ADVANCES IN CLOSE-RANGE PHOTOGRAMMETRY

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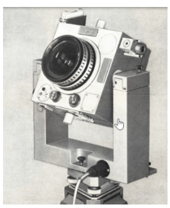
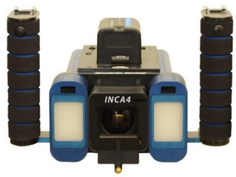
Evolution 1: film to digital

Metric film cameras



Custom-made metric digital cameras

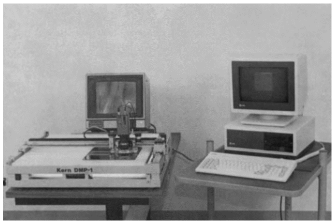


Off-the-shelf & ‘modified’ digital Cameras

Video essentially bypassed within photogrammetry

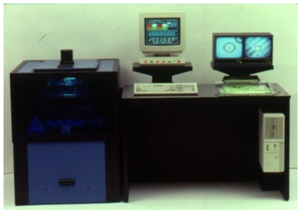
Evolution 2: Manual to automatic image meas. & orientation

Manual monocomparator



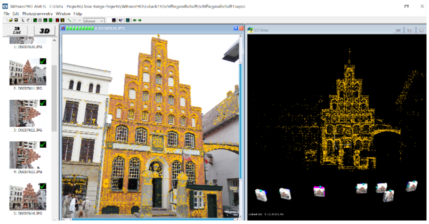
Computer-assisted monocomparator

Analytical plotter



Automatic comparator with image EO

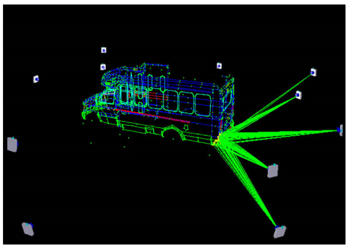
Fully automatic network orientation using targets



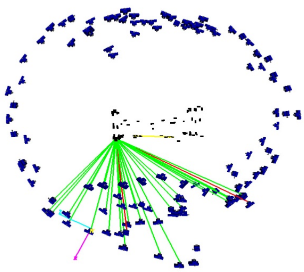
Targetless automatic image meas. & network orientation

Evolution 3: Manual Feature Extraction & Graphical Output to Automatic 3D Point Cloud Generation

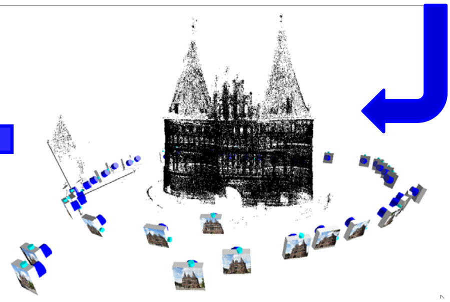
2D plan or map



3D feature points



Targetted feature points



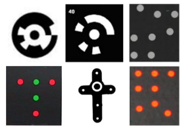
3D Point cloud, sparse or dense

Textured dense point cloud or mesh

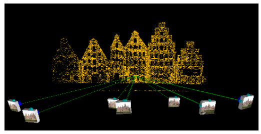
Further feature extraction & modelling, eg within CAD

Major CRP Developments in the Digital Era

- **Coded targets/markers –** facilitated auto-orientation & 3D point determination, in both off-line & on-line/real-time CRP systems

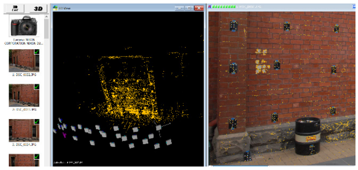


- **FBM/SfM auto-orientation –** facilitated auto-orientation & sparse 3D point cloud generation



- **Dense image matching –** facilitated dense 3D point cloud generation to pixel-level resolution

- ***Automatic camera calibration –*** *facilitated by coded targets or FBM orientation; has enhanced accessibility to CRP*



Options for Orientation & 3D Object Reconstruction

Initial Network Relative Orientation

- (A) Manual to Semi-Automated Image Measurement
- (B) Automatic, using coded targets
- (C) Automatic with no targets (SfM approach)

Bundle adjustment (+self-calibration) for Refined Network Relative/Exterior Orientation

Bundle Adjustment

Subsequent Determination of 3D Points (generally with final Bundle Adjustment)

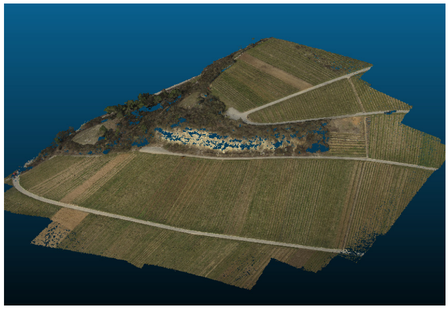
- (A) Manual or semi-automated referencing or measurement of targetted or untargetted points
- (B) Automatic 3D coordinates for targetted points
- (C) Automatic generation of dense point cloud – no targets

Direct versus Indirect Feature Point Extraction

Direct

Direct

Indirect



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Scenario: Auto-orientation followed by manual feature point extraction

Manual Image Measurement

- Applicable when there's no targets, no texture and/or network geometry not conducive to auto-orientation
- >2000 users of CRP in accident reconstruction in the US alone (CRP has many attributes)
- On-line image measurement yields robust error detection & blunder free solutions
- Conditions might be considered extreme, but they are the norm

Note: Sfm is no panacea

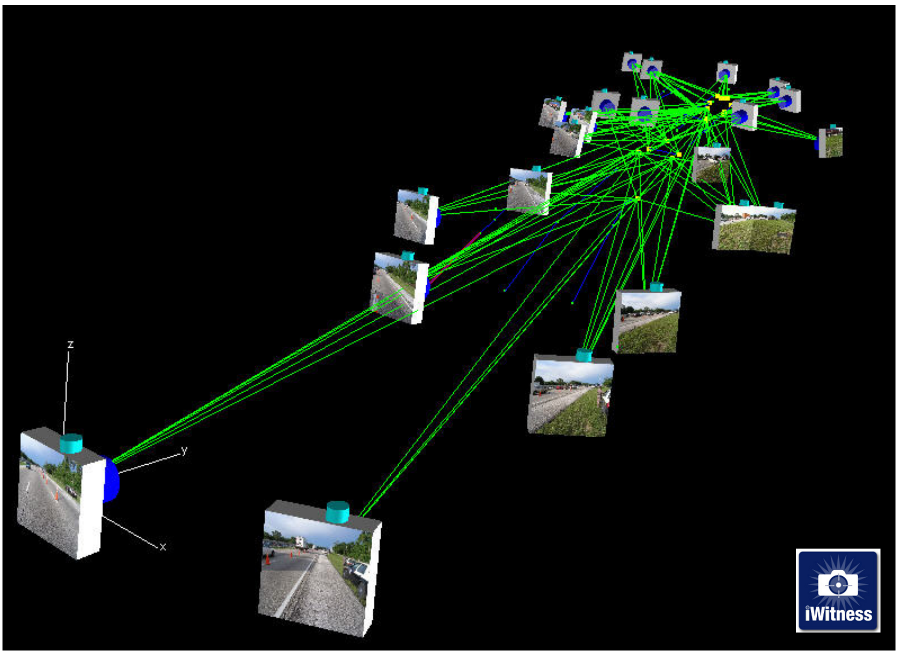
Attributes of photogrammetry for accident reconstruction & forensic measurement

- Fast scene recording → minimal road closures & less traffic disruption
- Photography offers a permanent record; feature measurement at any time
- Technology is very low-cost; can use any camera
- Systems such as *iWitness* are very easy to use & provide fast & accurate 3D measurements
- Operational scenarios: manual through semi- to fully automatic
- Data redundancy affords robust and reliable quality measures

