UAV Photogrammetry in Cultural Heritage Modeling and Monitoring

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Abstract

UAVs – Unmanned Aerial Vehicles have recently become a strong focus of attention both in the scientific-technical and professional communities, since inexpensive platforms, navigation and control devices and sensors have become available. Platforms range from stratospheric airships to low flying fixed wing aircrafts, model helicopters, quadro-, hexa- and octocopters and others. Especially the model helicopter and its derivatives like multiple blades copters, equipped with GPS, IMU, stabilizing platform and digital cameras and (in the future) laserscanners have excellent application prospects. They combine all features which make them attractive as a data acquisition device: Inexpensive, very flexible in operation (can operate in nadir, oblique and quasi-terrestrial mode), stable with respect to wind (as opposed to balloons and kites), able to fly into confined spaces, operable on-demand and with on-line and real-time processing capabilities.

Especially in archaeology and Cultural Heritage applications we see great potential for this technology. The mostly small extensions of the project areas lend themselves favorably to the use of UAVs.

UAV Photogrammetry in Cultural Heritage Modeling and Monitoring

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1. **Introduction**
2. **Projects, experiences**
3. **Conclusions**

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Sensors & Systems NEWSLETTER
Monitoring, Analyzing and Adapting to Global Change
Volume 6 / Issue 34 / Aug. 21, 2012

How does the geospatial industry bridge the divide with the unmanned aerial community? Matt Ball

UAVeek 2012

1st microdrones International
Research Workshop

Siegen, Germany
20-21 November 2012

Program UAV week

2

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Various UAVs

3

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Parrot
AR.Drone
When video games become reality

Photos   Videos   Developer Zone

The first helicopter with automatic flight stabilization!

Read more

4

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UAV project RAMS, Korea

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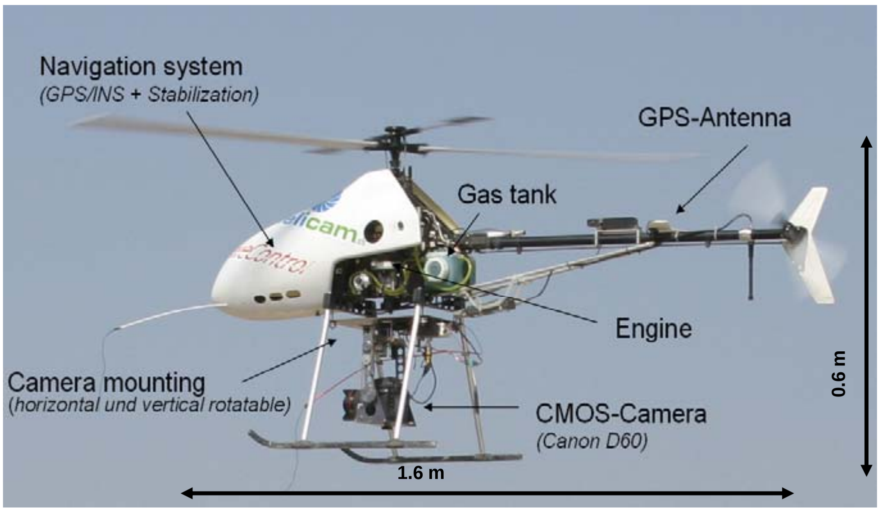
Our model helicopter Helicam (weControl, 2004)



6

Swinglet CAM (sensefly)

- weight: < 500 g
- 30min flight
- climb speed of 3m/s, cruise speed of 10m/s
- Canon IXUS 220 IS,
  covers an area of up to 10 sqkm in only one flight
- autopilot, autonomous take-off and landing

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Falcon-8 flight

AscTec Falcon 8 - Facts

500 g load
max 20 min flight time
max 10 m/s wind speed
redundancy through 8 rotors
GPS, height sensor, compass, IMU
max. Total weight 1,8 kg

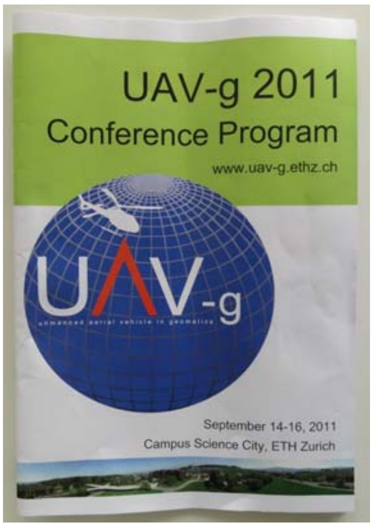
md4 – 1000, microdrones GmbH

Climb rate 7.5 m/s
Cruising speed 15 m/s
Vehicle mass approx. 2650g
Recommended payload mass 800g
Maximum payload mass 1200g
Maximum take-off weight 5550g
Dimensions 1030 mm
Flight time up to 70 minutes
Wind tolerance steady pictures up to 6m/s
Flight radius 1000 m on RC, with waypoint even more
Ceiling altitude up to 1000m
Take-off altitude up to 4000m ASL

