Unmanned Aerial Systems (UAS)

complementary to conventional aerial survey and photogrammetry?

PEJUTA ICES Malaysia Conference, Kuala Lumpur
8th January, 2015
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An alternative method for:

- Image capture and processing
  over small areas within the dynamic, geospatial process while retaining:

- Data sharing, analysis, adding value and data delivery
  as we know it in photogrammetry, RS, GIS
Why? a convergence of . . !

**HW:** low cost; ease of use; free GNSS signals; an abundance of users and expectations; compact digital non-metric cameras, powerful batteries; strong, light material; micro electronics & miniaturisation; able to exercise image capture when required; HW specialisation

**SW:** low cost; ease of use; open CV algorithms; an abundance of users and expectations; supports high automation; powerful portable WS, PCs, GCs; high degree of functionality & workflow; black-box solution in ideal case; merge of vertical, oblique, terrestrial images possible; no or reduced number of GCPs; SW specialisation

**SW – the biggest advances!**
Overview

• Definitions
• UAS: airframe, sensors, software/hardware
• Operations: field, office
• Product accuracy: error sources, solution
• Applications: end products, users
• Projects: topography, overview, orthophoto
• Challenges: technical, non-technical
• Conclusions
Definitions: explanations

• **UAS**: Unmanned Aerial System, all components
• **UAV**: Unmanned Aerial Vehicle, HW, drone
• **RPAS**: Remotely Piloted Aircraft Systems
• **Users**: military, academia, science, geomatics, hobby
• **Photogrammetry**: science of extraction of accurate spatial 3D data from imagery
• **Photogrammetry mapping**: large format metric camera; piloted aircraft, GPS, IMU; rigorous digital data processing; wide range of raster, vector products; high relative and absolute accuracy +/- 5cm possible; project duration 1 month and more; costly
Definitions: explanations

• **Imagery platforms:** satellites; aircraft; **UAVs**, (fixed wing, delta wing, drone, helicopter, quadcopter etc), kites, masts, balloons, blimps, terrestrial

• **Performance factors:**
  
  **Camera:** RGB, NIR, high resolution full frame, consumer digital, thermal, video
  
  **Fixed wing:** area coverage, lighter payload, faster flying, longer duration, generally nadir
  
  **Rotor:** dedicated objects, slower speed, operate in restricted & urban space, nadir and oblique
Definitions: explanations

- **GSD:** Ground Sample Distance for digital imagery (camera pixel footprint on ground); not scale as with film imagery; image size in pixels e.g. 16Mp, 80Mp, 230Mp
- **UAS technology for photogrammetry:** reduces gap between aerial and terrestrial platforms
- **Product fit for purpose:** what you need is what you get – a focus on needs, not on top technology!
Definitions: legal operating framework

• **Example:** Switzerland, BAZL, since 1st Aug, 2014

• Apply to UAVs up to 30kg
• No diff. betw. private, commercial, professional, scientific use
• Protection of private sphere, data collection security
• Direct eye contact by pilot during flight, VLOS
• 5km distance from airfield, to within 100m of crowds
• Aerial images allowed provide military security not breached
• Liability insurance cover min CHF 1 mill. for UAVs > 0.5kg
• Autonomous flight allowed provided pilot intervention poss
• Local authorities may impose additional regulations
• Special permission, fees above 30kg?
**Definitions: explanations**

**UAS:** between aerial & terrestrial, an alternate platform

- rmse accuracy
- **UAS:** industrial photogrammetry, terrestrial laser scanning
- area: 0.01mm, 0.1mm, 1mm, 1cm, 10cm, 1m, 10m, 100m, 1000km, 10,000km
- accuracy: 10m, 100m, 1ha, 10ha, 1km, 10km, 100km, 1,000km, 10,000km

- engineering/architectural photogrammetry
- GNSS / GPS
- total station
- conventional aerial photogrammetry
- satellite photogrammetry
Definitions: photogrammetry process

- Image/point clouds
  - Camera cal., AT, aerial triangulation orientation parameters of imagery
  - GCPs, XYZ absolute
  - DTM, digital terrain model
    - OPs, orthophotos mosaics
    - Vector extraction, 3D measurements
      - Line maps
      - Visualisations, 3D models, videos
Definitions: processes, deliverables

