DRONES IN HYDROLOGY

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Growing ideas through networks
Unmanned Arial Systems (UAS) in Hydrology

Scope: state of the vegetation, streamflow (speed and water level), extension of the flooded areas and morphology.

Objective: To define integrated procedures to improve hydrological/hydraulic monitoring capacity using UAS.

Scale: from plot-scale to the river basin scale providing operational monitoring tools.
TOP APPLICATIONS

Environmental monitoring: ecological state of ecosystems, plant stress, water pollution, soil contamination, water contamination, monitoring of water systems (rivers, lakes, dams etc.).

Precision agriculture: management of crops to guarantee efficiency of inputs like water and fertilizer and maximize productivity, quality, and yield. It also involves the minimization of pests, unwanted flooding, and disease.

Energy, mining, and utilities: resources management and research requires monitoring over large territories, often in inaccessible areas.

Real estate, construction, and land development: need managing and mapping large portion of land or collections of buildings.
Environmental Monitoring

<table>
<thead>
<tr>
<th>Global</th>
<th>Few hectares</th>
<th>Few m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 30cm</td>
<td>Up to 1cm</td>
<td>Up to 1cm</td>
</tr>
</tbody>
</table>

Comparable Scales
UAS vs Satellite

Manfreda et al. (Remote Sensing, 2018)
Number of articles extracted from the database ISI web of knowledge

- **UAS applications**
  - Automation of a single or multiple vehicles,
  - Tracking and flight control systems,
  - Hardware and software innovations,
  - Tracking of moving targets,
  - Image correction and mapping performance assessment

- **Environmental Applications**

Data from 1990 up to 2017 (last access 15/01/2018)
DRONES

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**Large**
- Large operating range (~500 km)
- Long flight time (up to 2 days)
- Medium to high altitude (3-20 km)
- Payload size ~200 kg internally and ~900 kg in under-wing pods
- Operational constraints: High set-up and running costs; requires ground-station support, full aviation clearance, long runway for take-off and landing, hangar for storage; altitude ceiling above commercial air traffic
- Example platforms: NASA Ikhana

**Medium**
- Large operating range (~500 km)
- Medium flight time (~10 hours)
- Medium altitude (<4 km)
- Payload size ~50 kg
- Similar requirements to large UAVs but with reduced overall costs, reduced requirements for take-off and landing, and easier control
- Example platforms: NASA SIERRA

**Small**
- Small operating range (<10 km)
- Low endurance (<2 hours)
- Low altitude (<1 km)
- Payload size <30 kg (small); up to 5 kg (mini)
- Example platforms: Quest UAV

**Micro**
- Small operating range (<10 km)
- Very short flight time (<1 hour)
- Very low altitude (<250 m)
- Payload size <5 kg
- Example platforms: AR-Drone Parrot

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(Anderson & Gaston, 2013)
Example: multi-copter 6 engines equipped with a thermal camera

- **Electronic systems**: Mikrokopter®
- **Frame**: (carbon fiber Air-Sci UAVEurope®)
- **Propellers**: (APC 12x3,8 inc)
- **Li-Po Battery**: 8Amp 30C
- **Cameras**: camera mount servo-stabilized carbon-fiber UAVEurope®
- **Thermal camera**: GOBI384 Xenics®!
- **Engines**: MK3638
- **Ubiquiwifi**: on line wi-fi data streaming
HydroLAB Equipment

- Phantom 3 and 4 pro;
- Single wing skywalker;
- Portable radar;
- FLIR FLEA USB3;
- Uncooled LWIR Thermal;
- ADC Snap Camera.
Evolution of a fungal pathogen

(from Lyndon Estes, 2015)
Evolution of a fungal pathogen

(from Lyndon Estes, 2015)
Related Publications


- Manfreda, Lacava, Onorati, Pergola, Di Leo, Margiotta, and Tramutoli, On the use of AMSU-based products for the description of soil water content at basin scale, Hydrology and Earth System Sciences, 15, 2839-2852, 2011.
Summer School on Monitoring and Modeling Surface Hydrological Processes, Parco Appennino Lucano, Marsico, 2011.
Summer School on Applied Course on UAVs for Environmental Monitoring, UniBas, Matera, 2015.
Summer School on UASs for environmental monitoring, UniBas, Matera, 2016
TRAINING COURSE

Harmonized UAS techniques: Introduction to data acquisition and preprocessing, Reykjavik, Iceland 02-08 September 2018
DRONES IN HYDROLOGY: HARMONIOUS

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COST Action HARMONIOUS

A network of scientists is currently cooperating within the framework of a COST (European Cooperation in Science and Technology) Action named “Harmonious”.