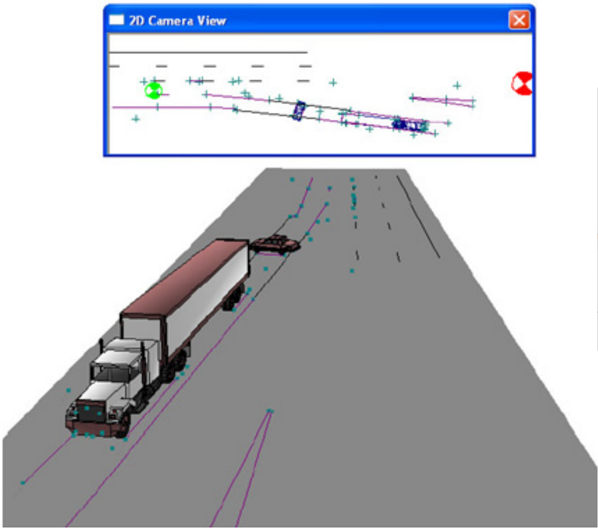
iWitness

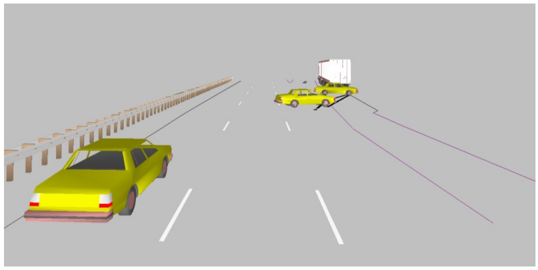
Photogrammetric measurement for accident reconstruction & forensics

Near-planar geometry not conducive to targetless orientation

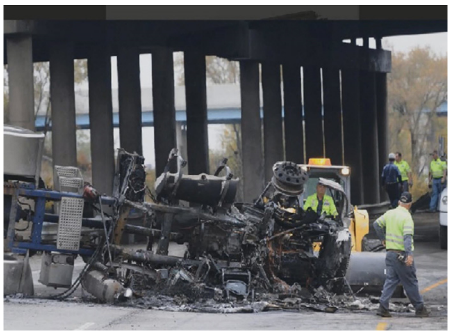


Accident Reconstruction Undertaken by the Florida Highway Patrol



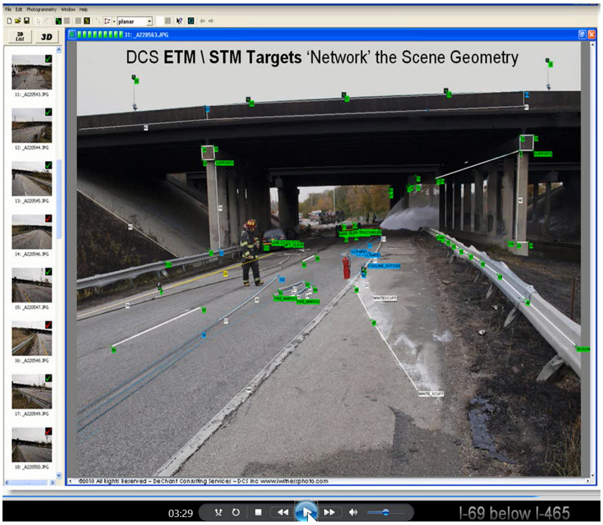


Project Example: Crash scene mapping of a tanker explosion, Indianapolis at I-465 and I-69

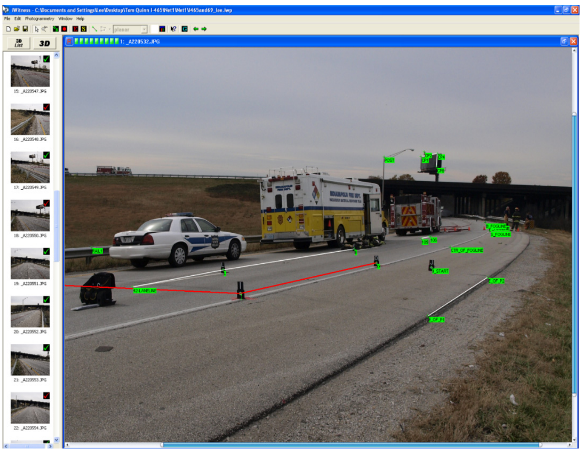


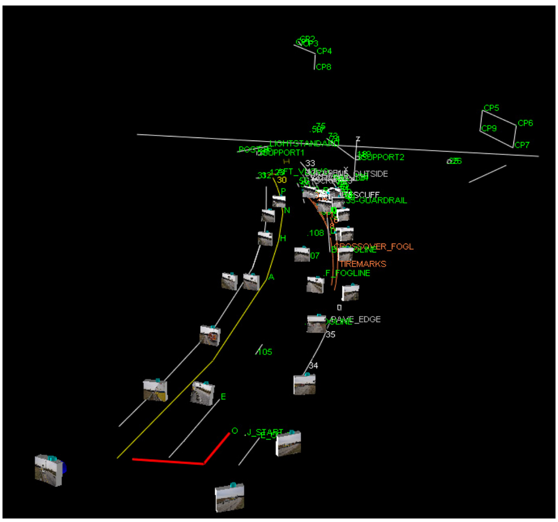
Multi-level site was recorded in 3 networks spanning 300m, in 70 minutes

Example Project: Scene mapping of tanker explosion



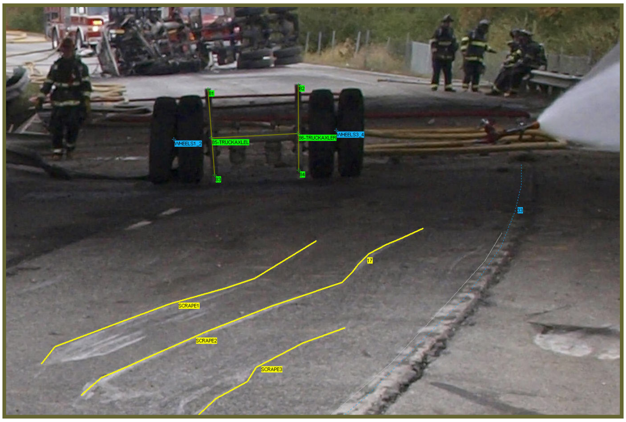
Example Project: Scene mapping of tanker explosion