Aibot X6: multicopter with collision avoidance, crash safety and easy operation

Ongoing R&D work

Public notice



Conference conclusions

- + ***Robotic:*** Real-time applications (navigation, control, 3D modeling (3D maps)), Lower precision and reliability sufficient
- + ***Geomatics:*** Diverse applications, 3D modeling, high accuracy (precision and reliability)
- + Many different applications
- + More platforms, variation in type
- + Increase of robustness (?)
- + Different sensors (Thermal and MS cameras, 5-camera head, LiDAR, 3-axes magnetic sensor, SAR)
- + Open source HW and SW vs. commercial
- + Camera calibration
- + Accuracy testing
- + 3D modeling
- + Flight regulations, permissions

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Advantages of UAVs

- Flexibility in sensor design and integration, data acquisition and flight pattern (navigation, flying height)
- Use in high-risk situations
- Flight close to object
- Production of vertical, oblique and horizontal images
- Fast data processing (download, on-line, real-time)
- Inexpensive platform (manufacturing, operation)
- High educational value

13

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Disadvantages of UAVs

+ Weather conditions
+ Weight restriction (small sensors)
+ Local operation ~1-3 km
+ Limited absolute flying height (helis: lack of uplift and oxygen)
+ Professional training and attendance for helicopter pilot
+ Safety issues
+ Cannot cope with obstacles (avoidance of collisions)
+ Payload limit in Switzerland < 30 kg
+ Other legal regulations (permissions from terrain/object owners, flight control authorities, etc.)
+ Technology (hard- and system software) is not mature enough

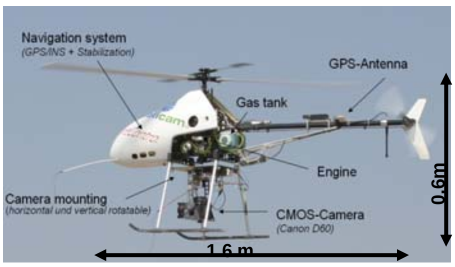
14

Unfortunate events

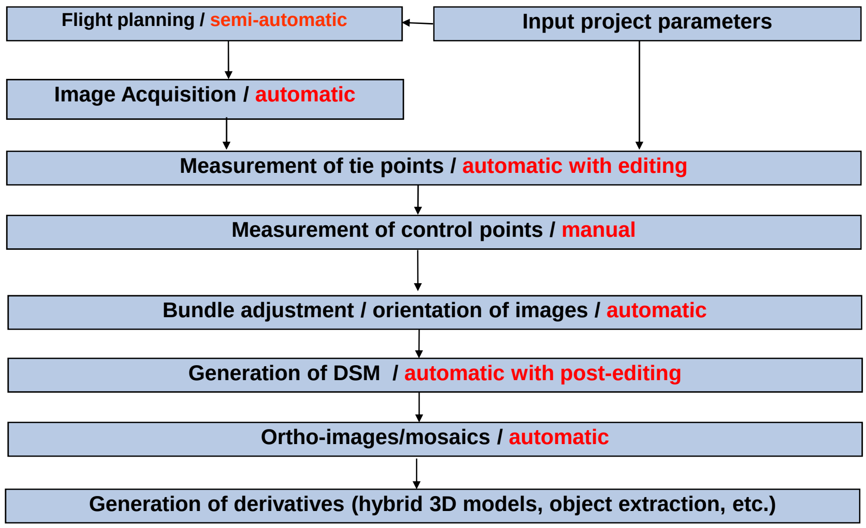
Photogrammetric UAV systems

Characterization of “photogrammetric”:

+ Long flying time for image block data acquisition
+ Large image sequences (100 – 10 000)
+ Navigation devices for automated control of trajectory and orientation
+ Image-based and/or range-based sensor(s), modular/exchangeable
+ Calibration of sensors and system
+ Image-based navigation
+ Accurate geo-referencing (direct/indirect)
+ 3D modeling of objects and processes (geometry and texture)
+ Automated image analysis and fast processing (sequential estimation)
+ Standard photogrammetric pre- and post-processing functions
+ Good software !!!!!



Current photogrammetric workflow



17

Image-based measurement and modeling

Levels of complexity

+ **Point positioning**. A number of single points must be determined. Often very high accuracies are required (e.g. industrial quality control). Points are mostly signalized. Math model (functional and stochastic parts) must be highly developed.

+ **Surface determination.** Determination of masspoints describing one or many surfaces. Usually relaxed accuracy requirements. But problem: How from points to surfaces?

+ **Object extraction.** Measurement and modeling of discrete objects, predominantly defined by points and edges. Often attributes required. How to understand objects and attributes?

+ **Moving objects.** Monitoring of dynamic processes.

Point cloud ⟹ Surfaces ⟹ Objects ⟹ Object tracking

Photogrammetric measurement / modeling

(a) Traditional (manual) procedure

Minimal number of points to describe object

High reliability for all points, but: how to define (model) surface?