The intention of “Harmonious” is to promote monitoring strategies, establish harmonized monitoring practices, and transfer most recent advances on UAS methodologies to others within a global network.
HARMONIOUS Action

WG1: UAS data processing
Leader: Pauline Miller
Vice leader: Victor Pajuelo Madrigal

WG2: Vegetation Status
Leader: Antonino Maltese
Vice leader: Felix Frances

WG3: Soil Moisture Content
Leader: Zhongbo Su
Vice leader: David Helman

WG4: Leader: Matthew Perks
Vice leader: Marko Kohv

WG5: Harmonization of methods and results
Leader: Eyal Ben Dor
Vice leader: Flavia Tauro

Geometric Correction and image calibration
Contrast Enhancement

Harmonization of different procedures and algorithms in different environments
WG1: Data Collection, Processing and Limitations

WG2: Vegetation Monitoring

WG3: Soil Moisture Monitoring

WG4: River and Streamflow monitoring

WG5: Harmonization of different procedures and algorithms in different environments

a) Peculiarities and specificity of each topic

b) Identification of the shared problems

c) Identification of possible common strategies for the four WGs

d) Definition of the correct protocol for UAS Environmental Monitoring
On the Use of Unmanned Aerial Systems for Environmental Monitoring

Environmental monitoring plays a central role in diagnosing climate and management impacts on natural and agricultural systems, enhancing the understanding hydrological processes, optimizing the allocation and distribution of water resources, and assessing, forecasting and even preventing natural disasters. Nowadays, most monitoring and data collection systems are based upon a combination of ground-based measurements, manned airborne sensors or satellite observations. These data are utilized in describing both small and large scale processes, but have spatiotemporal constraints inherent to each respective collection system. Bridging the unique spatial and temporal divides that limit current monitoring platforms is key to improving our understanding of environmental systems. In this context, Unmanned Aerial Systems (UAS) have considerable potential to radically evolve environmental monitoring. UAS-mounted sensors offer an extraordinary opportunity to bridge the existing gap...
Twitter

https://twitter.com/COST_HARMONIOUS
Facebook Harmonious-European-COST-Action

352 followers on facebook

WG1:  
UAS data processing

Examples of Common image artifacts

(a) saturated image;  
(b) vignetting;  
(c) chromatic aberration;  
(d) mosaic blurring in overlap area;  
(e) incorrect colour balancing;  
(f) hotspots on mosaic due to bidirectional reflectance effects;  
(g) relief displacement (tree lean) effects in final image mosaic;  
(h) Image distortion due to DSM errors;  
(i) mosaic gaps caused by incorrect orthorectification or missing images.

(Whitehead and Hugenholtz, 2014)
Comparison between a CubeSat and UAS NDVI map

Multi-spectral false colour (near infrared, red, green) imagery collected over the RoBo Alsahba date palm farm near Al Kharj, Saudi Arabia. Imagery (from L-R) shows the resolution differences between: (A) UAV mounted Parrot Sequoia sensor at 50 m height (0.05 m); (B) a WorldView-3 image (1.24 m); and (C) Planet CubeSat data (approx. 3 m), collected on the 13th, 29° and 27th March 2018, respectively.
UAS thermal survey over an Aglianico vineyard in the Basilicata region (southern Italy)
How to detect water stress from an UAV?

From Xurxo Gago
Aerial thermography for water stress detection

(Berni et al., 2009)
Aerial thermography for water stress detection

(González-Dugo et al., 2012)
How to detect the drought from an UAV?