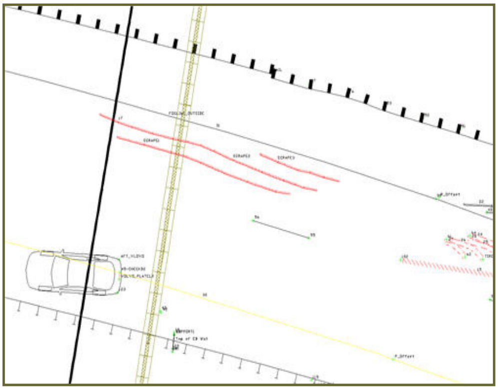




I-69 below I-465

Example Project: Scene mapping of tanker explosion



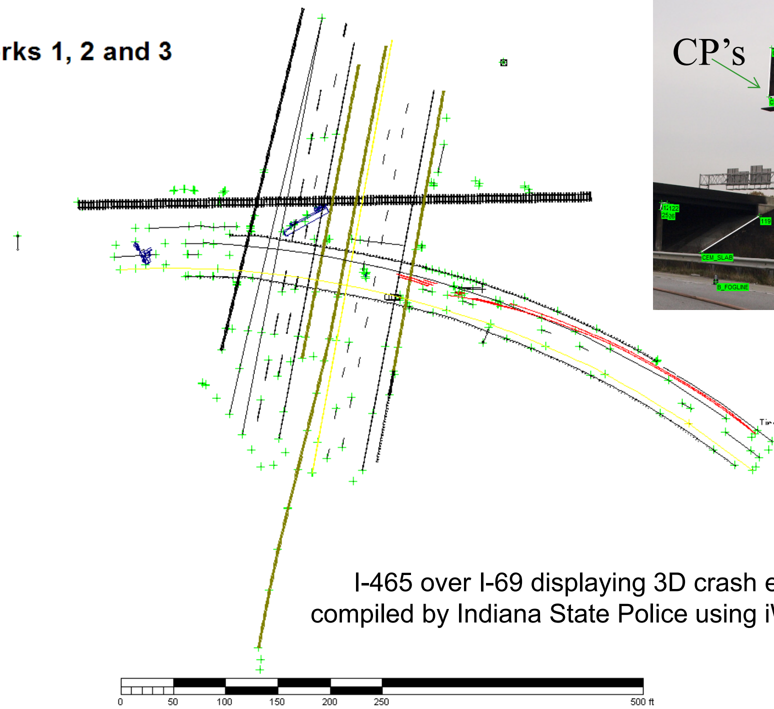


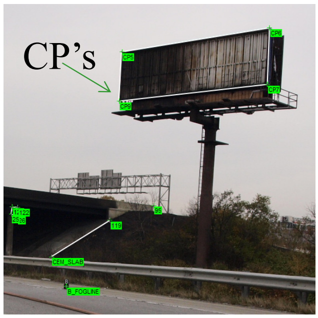
iWitness

Feature mapping for provision of evidence

Example Project: Scene mapping of tanker explosion

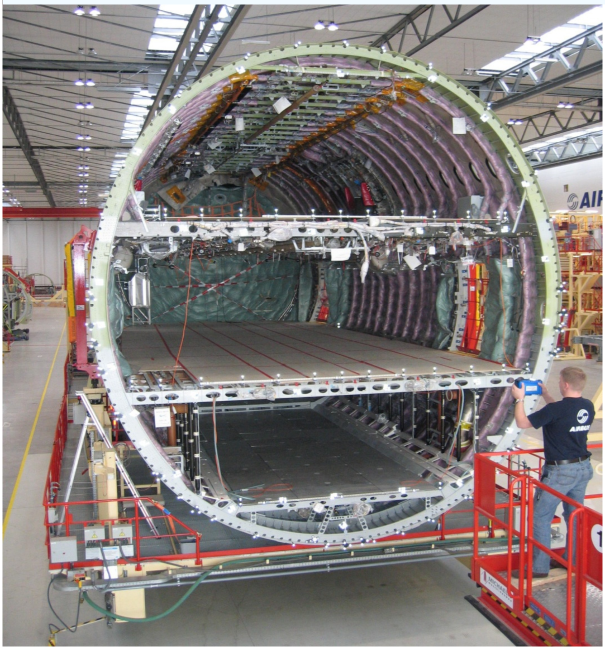
Networks 1, 2 and 3





I-465 over I-69 displaying 3D crash evidence, compiled by Indiana State Police using iWitnessPRO

Automated CRP Measurement using Targets



Aircraft Manufacture

AIRBUS Hamburg
Fuselage Sections
And Seat Rail Measurements
(A380, A340, A330, A321, A320, A319, A318)

Measurement Example: Passenger Door Frame & Door Hinges at AIRBUS Hamburg

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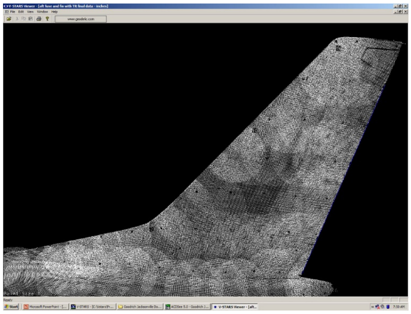
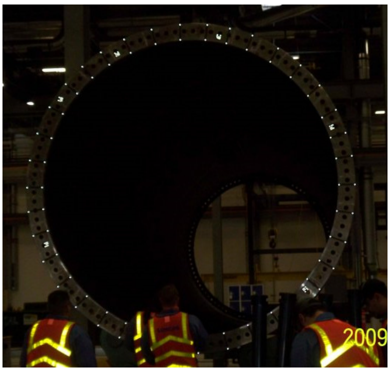
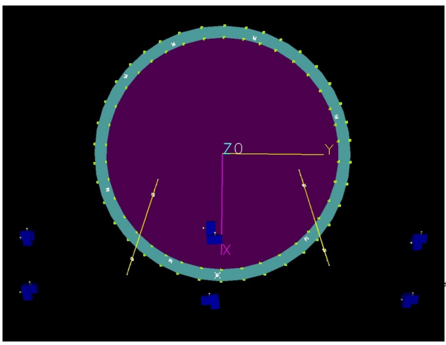
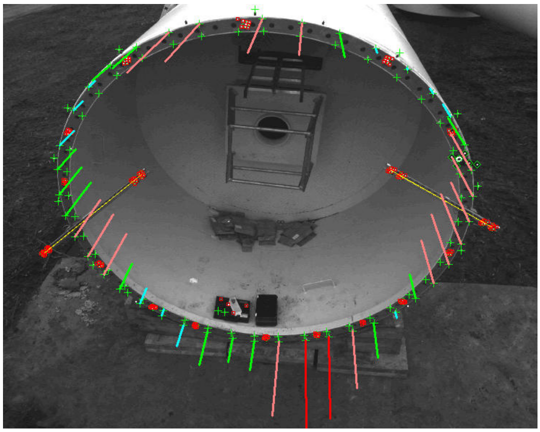
Measurement Example: Entire surface of Boeing 737



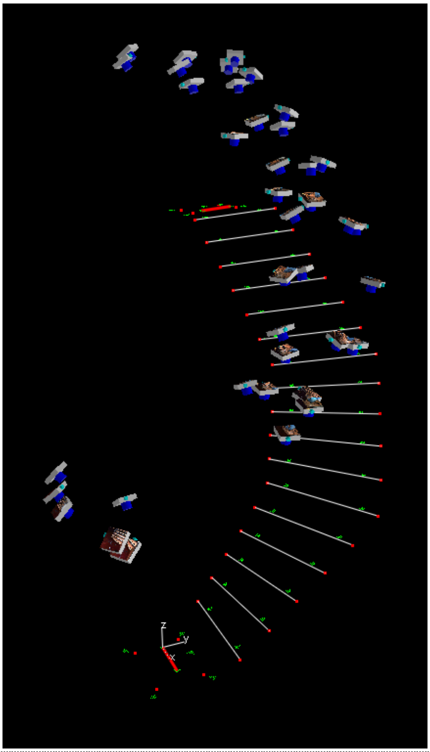
Automatic measurement of wind turbine tower flanges





