>
</tbody>
</table>

Topographic Survey Example

Surface model generated from UAS survey (300,000 measurements)

Surface model generated from GNSS survey (100,000 measurements)

Flight Calculator Table

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>GSD (cm)</th>
<th>Flight Lines</th>
<th>Coverage (ft²) 30%</th>
<th>Coverage (ft²) 60%</th>
<th>Coverage (ft²) 90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>2.4</td>
<td>40</td>
<td>1.14</td>
<td>0.76</td>
<td>0.38</td>
</tr>
<tr>
<td>100</td>
<td>3.2</td>
<td>30</td>
<td>1.80</td>
<td>1.20</td>
<td>0.80</td>
</tr>
<tr>
<td>120</td>
<td>3.8</td>
<td>25</td>
<td>2.52</td>
<td>1.76</td>
<td>0.96</td>
</tr>
<tr>
<td>150</td>
<td>4.5</td>
<td>20</td>
<td>3.12</td>
<td>2.08</td>
<td>1.04</td>
</tr>
<tr>
<td>200</td>
<td>6.4</td>
<td>15</td>
<td>4.44</td>
<td>2.96</td>
<td>1.46</td>
</tr>
<tr>
<td>250</td>
<td>8.2</td>
<td>12</td>
<td>5.76</td>
<td>3.84</td>
<td>1.92</td>
</tr>
<tr>
<td>300</td>
<td>9.5</td>
<td>10</td>
<td>7.09</td>
<td>4.72</td>
<td>2.36</td>
</tr>
<tr>
<td>350</td>
<td>10.8</td>
<td>8</td>
<td>8.42</td>
<td>5.56</td>
<td>2.78</td>
</tr>
<tr>
<td>400</td>
<td>12.2</td>
<td>6</td>
<td>9.73</td>
<td>6.49</td>
<td>3.24</td>
</tr>
<tr>
<td>500</td>
<td>13.6</td>
<td>4</td>
<td>11.06</td>
<td>7.65</td>
<td>4.13</td>
</tr>
<tr>
<td>750</td>
<td>16.3</td>
<td>4</td>
<td>13.65</td>
<td>9.26</td>
<td>5.13</td>
</tr>
</tbody>
</table>

* 80% overlap is the default in Trimble Access Aerial Imaging Module
Legal Flight Operations
Pathways to Legal Flight for Unmanned Aircraft

Certificate of Waiver or Authorization (COA)
- Public Entities
- Public Aircraft
- Aircraft Model
- Defined Location(s) Approved by UAS Integration Office

Special Airworthiness Certificate (SAC)
- Manufacturers
- Registered Aircraft
- Aircraft Serial Number
- Defined Location(s) Approved by Manufacturing Inspection District Office

FAA Modernization and Reform Act of 2012, Section 333 Exemption
- Civil Operators
- Waiver request for commercial operation
- Aircraft Model
- Potentially Flexible Location
- Approved by Administrator of the FAA

Key Requirements for COAs
- Public Entities
  - Public universities, law enforcement, department of transportation, etc.
- Aircraft
  - Must be owned by the proponent
  - Airworthiness of aircraft is self-certified by proponent
- Operator
  - PPL Ground school passing grade for Class G airspace
  - PPL for controlled airspace (other than G)
  - Observer and Pilot must each have a current 2nd Class Medical
- Airspace
  - Controlled or uncontrolled airspace, but not class B
  - Determined by agreement among Flight Standards and Air Traffic Control Office
### Legal Flight Operations

<table>
<thead>
<tr>
<th>Certificate of Waiver or Authorization (COA)</th>
<th>Special Airworthiness Certificate (SAC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Entities</td>
<td>Manufacturers</td>
</tr>
<tr>
<td>Public Aircraft</td>
<td>Registered Aircraft</td>
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<tr>
<td>Aircraft Model</td>
<td>Aircraft Serial Number</td>
</tr>
<tr>
<td>Defined Location(s)</td>
<td>Defined Location(s)</td>
</tr>
<tr>
<td>Approved by UAS Integration Office</td>
<td>Approved by Manufacturing Inspection District Office</td>
</tr>
</tbody>
</table>

### Key Requirements for SACs

- **Manufacturers**
  - Experimental category for non-type certified aircraft
- **Aircraft**
  - Requires a FAA registration
  - Airworthiness of aircraft is approved by FAA
- **Operator**
  - PPL and 2nd Class Medical
  - Observer and Pilot must have 2nd Class Medical
- **Airspace**
  - Determined by agreement among Flight Standards, Air Traffic Control, and Manufacturing Authority