Thermal indexes... an attempt to normalize the environment (Idso et al., 1980; Jones, 1999)

- **CWSI** = \( T_{\text{canopy}} - T_{\text{Twet}} / T_{\text{Tdry}} - T_{\text{Twet}} \)
- **IG** = \( T_{\text{dry}} - T_{\text{canopy}} / T_{\text{canopy}} - T_{\text{Twet}} \)
- **I3** = \( T_{\text{canopy}} - T_{\text{Twet}} / T_{\text{Tdry}} - T_{\text{canopy}} \)
- And the leaf energy balance:

\[
T_l - T_a = \frac{r_{HR}(r_{aw} + r_s)\gamma R_{ni} - \rho c_p r_{HRD}}{\rho c_p [\gamma (r_{aw} + r_s) + s r_{HR}]} \\
\]

\[
r_s = \frac{-\rho c_p r_{HR} [s (T_l - T_a) + D]}{\gamma [(T_l - T_a)\rho c_p - r_{HR R_{ni}}]} - r_{aw} \\
\]
Soil Moisture Monitoring

**Blue:** Wet soil  
**Red:** Dry soil

http://bestdroneforthejob.com/
Relationship existing between surface and root-zone soil moisture

Developing a relationship between the relative soil moisture at the surface to that in deeper layers of soil would be very useful for remote sensing applications.

This implies that prediction of soil moisture in the deep layer given the superficial soil moisture, has an uncertainty that increases with a reduced near surface estimate.
Soil Moisture Analytical Relationship (SMAR)

The schematization proposed assumes the soil composed of two layers, the first one at the surface of a few centimeters and the second one below with a depth that may be assumed coincident with the rooting depth of vegetation (of the order of 60–150 cm).

This may allow the derivation of a function of the soil moisture in one layer as a function of the other one.

\[
s_2(t_j) = s_w + (s_2(t_{j-1}) - s_w) e^{-a(t_j-t_{j-1})} + (1 - s_w) b y(t_j)(t_j - t_{j-1})
\]

Manfreda et al. (HESS - 2014)
Sensitivity of SMAR’s parameters

The derived root zone soil moisture ($S_{RZ}$) is plotted changing the soil water loss coefficient (A), the depth of the second soil layer (B), and the soil textures (C).

Manfreda et al. (HESS - 2014)
SMAR-EnKF optimization and prediction

Root mean square errors ranging from 0.014 - 0.049 [cm$^3$ cm$^{-3}$].

(Baldwin et al., J. Hydr., 2017)
Stream flow monitoring with UAS Particle Tracking Velocimetry (PTV)

Lagrangian method (Tauro et al., 2016)

Image processing
Particle Tracking

Particle detection

Velocity vectors
Monitoring River Systems

NUMERICAL SIMULATIONS

WHITE PARTICLES ON BLACK BACKGROUND

DIFFERENT DENSITY AND DISPLACEMENT

PARTICLES WITH NOISE

a) b) c)

PARTICLES ON DIFFERENT BACKGROUND

WHITE PARTICLES ON CLEAR AND TURBID BACKGROUND

BLACK PARTICLES ON CLEAR AND TURBID BACKGROUND

d) e) f) g)

DEFINITION OF THE OPTIMAL PARAMETERS

(Dal Sasso et al., E.M.A. 2018)
Optimal parameter settings for PTV techniques

Box plot of the relative error for the different densities investigated in the configurations: a ideal condition, b real condition

(Dal Sasso et al., E.M.A. 2018)
Image Velocimetry Techniques: Intro
Image Velocimetry

2-D flow velocity field derived using an optical camera mounted on a quadcopter hovering over a portion of the Bradano river system in southern Italy. One of the images used for the analysis is shown as a background, where surface features used by flow tracking algorithms are highlighted in the insets (a, b).
Surface Flow Velocity

Charcoal

UAV derived surface velocity (m/s)

Surface Velocity measure with traditional techniques (m/s)

\[ y = 1.0849x + 0.0869 \]

\[ R^2 = 0.9 \]
Field Experience with UAS

Validation with current meters
Stream Flow Monitoring – Data Collection for Benchmarking Optical Techniques
## Stream Flow Monitoring – Data Collection