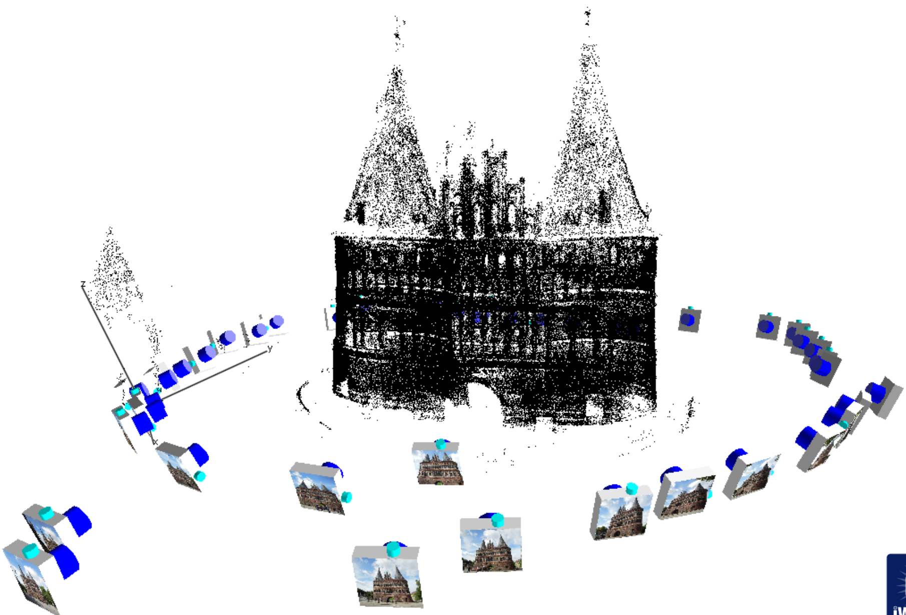


A 15 minute task for a 3D meas. accuracy of 0.015mm; no operator intervention beyond loading the images



Automated stairway measurement for stairlift design & manufacture

Targetless, Automated Image Orientation

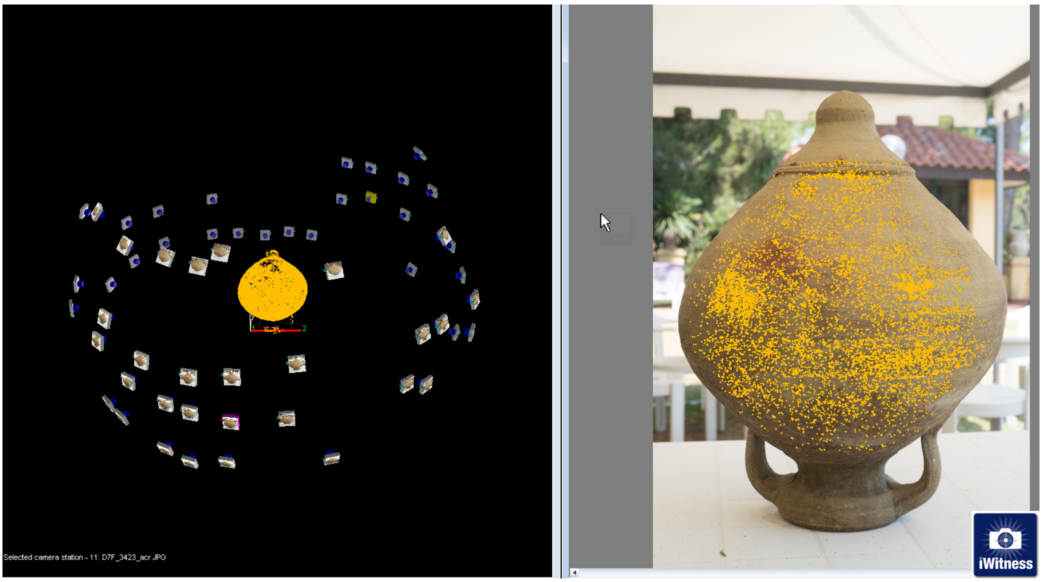


Holstentor, Luebeck: 43 image-network yielding 250,000 3D surface pts

Automated Object Reconstruction via Dense Matching

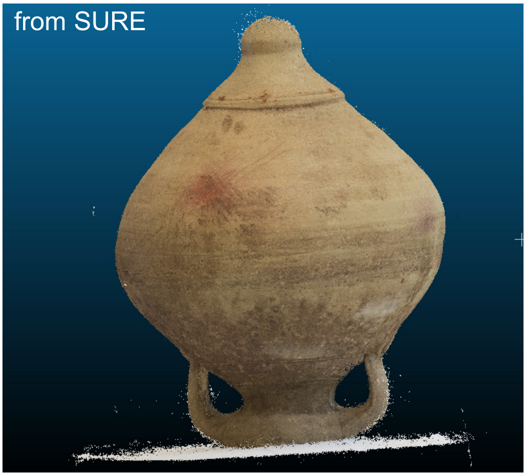
Approx. 55 million (visible) 3D points from dense image matching

Targetless Network Orientation via FBM: Amphora

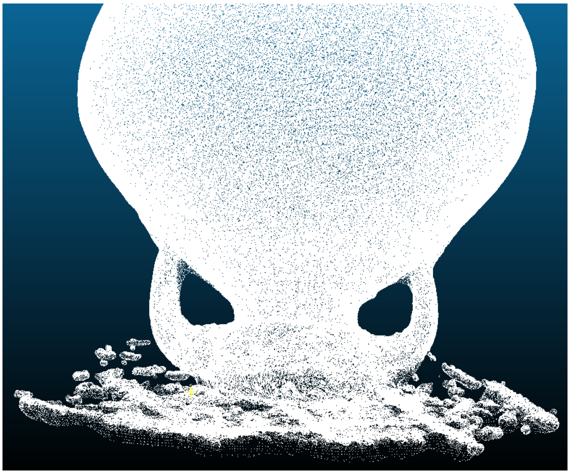


57 images, 90,000 pts ('sparse' p.c.), RMS vxy – 0.35 pixel

Targetless object reconstruction via dense matching: Amphora

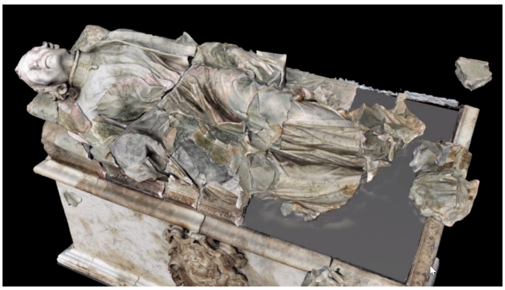


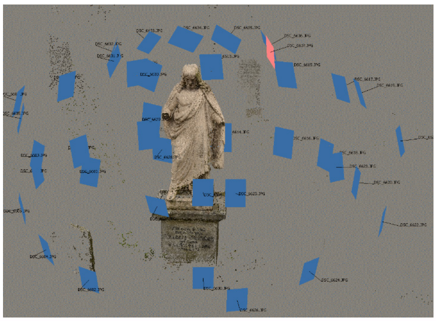
Dense point cloud from SGM (via SURE) comprising 116 million points



Triangulated mesh

Targtless object reconstruction via SfM & dense matching





Examples taken from Photoscan Showcase (http://www.agisoft.com/community/showcase)

What did photogrammetrists get out SfM developments?

- A powerful new approach to solving the image-point correspondence problem, albeit to a precision that could be 10 times poorer than when using targets (eg 0.3 pl versus 0.03 pl)
- Some new approaches to determination of initial values for non-linear photogrammetric orientation models (eg bundle adjustment), but these are not universally applicable
- Adoption of RANSAC-type approaches, eg for filtering of matches and initial value determination; ie the notion of using solution plausibility involving many point combinations rather than relying on high-quality control/constraints comprising a few points.
- And … the headaches of processing & interacting with dense point clouds (though not really a CV inspired issue!)