- **AT**: aerial triangulation – a critical process for joining of images in one homogeneous block in a consistent coordinate system, w/wo GCPs
- **DTM**: digital terrain model – represents the terrain surface in digital elevations with TIN or grid surface
- **OP**: orthophoto – rectifies an image into a photo map, allowing consistent scale, true directions, distance
- **Mosaicing**: several OPs, seam lines, colour balancing
- **Line maps**: features represented by vector lines of different weights, colours, symbols
- **Visualisation**: 3D models of terrain & buildings, videos, etc
Definitions: project work phases

- **Accuracy**: function of Z, GSD, GCP, image redundancies
- **Office preparation**: site definition, flight & GCP planning, security, air space restrictions, operation permissions, flight plan upload to UAV autopilot, weather check, logbook
- **Site occupation**: access, reconnaissance and terrain check, landing site, GCP signalisation and survey, UAV preparation and pre-flight checks, UAV launch, safety, security
- **Data capture**: imagery, weather (light, wind, rain), VLOS, security and manual intervention; GPS signals; UAV landing
- **Data check**: SW, full area coverage, image quality, overlap, before leaving the area
Definitions: explanations

- **Film based and digital photogrammetry**: based on image correlation and stereo observations

- **Film**: rmse – image from 1,000m a.g.l.
  Scale: 1: 6,580  (Leica RC30, c = 152mm, pan, colour)
  Area of 1 image: **2.25km²**
  Accuracy: XY: +/- 5cm; Z: +/- 8cm.

- **Digital**: rmse – image from 1,640m a.g.l.; pixel = 5.6 micron
  GSD: 10cm; (Z(I DMC II/230, c = 92mm, pan, colour, NIR)
  Area of 1 image: **2.20km²**  (15,552 x 14,144 pixels)
  Accuracy: XY: +/- 5cm (1/2 GSD); Z: +/- 7cm (2/3 GSD)
Definitions: explanations

• **UAV imagery**: $Z = 165\text{m.a.g.l.}; \ c = 29.7\text{mm}$
camera pixel = 0.009mm;  GSD = 5cm; Canon IXUS 16Mp
Area of 1 image: 0.03km$^2$  (ca 100 stereo images/km$^2$
RAW format: improved resolution, most grey scales

• **Summary** of image sizes

<table>
<thead>
<tr>
<th>camera</th>
<th>flying height</th>
<th>GSD</th>
<th>area cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC30</td>
<td>1,000m.a.g.l.</td>
<td>5cm</td>
<td>2.25km$^2$</td>
</tr>
<tr>
<td>DMC II/230</td>
<td>1,277m.a.g.l.</td>
<td>5cm</td>
<td>2.20km$^2$ (230Mp)</td>
</tr>
<tr>
<td>Canon IXUS</td>
<td>165m.a.g.l.</td>
<td>5cm</td>
<td>0.03km$^2$ (16Mp)</td>
</tr>
</tbody>
</table>
Definition: when, where to use UAS

- **Easy, rapid** user deployment of image capture, no/little permission necessary in some cases
- **Repeat** operations over time, small areas, as-is as-built situations, monitoring works progress
- **Low cost** of image capture, processing, data sharing and production of photo deliverables
- **Modern** satisfy fast update cycle of GIS
- **Flexible** processing results relative to cost
UAS: airframe, sensors

- **Swinglet CAM**: typical mini UAV for geomatic use
  
  - **Weight**: 0.5kg w payload; **Speed**: 36kph; **Duration**: ca 30 mins
  - **Camera**: Canon IXUS/ELPH 16Mp, **Range**: ca 12 linear kms;
    **Coverage**: 1-10km² (GSD 5-30cm) with one battery charge.
UAS: airframe, sensors, hardware

- **HW feature**
  - Strong, light material
  - Component miniaturisation, good component integration
  - COTS camera, non-metric
  - Autopilot
  - Special features, engine cut-out
  - Automatic flight operation

- **HW benefit**
  - Rigid, light-weight airframe, portable, easy deployment
  - GPS, attitude sensor, auto-pilot, elec. motor, battery, barometer, accelerometer, gyroscope,
  - Low cost, high resolution, colour, digital, low weight
  - Largely autonomous flying, little operator training, simplicity
  - Glides, reduce vibration & blur
  - Efficient, labour cost reduction
UAS: airframe, sensors, software