How to integrate additional information, e.g. edges?

How to deal with uneven point distribution?

(b) Automated procedures (image matching, laser-scanning, structured light)

Very dense point cloud

Mismatches, irrelevant points, missing object parts, systematic errors, blunders

Needed: Intelligent measurement device, considering performance of (surface) modeler

Main problems with automated reconstruction

+ Image interpretation
+ Automated control of level of detail
+ Correct topology

Currently: No progress in automated image interpretation
Way out: Multi sensor/data concept

Professional practice cannot and should not wait!!
Therefore: Development of semi-automated approaches

Criteria for 3D modeling

+ Resolution (defined by users and sensors)

+ Accuracy (defined by operators/procedures and sensors)

+ Completeness (defined by procedures/operators)

+ Topological correctness (defined by users/applications)

+ Appearance correctness (defined by applications)

Options:

„Quick and dirty“ or „nice looking but wrong“ vs. „high quality“

With texture you can easily cheat !

The problem of quality control – what is the accuracy and completeness of these models?

- How accurate are the models in terms of geometry, topology and texture (appearance/perception)?

- How do the different techniques compare to each other?

→ Very few quantitative studies !

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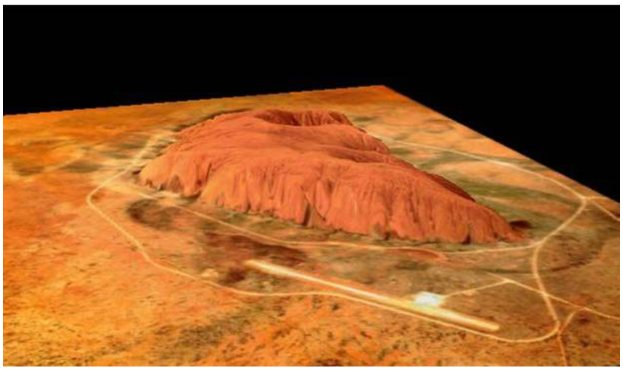
3D Modeling of Landscape

Ayers Rock

2 aerial colour images, no GCPs



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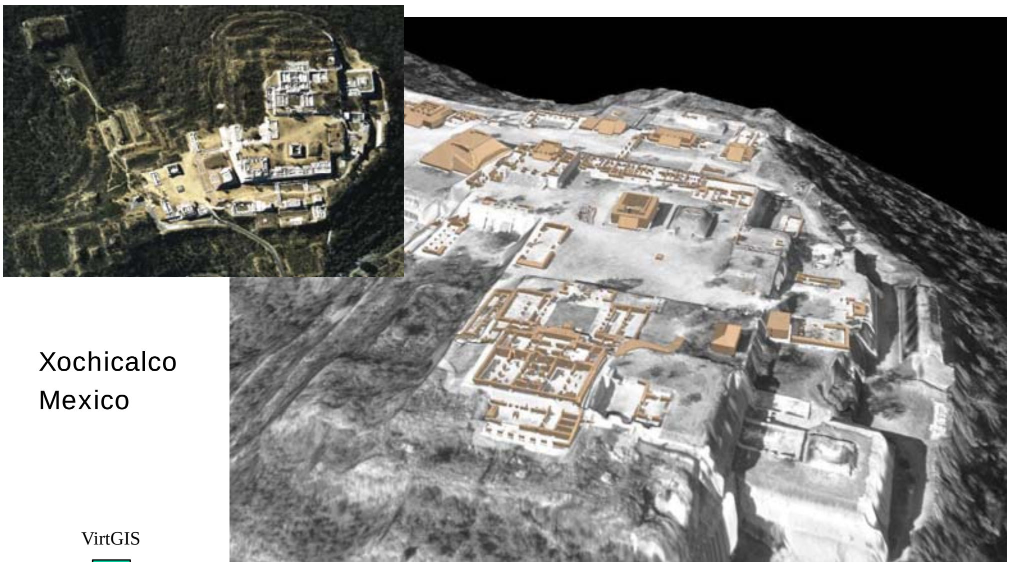

Xochicalco
Mexico

VirtGIS

Student project: Castle Landenberg

Symbol of Obwalden in the Swiss passport

Landenberg: Flight planning

- Circle with a radius of 25 meters
- 24 images; every 15°
- Images oblique
- Simulation

Student project: Castle Landenberg

Our examples, projects

- *Pinchango Alto, Palpa/Nasca, Peru (archaeology)*
- *Copan, Honduras (Cultural Heritage)*
- Maize field (plant sciences)
- Randa (geology)
- Hoenggerberg (student work)
- *Landenberg (Cultural Heritage, student work)*
- Volumetric changes of gravel pits (civil engineering)
- *Drapham Dzong, Bhutan (archaeology, Cultural Heritage)*
- NUS, Singapore (city planning, flooding, etc.)
- *Shuhkov towers, Russia (construction engineering)*
- Chiliwung River, Indonesia (hydrology, landscape architecture)