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Project Example: UAV *WitnessPRO* mapping, British Columbia

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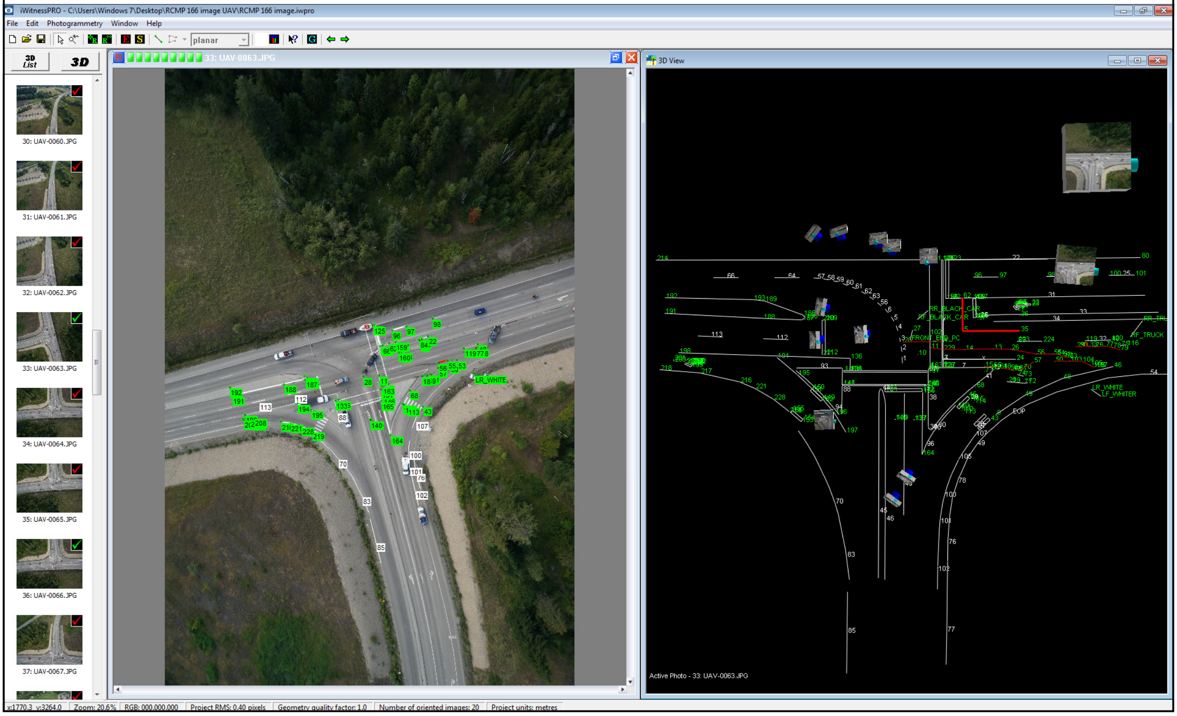
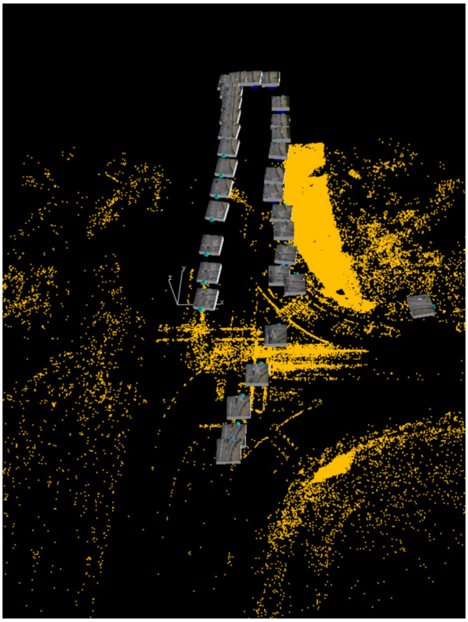
UAV *WitnessPRO* mapping, RCMP British Columbia



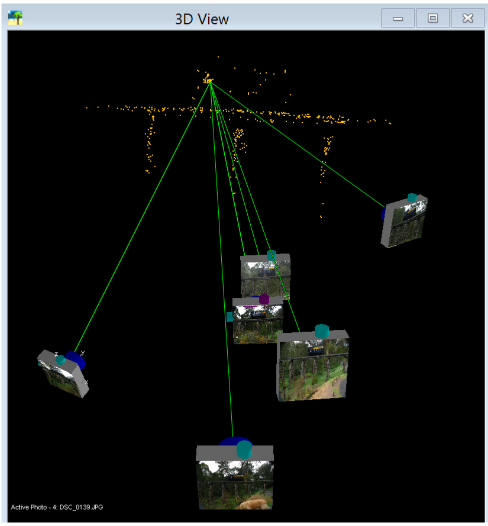
Prospects for presentation in court of annotated 3D photo-realistic models

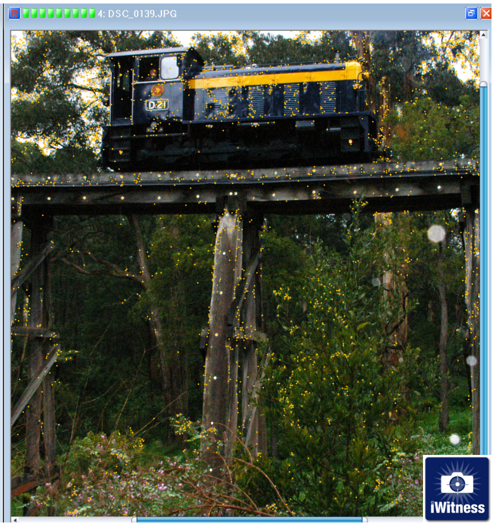
Prospects for post-orientation, 3D feature point extraction via monoplotting



- 3D Feature points from single images

FBM-based auto orientation can work OK … but beware! Case 1: Bridge Deformation Survey

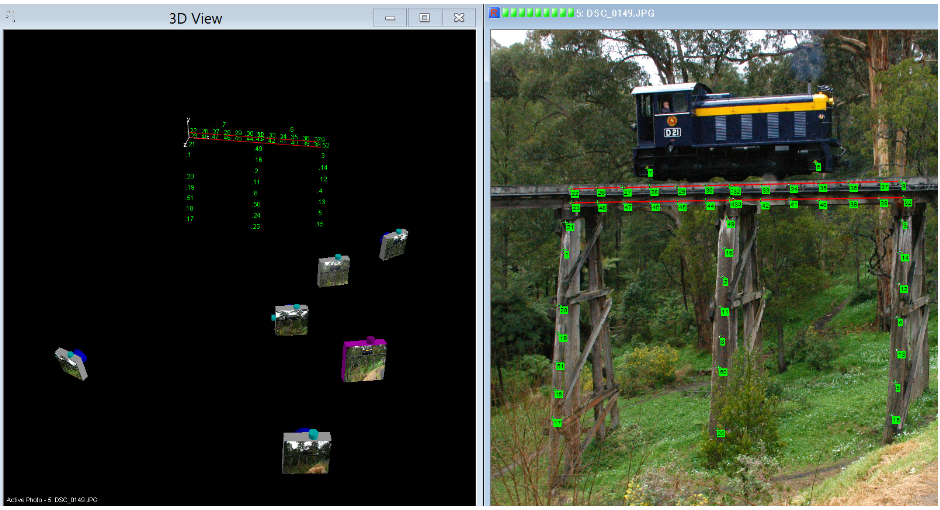




8 images, >400 pts, RMS vxy=0.31pl, Accuracy 1:1,600

Summary of results suggests reasonable network orientation

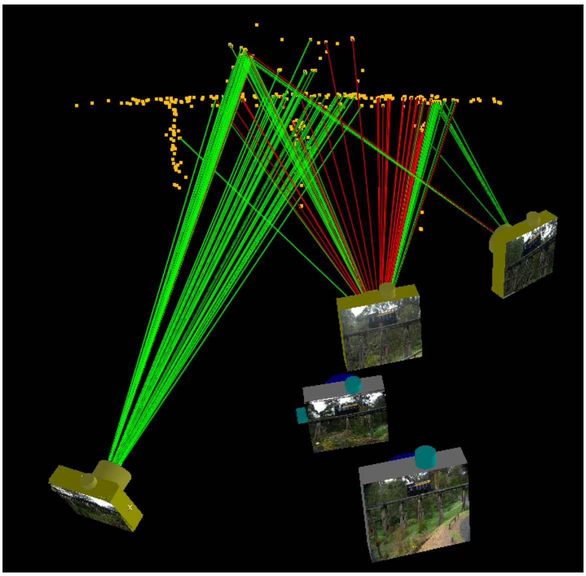
Target-based auto orientation: Bridge Deformation Survey