<table>
<thead>
<tr>
<th><strong>Original Video File Name:</strong></th>
<th>[River]_[Country][ddmmyearhhmmUTC].mov</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Camera Model:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Platform used:</strong></td>
<td>(gaugemcam, drone, mobile, etc.)</td>
</tr>
<tr>
<td><strong>Camera setting:</strong></td>
<td>(autofocus, field of view, ISO, stabilization, ...)</td>
</tr>
<tr>
<td><strong>Video resolution:</strong></td>
<td>(4000x2000, ...)</td>
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<tr>
<td><strong>Video frequency (Hz):</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Presence of tracers and type:</strong></td>
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</tr>
<tr>
<td><strong>Optional Info:</strong></td>
<td></td>
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<tr>
<td><strong>Lumen:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Wind speed and orientation:</strong></td>
<td></td>
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</tbody>
</table>

### Case Study

<table>
<thead>
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<th><strong>River Name:</strong></th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>River Basin Drainage Area (km²):</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Cross-Section Coordinates (Lat, Long WGS84):</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Flow regime (low, medium, high):</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Ground-true availability (yes or not):</strong></td>
<td></td>
</tr>
<tr>
<td><strong>File Format (mov, avi, mp4, etc.):</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Reference paper:</strong></td>
<td></td>
</tr>
</tbody>
</table>

### Processed Data

<table>
<thead>
<tr>
<th><strong>File Name of Processed Frames:</strong></th>
<th>[River]_[Country][ddmmyearhhmmUTC].zip</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
</tr>
<tr>
<td><strong>Frame rate (Hz):</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Pixel dimension:</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Pre-processing actions (contrast correction, channel used, orthorectification, stabilization, etc.):</strong></td>
<td></td>
</tr>
</tbody>
</table>

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**Earth System Science**

**Data**

[Image: Earth System Science logo]
FRCs are generally obtained using curve fitting methods with river stage ($H$) and discharge ($Q$) observations. The most common equation is:

$$Q = \alpha (H - h_0)^\beta$$
The Key Idea

Decomposing the parameter calibration according to the existing processes leads to more reliable model calibrations.

Manfreda et al. (HP - 2018)

Impact of physical information on the parameter space domain

Model Performances

Including physical info
The V Ω Method

The rating curve can be obtained as the product of two functions:

\[ Q = V(H - h_0)\Omega(H - h_0) \]

Manfreda (JH - 2018)
Comparison of the two methodologies

- FRCs derived with different permutation of the same dataset;
- Comparison is made on the calibration dataset and on the data excluded from the calibration.

Manfreda (JH - 2018)
Conclusion

- UAS-based remote sensing provides new advanced procedures to monitor key variables, including vegetation status, soil moisture content, and stream flow.
- The detailed description of such variables will increase our capacity to describe water resource availability and assist agricultural and ecosystem management.
- The wide range of applications testifies to the great potential of these techniques, but, at the same time, the variety of methodologies adopted is evidence that there is still need for harmonization efforts.
Related Publications


UAS Photogrammetry

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Outline

Principle of Photogrammetry

Surface from Motion Algorithms

UAS photogrammetry
  - Georeferencing
  - Direct and GCP-based georeferencing
  - Using check points and assessing accuracy

• UAS-based DSM accuracy assessment and survey strategies

• Introduction to the exercise
What is Photogrammetry?

Derived from Greek terms:
• Photos = light
• Gramma = to draw
• Metron = to measure

Fundamentally: The process of extracting metric information or measurements from imagery
Why is this useful?

Treat imagery as maps – make direct, reliable measurements

ORTHOMOSAIC or ORTHOIMAGE

• Necessary for topographic mapping
• Digital elevation models (DEM)
• Combines geometric and semantic properties of imagery

Applications:
• topographic and thematic mapping
• change detection
• feature extraction

• 3D building & city modelling
• 3D visualisation
• military applications
How is this achieved?