\+ Planned for December: Peru (archaeology)

Model helicopter over Pinchango Alto, Peru

(16.9.2004)

29

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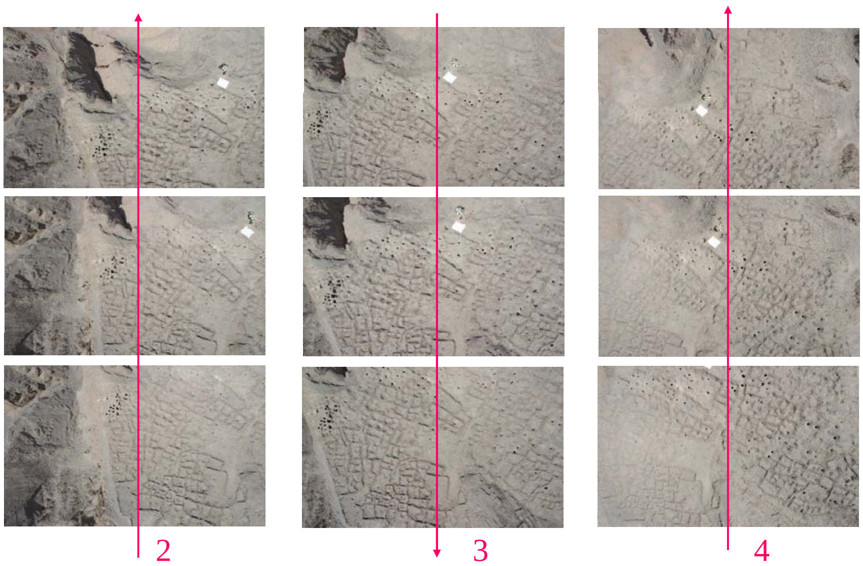
Image strips, overlap



30

Model helicopter over Pinchango Alto, Peru

3D Model

Heli flight

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UAV photogrammetry – excavation Pernil Alto (Palpa, Peru)

Archaic and Paracas periods

hg = 350 m

hg = 50 m

Heli landing
Pernil Alto

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UAV photogrammetry for National Geographic

http://channel.nationalgeographic.com/channel/episode/nasca-lines-the-buried-secrets



Nasca/Palpa, Peru



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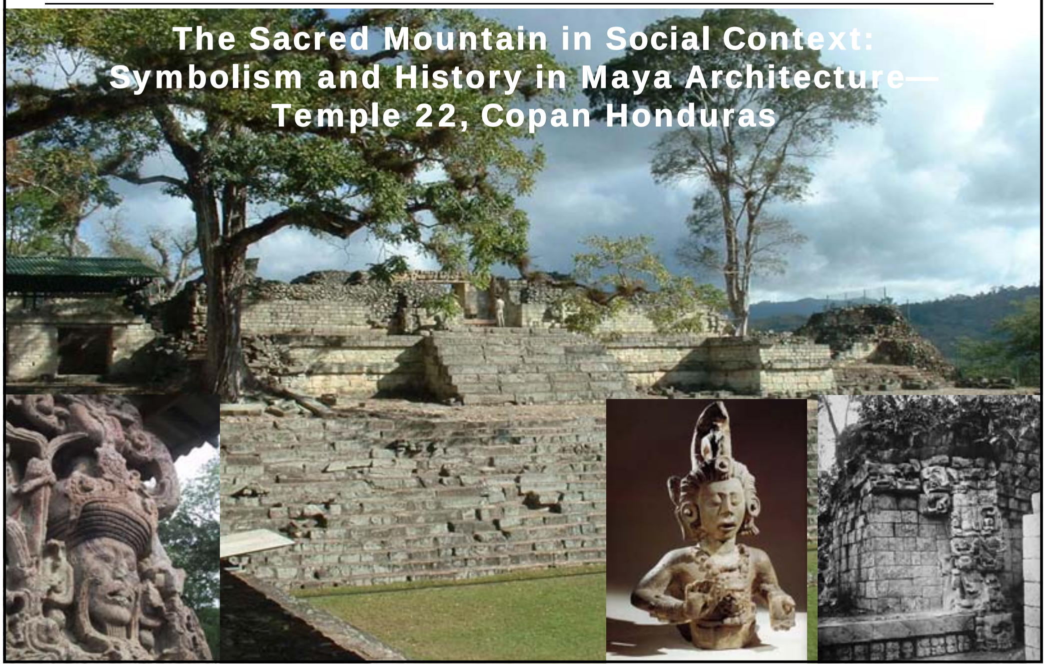
The Sacred Mountain in Social Context: Symbolism and History in Maya Architecture— Temple 22, Copan Honduras



3D Documentation of a Maya Site and Reconstruction of a Temple at Copan, Honduras