8 images, 52 pts, RMS vxy=3.2pl, Accuracy 1:800, all pts >5 rays

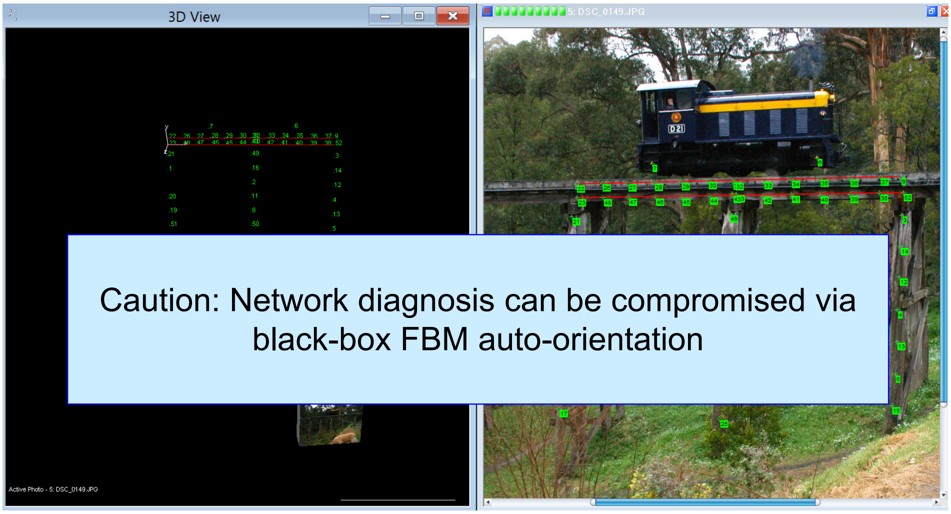
Solution via targets with >5-ray intersections suggests something is wrong!

FBM-based auto orientation: Network orientation problem



One image has excessive outliers & another has a limited number of points

Target-based auto orientation: Problem diagnosis

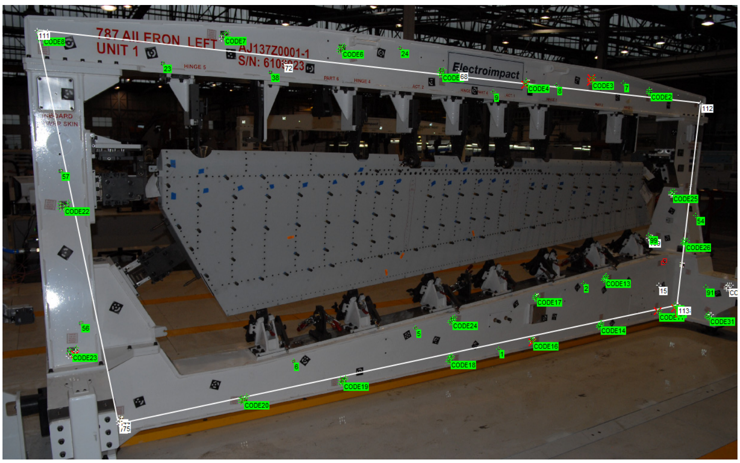


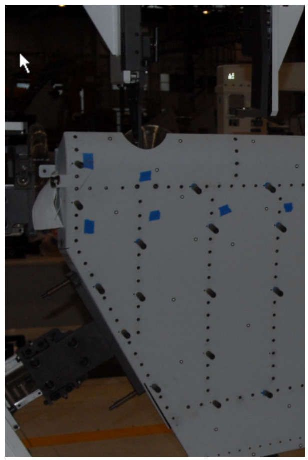
Caution: Network diagnosis can be compromised via black-box FBM auto-orientation

6 images, 52 pts, RMS vxy=0.18pl, Accuracy 1:7000, all pts >5 rays

Two images had the zoom setting changed from 18mm to 24mm

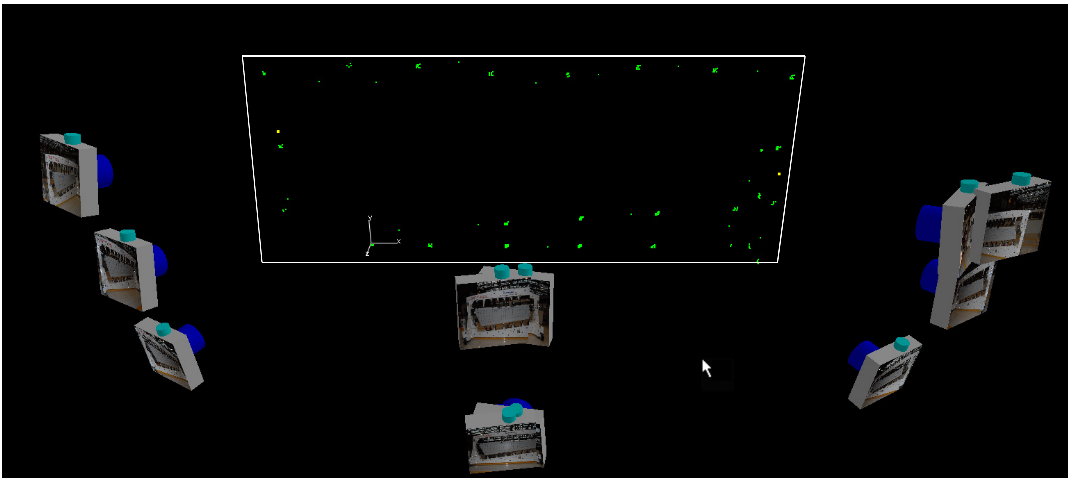
FBM-based auto orientation can work OK … but beware! Case 2: Aileron Tool





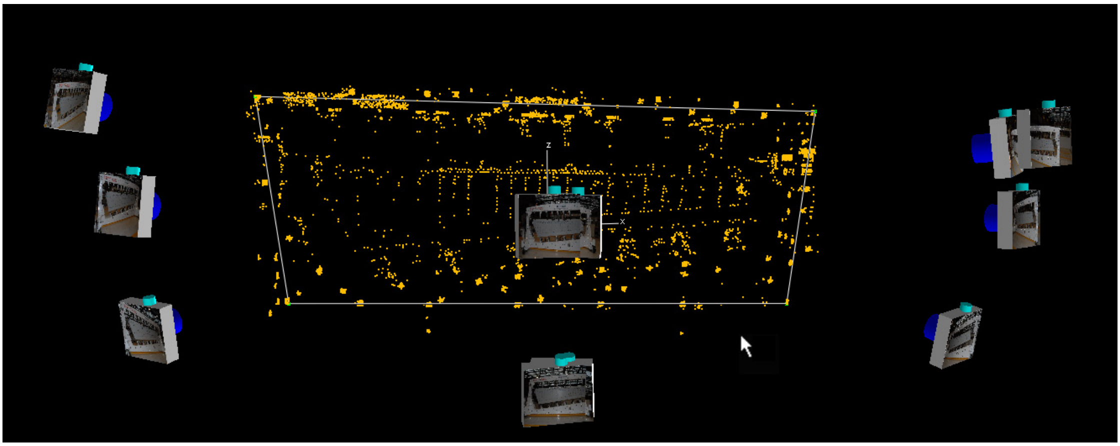
Dimensional inspection of an aircraft tool; required to measure tooling points and 'black holes'.