Relief displacement
- Elevated objects displaced outwards from centre
- Effect of ‘building lean’

Tilt distortion
- Image plane not truly level (effect of tilt at time of capture)
- Imaged terrain must be rectified to remove this distortion
Relief Displacement

From P. Miller (2018)
Tilt Distorsion

- Rectification to remove tilt distortion
- Ideally minimised at time of capture, but some effects still remain
Stereo Photogrammetry

- 3D (x,y,z) measurement: overlapping (stereo) imagery
Parallax

- $P_a = x_a - x'_a$
- $P_a =$ parallax of point A
- $x_a =$ x coord of A on left photo
- $x'_a =$ x coord of A on right photo
Parallax as a function of height

\[ P_a = x_a - x'_a \]

- \( P_a \) = parallax of point A
- \( x_a = x \) coord of A on left
- \( x'_a = x \) coord of A on right

Diagram showing the relationship between parallax and height, with labels for \( x_a \), \( x'_a \), and \( P_a \).
Space Resection

- If three or more points with known 3D ground coordinates are observed in an image, the camera position and orientation can be determined
- \{X, Y, Z, \omega, \phi, \kappa\}
Aerial Photogrammetry

- Most common application
- Relies on ‘near-vertical’ imagery captured from airborne camera
Lens Distortion

- Distortion increases with distance from centre of lens
- Metric cameras: few microns ($\mu$m)
- Non-metric: 20 –several hundred microns
Relative Orientation

- Relative orientation between camera centres. Offsets in XYZ
- Model coordinate system
Intersection

- If a point is observed in two or more cameras of known relative position and orientation, the 3D coordinates of the point can be determined.
RO: Tie Points

- Identify corresponding points in overlap (stereo) region
- Mathematical solution of intersection of light ‘rays’
- Transformation to stereomodelsystem 3D model coordinates
Absolute Orientation

Goal: transform stereomodel to ground coordinate system

Approach
- Ground control points (GCPs) measured in field (e.g. by GNSS)
- Natural targets or pre-marked
- Clearly visible in imagery
- Measure 3D model coordinates of GCPs
- Relate the two systems — 3D conformal transformation

Requirements
- Minimum: 2 PLAN & 3 HEIGHT points
- 2 points to scale and orientate the model
- 3 points to level
- Always add redundancy and measure more GCPs
Digital Photogrammetry

- Employs powerful Digital Photogrammetric Workstations (DPW)
- Very expensive
- Skilled photogrammetric operator
- Very robust & rigorous
- Incorporates **stereo viewing** system
- Solves using **bundle adjustment**
- Oriented images matched to **extract DSM**
- DSM then used to ortho-rectify imagery to generate **orthophoto or orthomosaic**
- Digital Photogrammetry
Bundle (block) Adjustment

In practice this is how we solve for exterior orientation

- A simultaneous least squares adjustment of all model parameters. Minimises residuals (errors).

**Inputs:**
- Tie point observations
- Ground control point observations & coordinates
- Camera geometry

**Outputs:**
- Tie point positions
- Camera position and orientations
- Camera parameters (optionally)
- Parameter uncertainty & overall accuracy of solution
Photogrammetry from UAS

Aim: Derive quantitative geospatial information from imagery
- Not a new challenge
- BUT, UAV platforms present new opportunities

Attractions
- Flexible data collection over small to medium extents
- Delivers DEMs & ortho-imagery at very high spatial resolutions
- Cost effective - relatively low initial investment
- Ease of uptake for standard application

- Photogrammetry from UAS
Photogrammetry: ease of application?

**Historically**
- Complex software workflows
- Careful parameterisation
- Expensive software/hardware and difficult to access
- Highly specialist-skilled operators

**Present Situation**
- Development of *structure-from-motion* (SfM), enabled through dense image matching developments (multi-view stereo)
- Low cost & quite ‘black box’
- Little expertise required

→ Bundle adjustment central to both approaches
SfM Software

Proprietary
- Agisoft Photoscan
- Pix4D
- nFramesSURE
- ...

Open Source
- VisualSFM
- Micmac
- PMVS/CMVS
- Bundler
- Apero/MicMac
- ...

