UASs IN GEOMATICS

Game Changer?

- Like GPS
- Societal impact? Major, like GPS
- Mandates operational changes? Yes, like GPS, often bigger
- Is it possible to fail with this technology? Yes, like GPS, often bigger failures
- Benefits when properly used and applied? Lots of big ones, like GPS, often bigger
- Lots of regulation? Yes, unlike GPS
What's in a name?

- Drone is popular
- UAV is in common use
- Many authorities prefer unmanned airborne system (UAS)
- When UAV is not autonomous; there is a pilot in constant communication

Contents

1. Overview
2. The aerospace technology
3. Operations
4. Data products
5. Regulatory issues
1. Overview

- Rotor wing
- Fixed wing

Types

- Fixed wing
  - Conventional
  - Flying wing
  - Others
- Rotorcraft (helicopters)
- Single rotor
- Dual rotor
- Multi rotor
Fixed Wing Conventional

- With wheels
- Without wheels

Flying Wing
Rotorcraft

○ Single
○ Dual
○ Multi-

Robotic, semi- or U-fly?

○ All modes have some reasonable application in geomatics

○ The fine points require quite a bit of understanding

○ Don’t think that this is just a fun toy with some business benefits...if you do, you are destined to fail (crash or lose aircraft)

○ Regardless, must understand something about aerodynamics and flight operations
UAS varies...

- Varies from fixed wing (single and multi engine), rotary (few to many rotors) and lighter than air vehicles
- Fully automatic to semi-automatic to manual

2. Aerospace technology
For the current majority...

- Scale or resolution may be set by changing focal lengths; usually for given sensor, changed by flying height above ground level (AGL)
- Performance criteria: launch speed, launch method, cruising speed, maximum image capture rate, max and min height above ground level (AGL)
- Weather limitations: clouds, precip, wind

...technology

- Conventional photography much slower/longer for equivalent size project
- Equipment bit bigger than RTK or total sta. but smaller than conventional photography
- Conventional photography requires clear skies, no precip, light winds; total stations & RTK, better but human factors have to be considered more than with UASs
Comparison with hobbyist aircraft

- Speed sensor
- GPS
- IMU or other attitude sensors
- Altimeter
- Autopilot
- Not all of above found with all UASs, but many are usually found

Level of automation

- Levels:
  - Manual (RC control)
  - Semi-automatic (manually assisted stages)
  - Automatic (all stages):
    - Launch
    - Flight
    - Camera triggering
    - Landing
Level of automation

- Potential pitfalls of manual assistance:
  - It may require technical capabilities unavailable (e.g. years of experience in remote flying)
  - It introduces the risk of human errors.
  - If assistance is required during the actual acquisition, data quality may be reduced

Conventional technology vs. UAS

- Conventional photography much slower/longer for equivalent size project
- Equipment bit bigger than RTK or total station but smaller than conventional photography
- Conventional photography requires clear skies, no precip, light winds; total stations & RTK, handle this better but human factors have to be considered more than with UASs
3. Operations

Review site

- Remote and on-site review for area, terrain, weather conditions, takeoff and landing sites
- How will UAS be monitored in flight visually?
- Assess risks? Sometimes they can be attenuated by breaking up the mapping into strategically placed missions
- Are there local weather conditions that should be understood
- Identify and locate all hazards
Specific missions

- Locate takeoff and landing site
- Minutes before mission finalize and review complete flight (simulate if possible)
- Takeoff and landing ideally into wind, never with the wind

...specific missions

- Cross-wind capability of UAS must be considered
- Cloud cover height and weather during mission must be reviewed
- While certain scale is desired, how do variations in ground height limit safe operations to achieve that scale
- Can the specific missions be revised to achieve the project objectives for scale?
...specific missions

- All mission planning has to also accommodate flight time your UAS can achieve
- Not a simple calculation as turns can eat up precious time with no productive image capture
- Typical to plan turns into wind to make them tight as possible so that they take up as little time as possible...but this is not always feasible when considered with other factors

Above all

- Do not risk your UAS to minimize flights to achieve the project objectives
- In the grand scheme of things one more flight is a small price to pay compared to replacing your UAS!
Area coverage speed

- Depends on:
  - Area coverage per flight
  - Cruise speed
  - Flight preparation time
  - Ability to refuel / swap batteries in a short time

Image overlap quality

- Depends on:
  - Aircraft control system design
    - Controlability of the attitude of the plane
      → inc. design of autopilot, sensors & actuators
  - Aircraft (fixed) wing design
    - Traditional (stable) design vs. optimized design
      → inc. design of aircraft shape & gravity center
  - Camera control
    - Dependability & accuracy
      → inc. position-based or time-based shooting
Speed

- Varies to a large extent based on launch speed
- Cruise varies from 30 km/hr to 80 km/hr
- Why is speed important? Coverage per minute of flying time
- However has to be correlated with flying height (scale); larger the scale the more quickly exposures need to be taken and you can run up against data writing limitations