Case 2: Auto-orientation via coded targets



11 images, 200 pts, RMS vxy=0.09pl, Accuracy 1:70,000 (0.12mm), all pts >8 rays

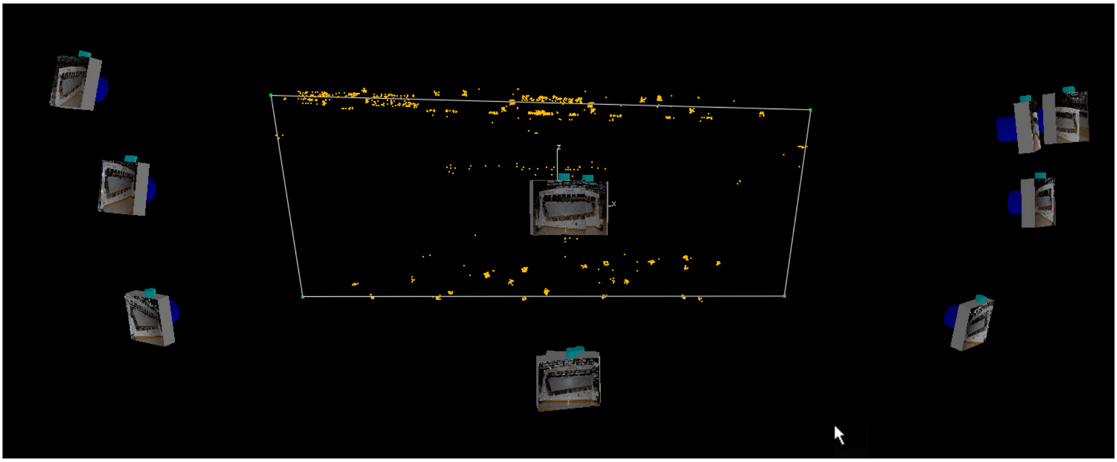
FBM-based auto orientation
Case 2: all successful matches triangulated



11 images, 5500 pts, RMS vxy=0.18pl, Accuracy 1:4,500 (1.7mm), incl. 2-ray pts

Sufficient texture variation, but too many like features and too many texture discontinuities. Descriptor-based feature matching yields more outliers than inliers

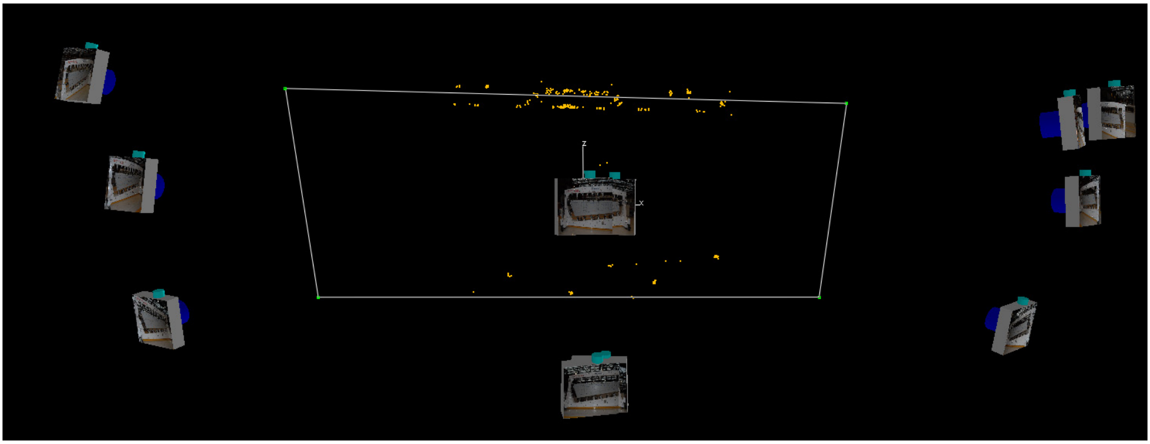
FBM-based auto orientation
Case 2: Only points with 4 or more rays



11 images, 1100 pts, RMS vxy=0.23pl, Accuracy 1:13,000 (0.56mm), >2-ray pts

Number of multi-ray points diminishes, as does distribution & thus geometric strength

FBM-based auto orientation
Case 2: Only points with 6 or more rays



11 images, 270 pts, RMS vxy=0.25pl, Accuracy 1:15,000 (0.48mm) >5-ray pts

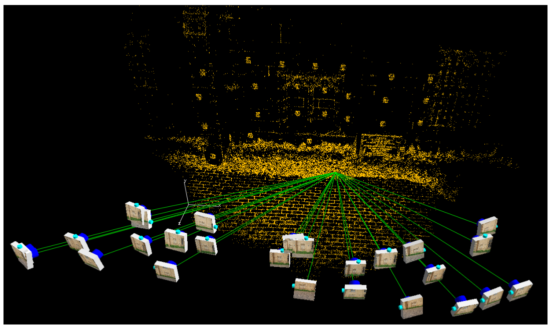
Geometric strength compromised through loss of multi-ray intersections

Automatic Camera Self-Calibration – with & without targets

11 million points via SGM; accuracy about 1:5000

Automatic Camera Calibration – with & without targets

Results of self-calibrations of the Nikon D200 camera for targeted and untargeted cases.

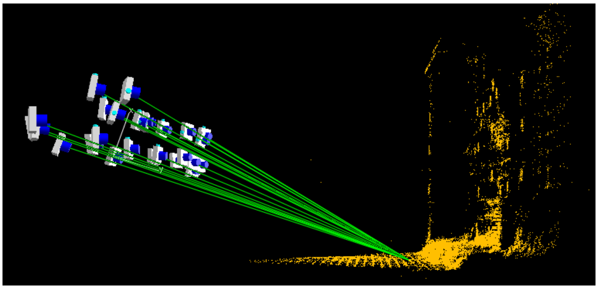


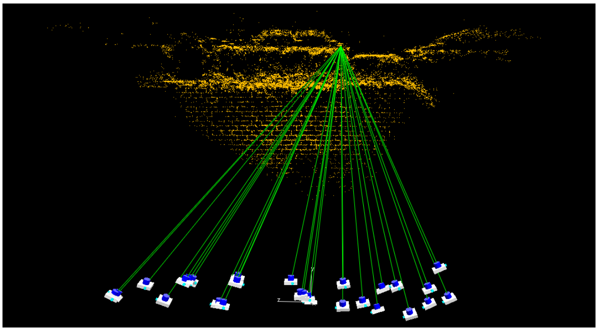
27 images, 25,000 feature points, 200 target points (25 codes)

	Focal length, c (σ_c) mm	x_p (σ_{xp}) mm	y_p (σ_{xp}) mm	Δr @ r=8mm µm	Δr @ r=10mm µm	Δr @ r=12.0mm µm	P(r) @ r=10mm µm	P(r) @ r=12mm µm	RMS v_{xy} No of points
Coded targets	17.632 (0.0010)	-0.038 (0.0007)	-0.193 (0.0007)	121.8	217.2	332.2	5.7	8.1	0.09 pl 200
Untargeted	17.627 (0.0008)	-0.036 (0.0005)	-0.193 (0.0005)	120.9	216.2	333.1	5.3	7.6	0.25pl 55,500

FBM-based Auto Camera Calibration – a useful tool

Results of self-calibrations of the Nikon D200 camera for untargeted case.