### Legal Flight Operations

<table>
<thead>
<tr>
<th>Certificate of Waiver or Authorization (COA)</th>
<th>Special Airworthiness Certificate (SAC)</th>
<th>FAA Modernization and Reform Act of 2012, Section 333 Exemption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Entities</td>
<td>Manufacturers</td>
<td>CoP Operation</td>
</tr>
<tr>
<td>Public Aircraft</td>
<td>Registered Aircraft</td>
<td>Waiver request for Commercial operation</td>
</tr>
<tr>
<td>Aircraft Model</td>
<td>Aircraft Serial Number</td>
<td>Aircraft Model</td>
</tr>
<tr>
<td>Defined Location(s)</td>
<td>Defined Location(s)</td>
<td>Potentially Flexible Location</td>
</tr>
<tr>
<td>Approved by UAS Integration Office</td>
<td>Approved by Manufacturing Inspection District Office</td>
<td>Approved by Administrator of the FAA</td>
</tr>
</tbody>
</table>
Key Requirements for Section 333

- **Civil Proponent**
  - Interested in commercial operation

- **Aircraft**
  - No clear requirement on aircraft ownership
  - Ownership of aircraft airworthiness is currently unknown

- **Operator**
  - May require CPL in order to perform “for-hire” work
  - Exemption can be requested

- **Airspace**
  - No clear restriction on airspace
  - Expected to be limited to C,D,E and G, but not all might be an option for Trimble aircraft

Airworthiness & Operator Approval

- Public Law 112-95 is the FAA authorization act of 2012. It addressed unmanned aircraft in sections 331 to 336.
- Goal posts for integration were set with dates and time frames.
- Section 333 was included to create a path for circumventing the traditional means of airworthiness should the administrator choose to pursue such a path.
- A 333 grant serves the purpose of granting both airworthiness and operator approval.

Aircraft

- The 333 exemption is an airworthiness grant.
- Trimble’s applies only to Trimble.
- Each aircraft must be registered (N number).
- The grant is specific to the UX5 aircraft.
The 333 exemption is an operator approval.
- Must be a Trimble employee and hold a Private Pilot License (PPL).
- May be a contractor for Trimble.
- Only Trimble may fly under Trimble’s 333.

Operator

Must be class G.
- Must be non-populated area.
  - Can not fly over yellow patches of sectional chart.
- Must obtain civil COA from FAA.
  - Is the means for notifying Air traffic Control.
  - Contains its own set of restrictions.
- Seem to be taking about a month or two.
  - The more desolate, the better.
  - The more simple the operating request, the better.

Airspace

In process of defining follow on procedure.
- Expect an expedited application process for customers who agree to Trimble’s limitations.
- Will publish the procedure to customers at no cost once the process is well defined.
- Trimble would like its customers and dealers to obtain their own 333 with our help.
- Continuing to work with FAA on COA requirements with desire reduce restrictions.
- Do not expect any relief on flying over people or flying beyond line of sight.

Next Steps
How Do I Learn More?

- SAC: 8130.34C – Airworthiness Certification of Unmanned Aircraft Systems and Optionally Piloted Aircraft
- Section 333: Public Law 112-95 – FAA Modernization and Reform Act of 2012

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Pathways to Legal Flight for Unmanned Aircraft

RULES FOR MODEL AIRCRAFT

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Advisory Circular 91-57 (1981)

- Specifically addresses model aircraft
- Compliance is voluntary
- Hobby or recreation only
Definitions from Public Law 112-95 (2012)

- Clearly defines civil aircraft vs. public aircraft vs. model aircraft
- Model aircraft is an unmanned aircraft (UA) that is—
  1) Capable of sustained flight in the atmosphere;
  2) Flown within visual line of sight of the person operating the aircraft; and
  3) Flown for hobby or recreational purposes.
- This is law, not voluntary – Advisory Circular 91-57 no longer applies
- Aerial surveying & mapping qualifies as neither hobby nor recreation – intent is commercial

Guidance to Model Aircraft Operators

- FAA-2014-0396: Interpretation for the Special Rule of Model Aircraft
  - Restates authority to take enforcement action
  - Published June 18, 2014
  - 30-day comment period
- What Can I Do With My Model Aircraft?
  - http://www.faa.gov/about/initiatives/uas/model_aircraft_operators/

THANK YOU