• **SW feature**
  - Flight planning and camera management
  - CV image correlation algorithms
  - Standard PC, laptop, anaglyph
  - Cloud computing SW
  - Stand-alone SW

• **SW benefit**
  - By pilot, 3D way points, changes possible in field
  - Simple black-box approach, non-specialist user, CV key to over- come low image location and disposition data, GPUs
  - No special computer HW, no stereo viewing suite
  - Economic, project-wise
  - Imagery in-country, independant
Operations: field

• **Easy to transport, deploy:** 1-2 man, weather limitations of rain, strong winds but below cloud
• **Minimum or no permission:** operate with VLOS
• **Rapid acquisition** of stereo imagery and field check: easy to interpret colour imagery, processing to obtain DTMs, mosaics, orthophotos; vector line maps require more production time
• **Autonomous flying** along pre-determined flight lines defined by GPS coordinates: reacts to manual intervention, simplicity flying speed 35kph; wind speed < 25kph
• **Low cost** to capture imagery, process imagery, production of deliverables, data sharing
• **Several sensors:** NIR, video, colour, thermal, LiDAR - all digital
• **GCPs** measured by GPS geodetic quality; RTK GPS of camera centers reduces GCPs
Operations: flight planning

• Screenshot of e-mo-tion flight planning SW
Operations: SW

- Conventional photogrammetry, specialists
  - Very strong functionality, editing; weak workflow; several modules; precision

- Imagery, aerial triangulation, EO
- External metric camera calibration
- Image orientation

- Point clouds, DTM, OP, contours, volumes
- Mosaicing, colour balancing
- Editing, residuals, GCPs
- Editing DTM, outliers
- Editing OP, seamlines, etc.

- Interactive/SAFE vector planimetry, heights capture, topology, annotation
- Editing, symbols, lines etc.

- Deliverables: digital vector, raster files, OP maps, fly throughs, videos, 3D models etc.
Operations: SW

• UAV photogrammetry, all users/black-box
  • Very strong workflow, good functionality, editing;
    1 SW packet; automation

deliverables: digital vector, raster files, OP maps, fly throughs, videos, 3D models etc.

image geotagging, non-metric camera calibration, AT, EO

point clouds, DTM, OP, contours, volumes etc.

mosaicing, basic annotation colour balancing

auxillary functions & SW, cosmetic improvements
Operations: summary, AT accuracy

- **Processing trade-off:** after AT, GSD = 5cm
  
  accuracy v. time v. cost v. deliverables

  **2 principles:** GIS accuracy, up to date v. high accuracy 3D

  - 1) geotag from L1 GPS log file, no GCPs, black-box autonomous image processing by non-experts
    
    rel: XY = 8cm; Z = 12cm; absol: 5m

  - 2) GCPs, processing without geotag bias
    
    rel: XY = 8cm; Z = 12cm; absol: 15cm

  - 3) GCPs, rigorous processing without geotag bias
    
    rel: XY = 5cm; Z = 8cm; absol: 15cm

  - 4) RTK GPS image centers, minimum GCPs, rigorous processing
    
    rel: XY = 5cm, (1 x GSD); Z = 8cm, (1.5 x GSD); absol: 10cm
Operations: office, AT accuracy

- Processing trade-off: accuracy v. time v. cost v. deliverables
  GIS accuracy, up to date v. high accuracy 3D

- 1) Download images, geotag from GPS log file, APM, no GCPs, preview, black-box image processing by non-experts with cloud/Pix4Dmapper, reports: GSD = 5cm after AT, basis of product accuracy, rmse:
  autonomous processing;
  Acc +/-; rel: XY = 8cm; Z = 12cm; absol: 5m
Operations: office, AT accuracy

• 2) Download images, geotag from GPS log file, GCPs, APM *w/o geotag bias*, preview, black-box image processing by non-experts with cloud/stand-alone Pix4Dmapper, reports: GSD = 5cm after AT, basis of product accuracy, rmse autonomous + manual processing with Pix4D; Acc +/-; rel: XY = 8cm; Z = 12cm; absol: 15cm
Operations: office, AT accuracy