Mapping area

- Depends on scale and cruise speed
- Most UAS use fixed focal lengths
- To get good results high (>75%) overlap and sidelap is required
- Mapping areas may have marked ground control or not depending on final results
- Feature points between photographs, if vision software is used can number in the thousands
Mapping

- Generate orthophotos within minutes of completion of flight
- Sparser the feature points, faster the results
- Select processing types based on use(s) for the map data
- Entirely feasible to generate sparse DSM initially and densify it later when time permits
- Similar speed and detail with DSM output

Surveying

- Create DSMs
- Generate X,Y,Z files to output into a variety of terrain modeling systems
- Contours, 3D representations, volumes
- With temporal database, monitor construction, erosion, accretion, waste generation, etc.
Suitability for geomatics tasks

- Area coverage per flight
- Area coverage speed
- Image overlap quality
- Image quality
- Level of automation
- Sized for the job?
- GNSS accuracy requirements

Area coverage per flight

- Depends on:
  - Range = total distance before landing needed
  - Ground speed = Airspeed - head wind
  - Ground coverage (strip width) per image
  - Required overlap

- It does not depend on:
  - Endurance = total flight time before landing needed
(some) Empirical Results

- Using 4-8 well distributed control points (in X, Y, Z) over 1.5 km² (0.6 mi²):
  - ±1 pixel in X and Y
  - ±2-3 pixels in Z
  - At 150 m AGL, one system’s pixel is 5 cm (0.16 ft)
  - [Three sigma values]

Typical Applications

- Mining
- Forestry
- Agriculture (row crops, plantations, orchards, vineyards)
- Construction (monitoring, QA/QC)
- Damage assessment (post-flood, windstorm, tsunami...)
- Damage prediction/monitoring (levee, fire, flood)
New Applications

- Accident carnage documentation
- Oblique (and nadir) imagery acquisition in difficult areas
- Asset monitoring
- Natural resources mapping; assessment
- NIR, IR, multispectral, hyperspectral for vegetation monitoring, heat loss, fire risk, crime, traffic, pollution
- Atmospheric sampling

More Sensors

- Multi-camera
- LiDAR
- Radar
Safety

- Theoretically one person crew
- Safety demands operator and observer
- Good planning
- Follow procedures, checklist
- Not for the non-process-oriented
- Failures will occur!

Operations

- Planning required
- Reconnaissance
- Siting of flight area in clear-to-fly zone?
- Apply for clearance, if needed
- Stay in contact with air controllers, if required
- Be observant: other aircraft, hazards, weather
Example workflow

Takeoff and Landing

- Hand thrown
- Manual taxi and climb-up
- Catapult (takeoff)
- Parachute (landing)
- Runway land
- Skid land
Mapping

RAW images ➔

A. Optimize GPS positions \([\text{m}]\) ➔
B. Optimize UAV angles \([\text{deg}]\) ➔
C. Camera calibration

Results
...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
...How it works

A. Finding matches between images
   (= Automatic Aerial Triangulation)

B. Finding the best scenario for:
   x, y, z (3)
   pitch, roll, yaw (3)
   camera (X)
   (= Bundle Block Adjustment)

2D, 3D & 4D, ...

- 2D: Orthophoto
  - semi-true
    - true

- 3D: Digital Surface Model
  - Point cloud
    - GRID
    - Semantically

- 4D: Change detection / monitoring
What will you do?

- Where?
- To do what?
- Resolution
- Terrain
- Flight height
- Weather
  - Wind
  - Precipitation
  - Cloud cover

Consider

- Area to be covered
- Speed vs. endurance vs. flight efficiency
- Prevailing winds
- Terrain
- Airspace restrictions
Drivers for UAS Use

○ Accessibility
○ Safety of personnel with land-based systems
○ Visitation interval
○ What are you trying to detect/measure?
○ Weather
○ Size of area to be mapped (too large for TS or GPS; too small for conventional aerial)

Benefits

○ Fast mobilization
○ Portable
○ Don’t have to be flown to site
○ Check in as luggage
○ Operates in difficult weather conditions
○ Fast mapping results (start to finish)
Drivers Against UAS Use

- Weather
- Safety
- Accessibility
- Visual tracking
- Population/urban areas
- Size of area

Biggest Issue With Surveyors

- “Have no idea what’s in the instruction manual (BTW where is it?)”
- “Did they mention it in training?”
- “I’ve got the check list memorized”
4. Data Products

- Individual images (rectified or non-)
- Orthomosaics
- DTM
- DSM
- Point clouds
- Imagery can be RGB or some combination with other such as IR
Image quality

- Depends on:
  - Camera quality
    - camera selected for mapping
    - inc. shutter speed, distortions etc
  - Vibration dampening
    - camera housing designed for mapping
    - inc. motor or rotor vibration dampening
UAS Photography

- Typically uses close range photogrammetric techniques
- High overlap ($\geq 75\%$) forward and side
- Varying scale exacerbated by low flight height
- Variation from planned nadir imagery
- Lack of precision and accuracy in roll, pitch and yaw measurements

A new tool

- Photogrammetry has formerly been the province of specialists for large areas
- Local surveyors use their land-based technologies over smaller areas
- The in-between ground is often expensive to map—time consuming for local surveyors, time taking for photogrammetrists
- UASs fill the gap effectively
UAS Photography