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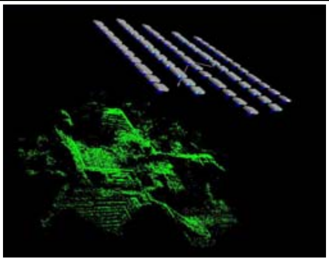
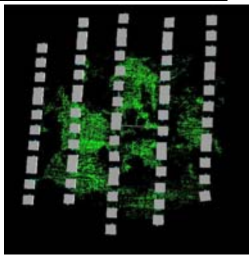
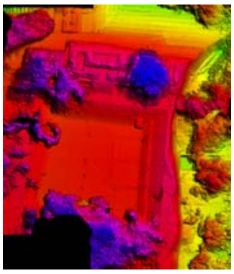
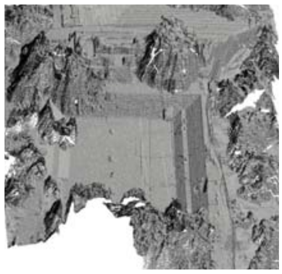
"Quick and Dirty" Stitching via Photoshop





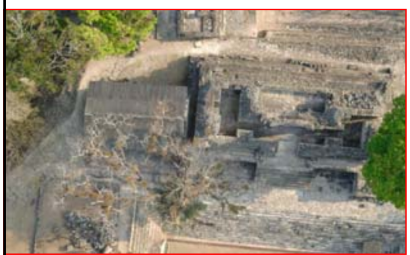
Automated tie points extraction and EO computation



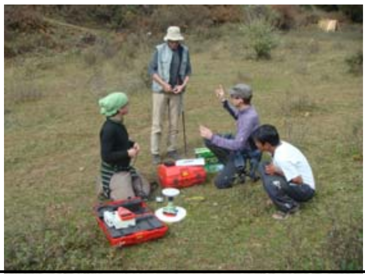


First results of DSM generation (SAT-PP, www.4dixplorer.com)

“Quick and dirty” model of Temple 22



The Bhutan-Swiss Archaeology Project



Bhutan – Land of the Thunderdragon

Towards Drapham Dzong





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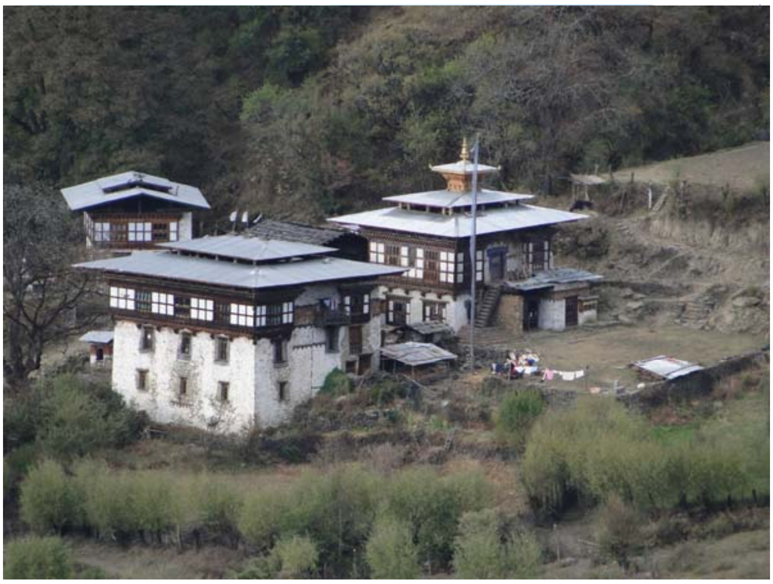
Drapham Dzong - environment



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Drapham Dzong – before and after

October 2007

November 2009

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Data collection

- **Environment**
  - GeoEye stereo model
- **Zhong**
  - UAV: quadrocopter Microdrone md4-200
    Camera: Panasonic Lumix FX35
  - Terrestrial images for texture
- **Separate structures (mill, etc.)**
  Terrestrial images
  - Nikon D2Xs; D3X
  - Sony DSC-HX1
- **Control Points**
  - GPS 500 (Leica Geosystems 2010)

Quadrocopter over Drapham Dzong

Ready for take-off

Landing

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Drapham Dzong

GeoEye satellite stereo model

Data processing
DSM large area: A (SAT-PP)
Phototriangulation: A (APERO)
Local DTM + buildings: M

Phototriangulation (Trento) – fully automatic

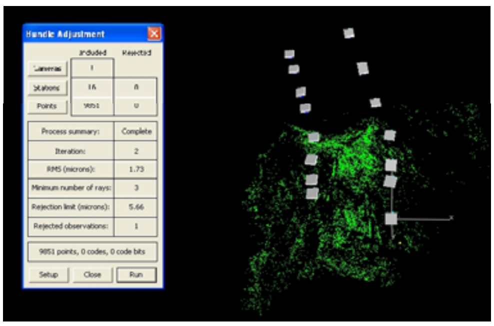

Image matching – problems (stereo across track)

Image matching – problems (stereo along track)