*Cost - European Cooperation in Science & Technology*
Photogrammetric Block Capture

Strip = sequential exposures in a single flightline
Block = multiple strips to build up area coverage
Flight Planning

- Sequential overlaps
- Parallel flightlines
- Height above ground
- Consider effect of wind
- Time for UAV to turn
- Auto-triggering best
- Include cross-strips
- Some oblique images
Photogrammetry from UAS

Match sensor size, focal length, flying height to GSD

Overlaps for stereo coverage (SfM)

- 80% forward overlap
- 60% sidelap

![Diagram showing overlaps and GSD calculations]
Ground Control Points

Well distributed in plan and height
Well distributed across area of interest
GCP Targets

- **Pre-marked** best for precise observations
- Must be large enough to be visible in images (link to GSD)
- Must be small/distinct enough for precise location at image scale
- Measured through GNSS (post-processed) or total station
- Positional accuracy must fit to purpose of study
Hands on a Flight Planning
Flight planning: Data Mapper
Definition of the Study Area
Selection the Study Area
Flight Settings
Plaght Plan
Photoscan 3D Modelling

1) photo alignment with high accuracy;
2) optimizing alignment,
3) dense cloud building,
4) mesh building using a dense cloud,
5) texture building with the default blending mode,
6) tiled model building,
7) DSM building using the default settings,
8) orthomosaic generation.
Photos Allignment
Cloud Point
Tiled Mesh
Digital Elevation Model
UAS-based DSM

A) Position of the study area within Europe (45.927N, 21.335E).
B) Description of the study area and distribution of the GCPs.
C) UAS-derived DSM of the area

Harmonious WG4 meeting in Timisoara
Assessing the Accuracy of Digital Surface Models Derived from Optical Imagery Acquired with Unmanned Aerial Systems

From Manfreda et al., Drones 2019
DSM accuracy in terms of planar and vertical RMSE as a function of the GCPs density

<table>
<thead>
<tr>
<th>Reference</th>
<th>Area (ha)</th>
<th>Number of GCPs</th>
<th>AGL (m)</th>
<th>RMSE_{xy} (cm)</th>
<th>RMSE_{z} (cm)</th>
<th>RMSE Total (cm)</th>
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<tbody>
<tr>
<td>Rock et al. [2011]</td>
<td>N/A</td>
<td>1042</td>
<td>50–550</td>
<td>N/A</td>
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<td>Tahar [2013]</td>
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<td>50.0</td>
<td>78.0</td>
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<td>40</td>
<td>0.8</td>
<td>10.0</td>
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<td>200</td>
<td>18</td>
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<tr>
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<td>7.4</td>
<td>6.2</td>
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<td>Cryderman et al. [2014]</td>
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<td>11</td>
<td>118</td>
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<td>Agüera-Vega et al. [2017]</td>
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<td>100</td>
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<td>James et al. [2017]</td>
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<td>7.4–7.9</td>
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</table>

(Manfreda et al., Drones 2019)
DSM accuracy in terms of planar and vertical RMSE as a function of the GCPs density

- The errors observed in the vertical precision are systematically higher compared with the horizontal precision, and decrease more slowly with an increase in GCPs.

- The planar error tends to stabilize after reaching 5 GCP/ha, whereas 10 GCPs/ha are needed to reach the same condition for vertical precision.

- We need to find new strategies to improve DSM accuracy, especially vertical accuracy.

(Manfreda et al., Drones 2019)
Data Collection with a low-cost UAS

Characteristics of the different surveys: flight pattern, AGL at the take-off, average AGL, camera tilt, GSD, and number of images.

<table>
<thead>
<tr>
<th>Flight</th>
<th>Flight plan</th>
<th>Level Above the Ground (m)</th>
<th>Camera Tilt (degree)</th>
<th>Avg GSD (cm/px)</th>
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DJI Phantom 4 Pro quadcopter

(A) (B) (C) (D) (E) (F)
UAS data Collection: Ground Control Points
UAS derived 3D dense point cloud derived from a UAS based survey of an earthen dam next to the village of Pișchia (Timisoara, Romania)
Mesh Model derived from a UAS-based survey

From Manfreda and McCabe, Hydrolink 2019
Tiled Model derived from a UAS-based survey

Such data provide the framework for development of high-resolution flood modeling, urban watershed mapping and civil engineering design and map updating.

From Manfreda and McCabe, Hydrolink 2019
### DSM Accuracy without GCPs

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#### Planar Coordinates—RMSE (m)

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#### Elevation—RMSE (m)

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#### Planar and vertical—RMSE (m)

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<th>Performances</th>
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**Note:** The table above summarizes the accuracy of DSM with and without GCPs for different flights. The RMSE values indicate the precision of the elevation and planar coordinates, with lower values indicating higher accuracy. The relative elevation and planar and vertical RMSEs further support the precision of the DSM.
RMSE and Number of GCPs

RMSE of the 3D model as a function of the number of GCPs adopted. A) \( \text{RMSE}_{\text{X,Y}} \); B) \( \text{RMSE}_Z \); C) \( \text{RMSE}_{\text{X,Y,Z}} \) for the combination of flights N.1 and N.4.