3) Download images, geotag from GPS log file, GCPs, APM, preview, black-box image processing w. manual finetuning for higher accuracy w. cloud/stand-alone Pix4Dmapper, editing (LPS, INPHO, etc) more aesthetic deliverables, training, expert photogrammetric consulting, reports: GSD = 5cm after AT, basis of product accuracy, rmse autonomous + manual rigorous SW solution

Acc +/-; rel; XY = 5cm; Z = 8cm; absol: 10cm
Operations: office, AT accuracy

- 4) as for 3) but with RTK GPS on UAV, GSD = 5cm

**advantage:** reduction of GCPs, suitable for inaccessible areas due to hostilities, nuclear or toxic exposure, geographic constraints etc

**disadvantage:** cost increase of UAV, real time comps on board, increased battery consumption after AT, basis of product accuracy, rmse

autonomous + manual rigorous SW solution

Acc +/-; rel; XY = 5cm; Z = 8cm; absol: 10cm
Product accuracy: error sources

- **Camera**: lens quality, reverse camera calibration by post processing, physical stability, temperature, set to «manual», focus at infinity
- **GPS**: L1 C/A 1Hz code effect on absolute position, improvement possible with RTK GPS of camera
- **Image disposition**: imagery quality due to wind, turbulence (crab, non-verticality, image blur)
- **SW processing**: methods and levels
- **All a challenge to automated image processing!**
Product accuracy: error sources

- **Camera calibration**: image residual deformation w/o non-radial distortion correction – 19 μm max, BINGO

- **Camera calibration**: image residual deformation w. non-radial distortion corr (add. parameters) – 15 μm max BINGO
Product accuracy: error sources

- Camera calibration
- Tangential distortion of Pix4Dmapper calibration
- Despite different error modelling, final accuracies achieved are predictable, acceptable (empirical)
Product accuracy: error sources

- **DTM**: compared with LiDAR DTM as reference:
  - DTM average: $Z$, +/- 15cm rmse at GCPs

- **OP line features**: compared with rigorous GPS observations as reference:
  - OP average: $XY$, +/- 10 - 15cm rmse at GCPs

- **Mosaic**: as for OP
Product accuracy: solution

- **Footprint** of UAV images. Heading, shape of footprint varies greatly due to wind
- **Large numbers** of highly redundant images and highly redundant observations compensate most error sources
- **SW** manages this extra computing, autonomously
- **Improved camera**
Product accuracy: solution, camera

Canon ELPH 110HS, NIR, 16Mp
Retractable lens, $c = 29.7\text{mm}$
Total weight: 136gr

SONY NEX7, RGB, 24Mp
Fixed focus Zeiss lens,
Total weight: 650gr/590gr
$C = 12\text{mm}/32\text{mm}$, 275gr/215gr
Applications: end products

• **3D modelling**: landmarks, terrain, buildings, BIM
• **Topo**: volumes, mining, profiles, earthwork quantities for small engineering projects, etc.
• **Change detection**: vegetation, pollution, housing encroachment, construction progress, assets etc.
• **Environmental studies**: heat loss, impact studies, waste management, inspection flights etc
• **Pictorial**: advertising, reconaissance and over-view flights, sports events, tourist areas, asset management, property, TV and movies etc.
• **Urban, surveillance**: quiet operation, assets
Applications: disaster management

Ideal for image cover of small areas, 1-10 km2, rapid revisits within short time

- **Disaster**: search, rescue operations caused by floods, fire, earthquake, slips, waste and toxic (nuclear) spills, security issues, detect change of vegetation, erosion, humanitarian needs
- As-is status record, insurance claims
- Reconnaissance surveys, risk assessment
- Staff, equipment, safety disposition planning
Applications: user segments

- **Civil Service:** disaster management, project managers, municipalities, academia, education
- **Professionals:** civil engineers, town planners, architects, surveyors, photogrammetrists
- **Vocations:** farmers (agriculture, crop monitoring), construction foremen, roof contractors, landscape gardeners, delivery
- **Security:** police, fire brigade, security staff, crowd control
- **Businesses:** land agents, map makers, asset managers, LBS providers, tourism, advertising, event managers, insurance
- **Science:** vegetation health, environ. monitoring
Project, topography: requirements