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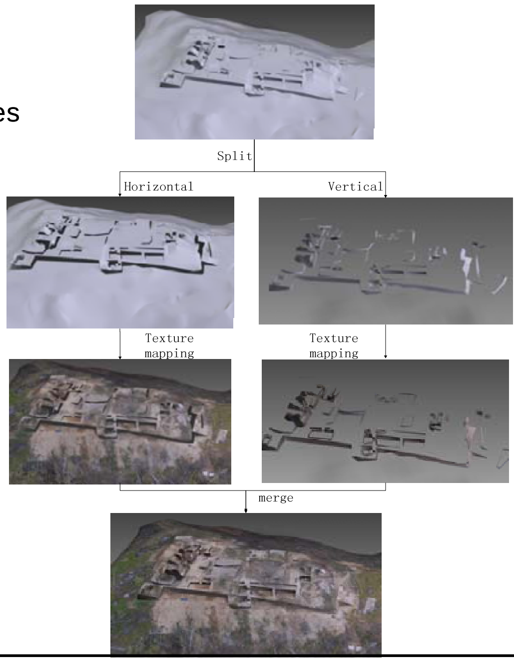
Texture mapping

Aerials and terrestrial images



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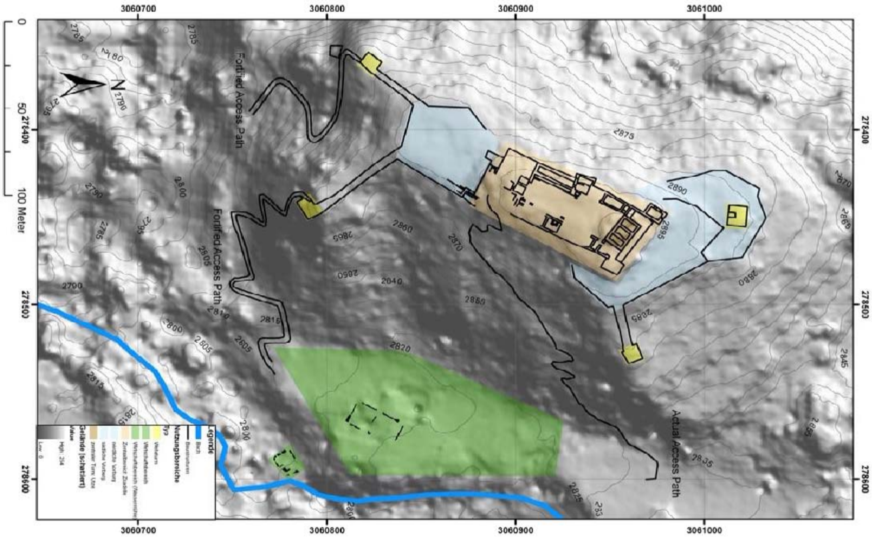
Drapham Dzong

Image mosaic

3D model

2D plan



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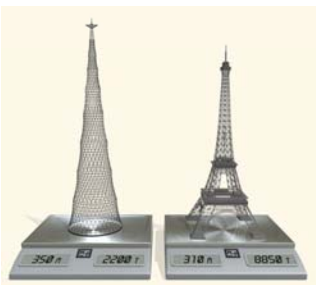
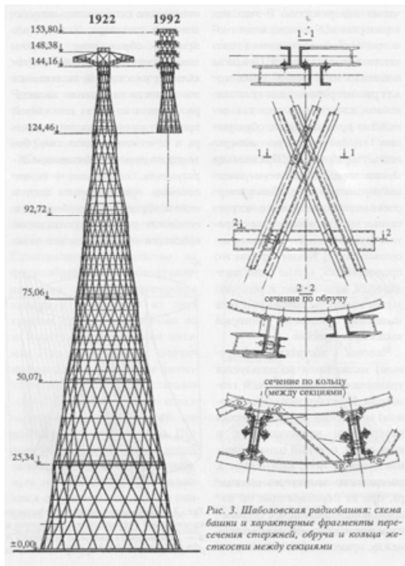
Vladimir G. Shuhkov (1853-1939)

Engineer, architect, inventor

Lattice towers

Iron, steel, hyperboloids
20 of more than 200 towers survived
+ Polibino, 1896
+ Schabolovskaya, 1921-22
+ Nigres, 1927





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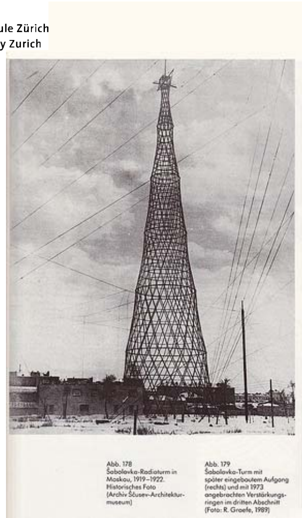
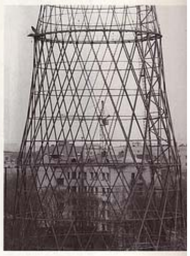
Project Vladimir G. Shuhkov (1853-1939)

Department Store Gum,
Moscow, 1889-93





53

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Schabolovoskaya Tower

Built 1919-1922

Radio station for international connections of the young Soviet state

First version: 350 m high, with Lenin's permission

After 1939: TV antennas

Today: Belongs to Russian State TV

Restricted accessibility

Transmitters for mobile communication

Project Vladimir G. Shuhkov

How to measure and model complex steel rods in 3D space ?