A sharp increase in DSM accuracy can be observed, moving from 3–4 GCPs to 5–6 GCPs.

The magnitude of planar errors seems to be fairly stable after five GCPs. Vertical errors are always larger and tend to be more stable after six GCPs.
RMSE and Number of GCPs

Comparison of results obtained changing the number of GCPs and adopting a single flight or a two flights dataset on the plane (A) and z-axes (B).
Spatial Distribution of GCPs

RMSE of the 3D model as a function of the mean distance between GCPs obtained for the flight N.2 (A, B) and for the combination of flights N.1 and N.4 (C, D).

(RMSE of the 3D model as a function of the mean distance between GCPs obtained for the flight N.2 (A, B) and for the combination of flights N.1 and N.4 (C, D).

(Manfreda et al., R.S. 2018b)
Conclusions 1/2

- UAS-derived orthomosaics can produce a planar accuracy of a few centimeters, whereas the vertical accuracy of DSMs is always lower. This is likely due to the fact that most UASs adopt a camera in a zenithal position that provides more accurate description of planar features. Vertical measurements are generally more complex, but also critical for studies of change detection.

- The flight plan and camera configuration may significantly impact the overall quality of the resulting DSM. Therefore, it should be planned thoroughly to produce the best depiction of the entire area. For instance, a transversal survey with respect to a given structure provides better description and quality of the resulting 3D surface.
Conclusions 2/2

- The use of a tilted camera can improve the amount of information (retrieved number of points) for inclined surfaces, providing higher DSM elevation accuracy. The tilted camera images increases the robustness of the geometrical model, providing a possible strategy to reduce the total number of GCPs adopted over a given area. This can be beneficial especially in inaccessible areas.

- The combination of several flights may be extremely beneficial for DSM accuracy. This may increase redundancy of information and improve the overall quality of the results, exploiting the benefits derived by different flight plans and camera configurations.

- The planar and vertical accuracies can be improved by increasing the number of GCPs. In particular, the quality of the 3D model tends to increase when both the relative plane and vertical distances of the GCPs increase. It is therefore convenient to evenly spread GCPs in space. In many cases, such ideal settings are not possible. In such cases, our results suggest adopting a combination of flights that are less sensitive to this parameter in the final vertical accuracy of the DSM.
Related Publications

UAS-based Mapping: Examples

Prof. Salvatore Manfreda
Associate Professor of Water Management and Ecohydrology - http://www2.unibas.it/manfreda
Chair of the COST Action Harmonious - http://www.costharmonious.eu
Example of Applications: Orthomosaic Timisoara (Romania)
Example of Applications: Orthomosaic Diga Saetta (Potenza)
Example of Applications:
Orthomosaic Iran
Neshabur

RGB Orthomosaic
5 cm resolution
Example of Applications: Orthomosaic Iran Neshabur

Thermal mosaic
19 cm resolution
Example of Applications: Orthomosaic Monteforte

RGB-based Indices

\[ TGI = R_{\text{GREEN}} - 0.39 \times R_{\text{RED}} - 0.61 \times R_{\text{BLUE}} \]

\[ \text{GLI} = \frac{(2 \times G - R - B)}{(2 \times G + R + B)} \]

\[ \text{NGRDI} = \frac{\text{GREEN} - \text{RED}}{\text{GREEN} + \text{RED}} \]

RGB Orthomosaic
4 cm resolution
Example of Applications: Orthomosaic Monteforte

Multi-spectral mosaic
5 cm resolution
Example of Applications: Orthomosaic Monteforte

Thermal mosaic
17 cm resolution
Example of Applications: Orthomosaic Cantine del Notaio Maschito)
Example of Applications: Orthomosaic Cantine del Notaio Maschito)
Example of Applications: Orthomosaic Murgia Timone (Matera)
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Example of Applications: Orthomosaic Murgia Timone (Matera)
Related Publications