Deliverables

• Terrain profiles (CAD format) on orthophoto background (raster format), for planning of footpath, surface drainage

Profile accuracy

• <10cm rmse
Project, topography: flight planning

- 3 flight lines
- Nikon D600
- \( c = 35\text{mm} \)
- \( Z = 150\text{m.a.g.l} \)
- GSD = 4cm
- Image: 24Mp
- No of images: 24, 80%/60%
- UAV: md4-1000, 4 rotor, 1.2kg, dia 1.2m, 5.5kg
Project, topography: profile locations

- Long section
- Cross sections
  (defined after imagery available)
Project, topography: deliverables

• Long sections and cross sections (able to be defined after imagery available)
  Format: DWG/DXF and PDF files

• Orthophoto (as background for the visualisation)
  Format: TIFF
Project, topography: profiles delivered
Project, topography: planned structures
Project, topography; other deliverables

Other possible deliverables from same images

- **Spot heights**
- **3D vectors** of certain planimetric features (restitution)
- **Digital Terrain Model (DTM)** as:
  - Raster
  - Point cloud, coloured
  - TIN surface
Project, topography: spot heights
Project, topography: planimetry
Project, topography: DTM raster
Project, topography: DTM point cloud
Project, topography: DTM TIN surface
Project: cost % related to work steps

- Befliegung: 23%
- Passpunkte: 20%
- Orientierung: 20%
- DOM: 11%
- DTM aus DOM: 6%
- Bruchkanten: 3%
Project overview: Construction progress
Project orthophoto: GSD 10cm
Challenges: technical

- **Commercial applications**: coming after the pioneers from military and universities; research on-going
- **HW component identification, integration**: improved LiPo batteries; electric motors; cameras and lens, fish eye lenses; precise GPS for position; sensors such as pollution & gas detectors; LiDAR (SICK, Riegl, Velodyne) for inside and outside buildings and 3D modelling
- **Added functionality**: real-time correction of flight disturbances and wind; oblique imagery; reliable & fail-safe mechanisms; recognize & avoidance systems; safer landing; safe-guards against cyber attacks
Challenges: technical

• **Improved SW algorithms:** for DTM, image recognition of GCP signals, camera calibration; theoretical & emperical accuracy tests; editing (DTM, seamlines etc); sensor integration; larger data sets; faster processing

• **Consolidation** of HW manufacturers, SW developers expected; commercial challenges; effect of regulations?

• **Photogrammetric education** for best understanding of technology
Challenges: non-technical

- **Main issue**: acceptance, safety, regulation clarity, use of shared outside air space, data privacy, international certification of UAVs, data distribution, insurance, pilot training, progress in USA, CH, NZ, Philippines + . . .
- **Commercial users**: driving civil regulation processes
- **Best operating practise**: cooperation among local authorities, HW manufacturers, SW developers, end-users.
Conclusion

Question:
• UAS: complementary to conventional aerial survey and photogrammetry?

Answer:
• Yes: a complementary, not competitive, tool to conventional aerial surveys, photogrammetry and land surveying

• providing users with the geospatial knowledge of small areas, that they require
Conclusions: statistical forecasts

- **UAS market**: worth $US 91 billion by 2024 fueled by military market (Teal Group)

- **UAV annual expenditure**: from 2014 – 2024 $US 6.4 billion to $US 11.5 billion (Teal Group)

- **Market shares**: Military 89%, civilian 11% and expected to grow to 14% by 2020 (Teal Group)

- **Global aerial imaging market**: 2013 $US 0.97 bill. expected annual growth to 2020, 13.4% (Transparency M R)

- **Surveying + mapping services**: increase from 2014 to 2015, expected to be 1.4% (IBISWorld)(Geospatial World, Dec 2014)
Questions?

Thank you for your attention

David Hughes  
dhGeoAdvice,  
Switzerland

Liu Man Kit  
AS Vision Ltd,  
Hong Kong

Acknowledgements: senseFly LLC; Pix4D SA; Bart AG; Switzerland.
Operations: trajectory

Flight trajectory visualised in Google Earth; courtesy senseFly LLC
Project, topography: flight planning