+ Resolution?
+ Accuracy?
+ Integration of rod models (combination of CAD and photogrammetry)

Sensors

+ UAV photogrammetry
+ GPS/INS for autopilot
+ Laserscanning
+ GPS for control points
+ Total station for control of high frequency movements

Falcon-8 flight

AscTec Falcon 8 - Facts
500 g load
max 20 min flight time
max 10 m/s wind speed
redundancy through 8 rotors
GPS, height sensor, compass, IMU
max. Total weight 1,8 kg

Camera Sony NEX-5
16mm lens fix, 14.2 Mpi, APS-C,
focus manually, live video,
pi = 5micron

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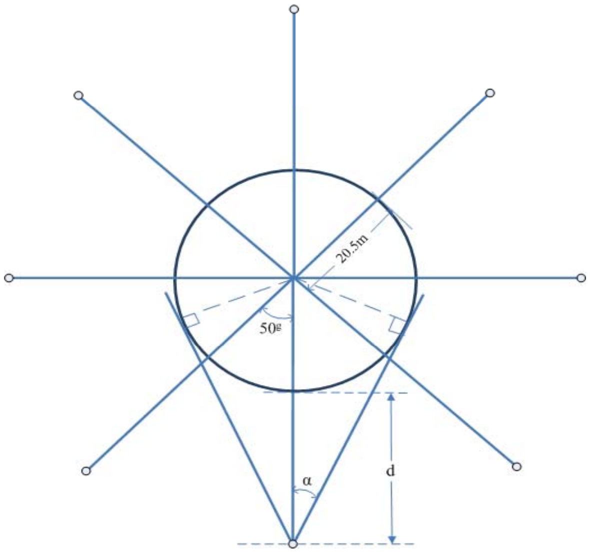
8-Star Design



d ≈ 26.8 m

α = 28.5^g

Object format (frontal):
25.8x38.7 sqm

MB = 1:1677

Footprint: 8.4 mm foreground

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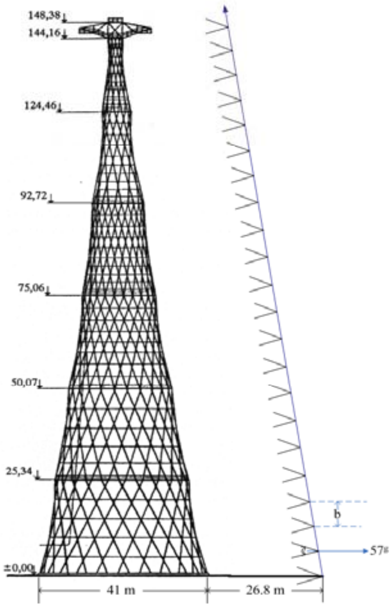

Network design:
80%l > b = 7.7m
- 20 images per strip
- 160 images in total

Schabolovskaya – UAV images

Schabolovskaya - terrestrial stereos

Schabolovskaya - terrestrial stereos

Polibino tower

All-Russian Exhibition in Nizhny Novgorod in 1897

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Polibino tower – UAV in operation

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Polibino tower – manual control

Polibino tower – UAV crash

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Polibino tower – substitute platforms

Polibino terrestrial stereo

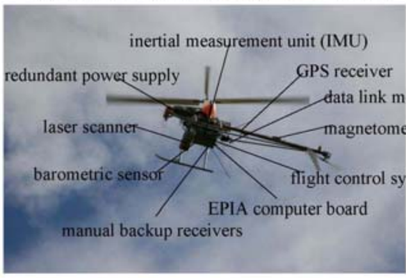
Polibino terrestrial stereo

Ongoing and future R&D work (2010)

+ Integration of other sensors (multiple cameras, multi-spectral, infra-red, LiDAR, etc.)
+ Development and testing of dynamic sensor models (LiDAR, Linear Array cameras)
+ System and sensor calibration
+ Improvement of positioning and orientation accuracy
+ Integration of image-based navigation (sequential estimation)
+ Improvement of level of automation in image analysis
+ Real-time and on-line processing
+ New applications