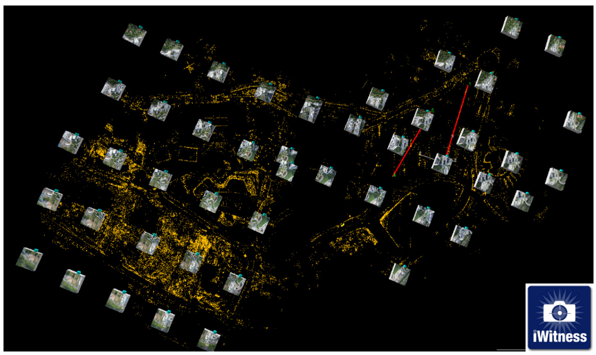




Feature-based matching was successful at both low incidence angle & up to 90^0 convergence angle

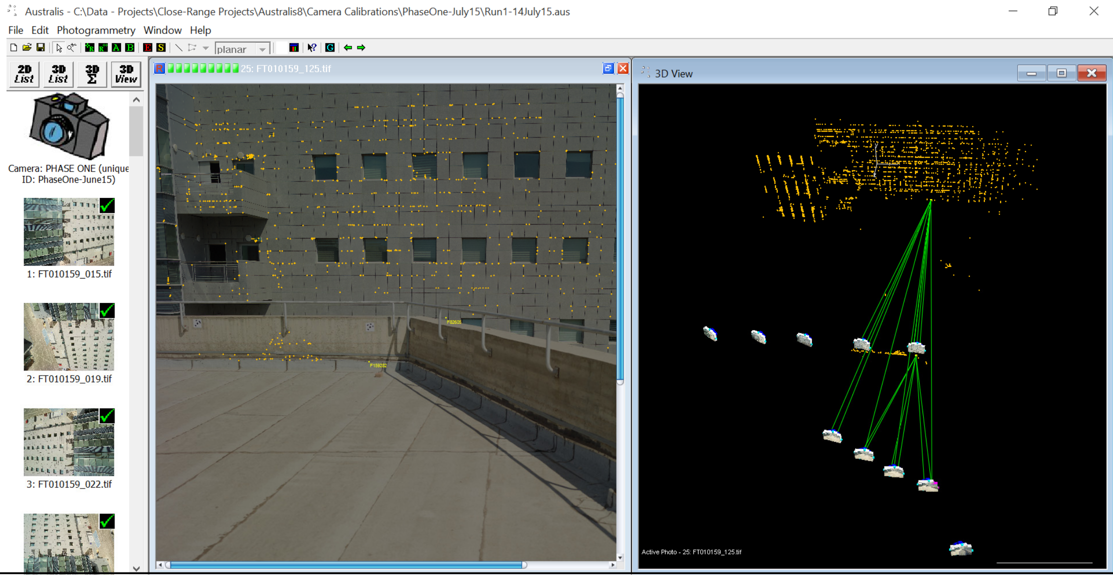
Prospects for in-field self-calibration

- Massive data redundancy afforded by FBM targetless orientation can mean that less stringent constraints need be applied to imaging geometry
- Example of 49-image, 41,000-point UAV network
- 18,000 points seen in >3 images; 6,000 pts seen in 6 or more images
- Feasible because Δh in object space approx. 60% of flying height H



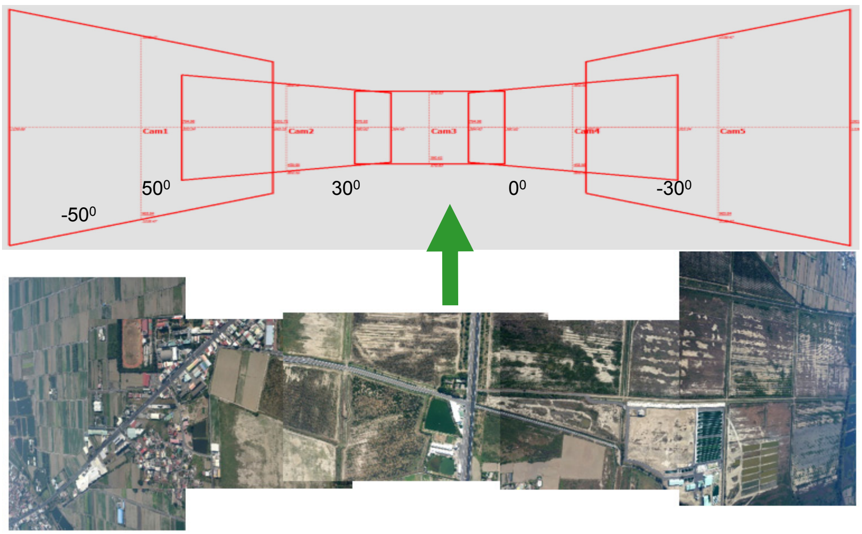
Prospects for ‘natural’ object point fields for self-calibration

- PhaseOne camera with 50mm lens
- 40-images, 3300 points (all with 6 or more rays), RMS vxy = 0.20 pixel
- Convergence could be relaxed because Δh in object space >50% of H
- Standard errors of 2 μm for c & <1 μm for xp,yp



In-field self-calibration – multiple cameras

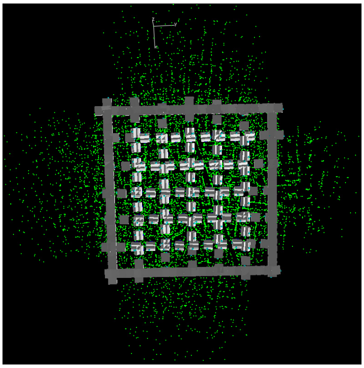
- 5 Sony Alpha 850s with 50mm lenses on a fixed-wing UAV
- Nadir & two oblique angles → 127^0 fov
- @ H = 800m, lateral coverage is 3200m

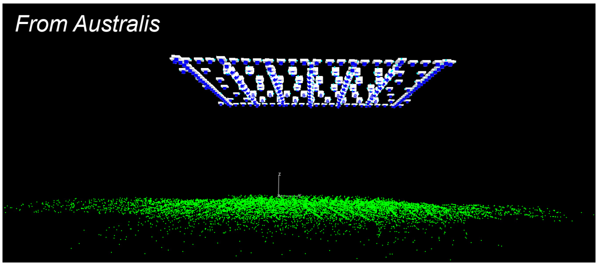


Project courtesy of Prof. J.Y.Rau, NKCU

In-field self-calibration – multiple cameras

- Block of 540 UAV images from 5 cameras; 10,900 points
- Self-Cal. Bundle Adjustment: RMS v_{xy} = 0.44pl, σ_{XY} = 0.08m, σ_Z = 0.11m
- All points seen in 4 or more images, 9200 in 6 or more & 390 in >20





- Question: What is the strength of recovery of camera calibration parameters in this multi-camera configuration over a near-planar object point array?

Project courtesy of Prof. J.Y.Rau, NKCU

Options for Orientation & 3D Object reconstruction

Initial Network Relative Orientation

(A) Manual to Semi-Automated Image Measurement

(B) Automatic, using coded targets

(C) Automatic with no targets (SfM approach)

Bundle adjustment (+self-calibration) for Refined Network Relative/Exterior Orientation

Bundle Adjustment

Subsequent Determination of 3D Points (generally with final Bundle Adjustment)

(A) Manual or se[mi-]automated referen[ce] measurement of ta[rgeted] or untargetted points

Real Question: What is actually needed from the photogrammetric survey?

(C) [Auto]matic generation of [den]se point cloud – no targets ([SfM] or FBM approach)

Final Remark

Choice for 3D object measurement/reconstruction via either sparse or dense surface matching & point cloud generation, or via targeted or manually measured feature points, will depend upon downstream priorities; some forms constitute final information products whereas others require subsequent data-to-information conversion

THANK YOU