- Benefits:
  - Thousands of feature points
  - Denser point clouds
  - Accurate calculation of orientation and position from the photographs alone is feasible

Vision software

- Highly suited for UAS photography
- Usually several hundred per sq km
- The best calculate accurate interior and exterior orientation (camera calibration and camera position and orientation)
- Ground control needed only to improve registration
- Aircraft position and attitude from GPS/gyro only speeds solution; doesn’t improve it
Vision software technology
Based on:
- Automatic Aerial triangulation (AAT)
  - Hundreds of feature points per image
  - “Spider web” of connections
- Robust Optimization Algorithm
  - Bundle block adjustment (BBA)
  - External & internal calibration
- Point Cloud densification
  - Up to pixel size height matching
  - “LiDAR” like results
- Close range photogrammetry

...Vision software technology
Example project

Reference project: 500 images, 5 cm GSD, 1 km²

<table>
<thead>
<tr>
<th>Product</th>
<th>Time</th>
<th>Quality level</th>
<th>Spatial accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid Mosaic</td>
<td>10 min</td>
<td>20 cm</td>
<td>1-3 m</td>
</tr>
<tr>
<td>High-res Orthophoto (semi-true)</td>
<td>3 hours</td>
<td>5 cm</td>
<td>5-10 cm (XY)</td>
</tr>
<tr>
<td>Dense DSM / true Orthophoto</td>
<td>1 day</td>
<td>20 mill. Points / 5 cm</td>
<td>10-15 cm (Z)</td>
</tr>
</tbody>
</table>

Actual time & accuracy will depend on:
- Manual interventions vs. full automatic processing
- Ground control for geo-referencing
- Computer power; desktop vs. cloud solutions

Engineering

- Road construction
- Belgium
- Gateway X100
- 0.8 km²
- 500 images
- 5 cm GSD
- True Orthophoto
Archeology

Heritage Mapping

Easter Island
Catching X100

2.5 km²
150 images
15 cm GSD
Raw DSM
produced for
orthophoto

Mining
Middle East
Gathering X100
40 km²
4000 images
15 cm GSD
Vegetation Monitoring

Cameroon
Cotewing X100

50 km²
8000 images
10 cm GSD
What about GNSS accuracy?

- Do we need high-accuracy GNSS solutions?
  - L1 positioning of images (2-3 m) is ok
  - GNSS positions of images are only a start condition
  - Image processing derives accurate external calibration
    - Based on advanced vision software technology

5. Regulatory issues
CAAs

- Civil aviation authorities have jurisdiction over flying objects
- Research how to comply with regulations
- Don’t forget communications links
- Permissions for overflights
- Insurance

U.S. FAA

- No private (commercial), non-hobbyist flying of UAS possible (some exceptions for manufacturers)
- Government agencies can fly with Certificate of (Waiver) Authorization (COA)
- Follow (and understand!) the application to respond appropriately
- Many are called, few are chosen (requires understanding of how flight operations are managed)
Airspace

○ Your nation’s civil airspace administrator’s (CAA) regulations must always be consulted

○ Become familiar with them: restrictions as to where you can operate and how you can operate

○ Rarely are skies unregulated

○ You have to consider other users and how the national resource is managed

U.S.

○ Federal Aviation Administration (FAA) is national regulator

○ Government agencies including educational institutions may fly with Certificate of Waiver or Authority (COA) which may have geographical or time restrictions
...U.S.

- Private entities may not fly for commercial purposes today
- With special airworthiness certificate they may fly for demonstration or training purposes

...U.S.

- FAA is currently engaged (including with other civil aviation authorities around the world) to develop new regulations that permit commercial UAS activities
Currently with FAA

- Pilot’s license usually required
- No out-of-visual-flight-range permitted
- Class 2 medical required of operator and observer
- Reporting of all out-of-nominal flights

With New Law

- Likely for small UAS (under 55 lbs) to fly mid-2014
- Procedures are unknown at this time
- Do not be misled into thinking that if you wish to do a project, that you can just go out and do it with an UAS
- Permits and approvals MAY be required for every flight

All italicized comments here and following slides are my conjecture.
With New Law /2

- Operator training will be required
- Ability to communicate with air controllers will be required
- Need to demonstrate ability (with equipment, personnel, communications, infrastructure) to deal with non-normal flight situations
- Detailed logbooks for equipment and people will be required
- Licenses and “check rides” may be required

With New Law /3

- Servicing by authorized centers
- Retraining with major changes in UAS configuration
- Still likely that flights over populated areas/urban areas are restricted
- Flights out of visual range likely to be restricted
- Medicals may be required
What To Do? (in the meantime)

- Read about UAS and UAS operation (take it seriously)
- Research who the current players are (operators, mfrs)
- Talk (mfrs, operators, regulators)
- Observe flights where possible (mfrs, operators, military)
- Visit (mfrs, research institutions, operators)
- Assess needs (how will it improve your business?)

Thanks!
Q & A