UAV with aerial laser scanner Riegl LMS-Q160

Aeroscout Scout B1-100



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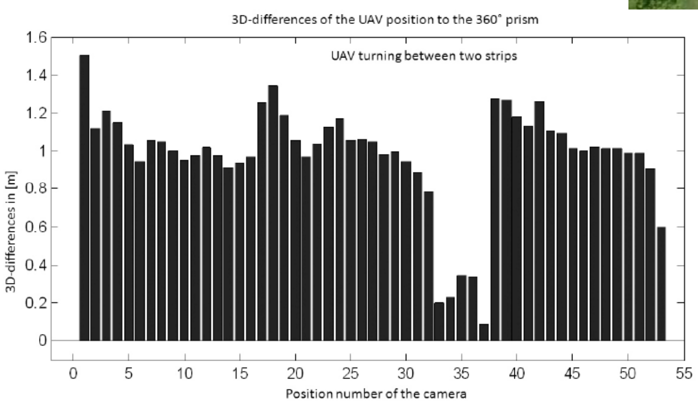
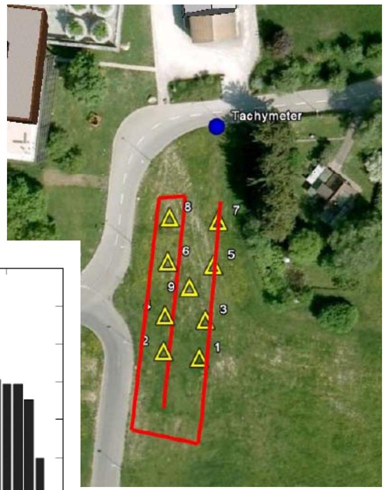
Tracking tachymetry

Leica SmartStation TPS1200+
5-7 Hz, sigma(t) = 120msec





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Tracking tachymetry

		Strip 1			Strip 2		
		X [m]	Y [m]	H [m]	X [m]	Y [m]	H [m]
Flight 1	X_M	-2.32	0.64	1.53	1.65	-1.36	1.38
	$\sigma_{X_{diff}}$	0.74	0.40	0.19	0.90	0.42	0.14
	RMSE	2.42	0.74	1.54	1.85	1.42	1.39
Flight 2	X_M	-2.93	0.74	-0.17	-2.84	0.71	0.03
	$\sigma_{X_{diff}}$	0.56	0.39	0.07	0.74	0.33	0.11
	RMSE	2.98	0.83	0.18	2.93	0.78	0.11
Flight 3	X_M	-2.30	0.41	2.24	1.23	-1.62	2.06
	$\sigma_{X_{diff}}$	0.50	0.32	0.16	1.15	0.49	0.11
	RMSE	2.35	0.51	2.26	1.66	1.69	2.07

UAV specifics

+ Cheap sensors – low data quality (GPS/IMU)
+ Interference with external microwave sources: Mobile antennas – electronic compass; control signal disturbance
+ Cameras (off-the shelf), 24Mpi, temperature instability, but main problem: Lens (colour refraction/colour seams, unsharpness in corners)
+ Errors in system software (spurious images, images and GPS/IUM not synchronized)
+ Overlap often irregular
+ Sometimes oblique images, complex networks
+ Much room for improvement of data processing methods

Conclusions

+ Model helicopters are very flexible devices for recording (cameras, orientation, navigation, real-time capabilities)
+ Cost-efficient
+ Many diverse applications, if area is not too large

But:

+ Technology (system hard- and software) not mature

+ Much room for improvement of data processing methods

+ Flight permissions, safety concerns

Conclusions

In general: Automated object extraction not solved yet !

Therefore:

Either use of **semi-automated techniques (success in city modeling, road extraction)**

or seek progress in

+ Image understanding
+ Use of multiple cues by multiple sensors

Conclusions, perspectives

+ **Point positioning**
Design of photogrammetric systems, measurement processes and geometrical aspects well controlled for conventional applications

+ **3D Modeling**
+ Experts in cartography are struggling for 8 000 years with representation of 3rd dimension (2.5D contours ⟹ 3D models)
+ No general solution for 3D surface modeling available
⟹ Manual intervention
⟹ Use variety of software
+ Consider object modeling task (software) at project design stage
+ Adjust network design to image analysis approach (large/small base), 3D object modeling and texture mapping task (more images)

Conclusions, perspectives

+ „Fast and dirty" modeling possible, but

+ High quality models need very much manual work (geometry & texture)
  Texture (appearance):
  - Can hide deficiencies in geometry
  - Can screw up a good geometry model
  - Can lead to the wrong perception/interpretation of a model

+ Address problems like
  - Creation of geometrical models (many methods)
  - Creation of photometric models (image-based, model-based, eigentexture)
  - Integration of generic models with real scenes (rendering VOs with real illumination distribution: geometry, illumination, time)

+ Conduct tests on international stage

This presentation introduces into the fundamentals of UAV photogrammetry and reports about the experiences collected by our group in this area in the past eight years. We will address hardware and sensor issues and discuss the need and use of advanced photogrammetric software for geo-referencing and 3D model building. We will also emphasize the advantages of multi-sensor concepts in modeling. A variety of applications in archaeology and Cultural Heritage will testify the usefulness of this technology. While 3D modeling is still a relevant problem for R&D, time has come to also look more closely into the issue of monitoring of Cultural and Natural Heritage sites. Again, UAVs constitute an excellent device for this task.