COMPARISON OF LASER SCANNING, PHOTOGRAMMETRY AND SfM-MVS PIPELINE APPLIED IN STRUCTURES AND ARTIFICIAL SURFACES

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Structure of presentation

• Reason	why should we compare
• Methods	that we are going to compare
• Test cases	scenarios
• Analysis	of the tests
• Conclusions	

Rationale
Emerging technologies

Do you remember...

- when land measurements were tedious and photogrammetry was fast ?
- when laser scanning made photogrammetry obsolete ?
- when computer vision lead to SfM-MVS ?

Rationale
Bundler & CMVS-PMVS or SfM-MVS

- SIFT (Lowe, 1999) - Scale Invariant Feature Transform
- SURF (Bay et al., 2006) - Speeded Up Robust Feature
- SBA (Lourakis et al., 2009) - Sparse Bundle Adjustment
- Bundler (Snavely et al., 2006)
- CMVS & PMVS (Furukawa et al., 2009)
  - [Clustered & Patched] Multi View Stereo

Rationale
Bundler - CMVS & PMVS work flow

- Full automation up to scale
  - Ability to manage 1000's of photos
  - Use of uncalibrated cameras
  - Easy & fast acquisition – simple rules & convergent geometry
- Very dense, colour point cloud generation
  - Fully automated capture of 1000000's of points
  - Minimization of blunders (noise) in point clouds
  - Density & accuracy vary to distance – common to all IBM
- … BUT unknown accuracy (& precision)

Rationale
Laser Scanning vs SfM-MVS

- Both are fast in acquisition & processing time
- Provide huge datasets of colour point clouds
- Advantages & disadvantages are apparent on both

… so why don't we perform a direct comparison,

… while adding the traditional photogrammetry in between

… from the engineer's point of view

Methods & hardware
Terrestrial Laser Scanning

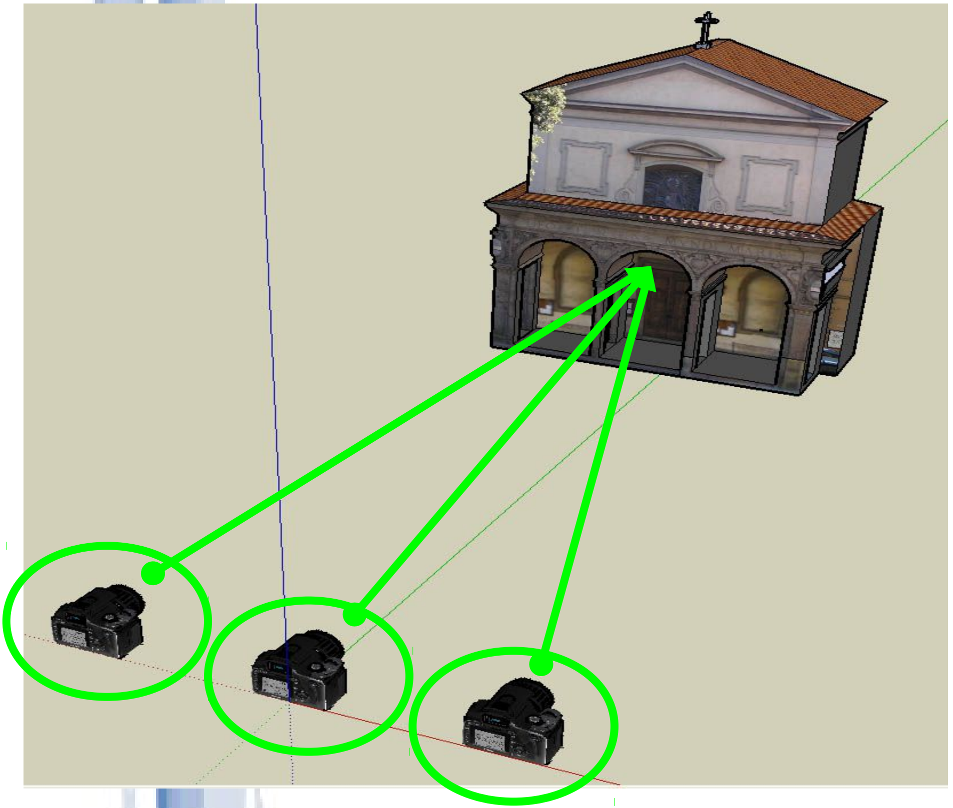
Leica ScanStation C10

Leica Geosystems

System Performance	
Accuracy of single measurement	
Position*	6 mm
Distance*	4 mm
Angle (horizontal/vertical)	60 µrad / 60 µrad (12" / 12")
Modeled surface precision/noise**	2 mm
Target acquisition***	2 mm std. deviation
Dual-axis compensator	Selectable on/off, resolution 1", dynamic range +/- 5', accuracy 1.5"

* At 1 m – 50 m range, one sigma
** Subject to modeling methodology for modeled surface
*** Algorithmic fit to planar HDS targets

Methods & hardware
Photogrammetry



- Zscan from MENCI
- Using triplets taken with parallel axis at known distances in between using a pre-calibrated bar (Triple stereo)
- Calibrated Nikon D90 with 24mm fixed focal
- May use control points and solve many triplets in a bundle (independent model) adjustment OR use bar distance to scale object

Methods & hardware

Photogrammetry

CAMERA-TO-OBJECT DISTANCE

BAR BASE

Accuracy table

Tabulated values of DEPTH ACCURACY are expressed in mm and are PURE THEORETICAL. Real values depend strongly on job conditions.

Baseline	100 mm	200 mm	300 mm	500 mm	750 mm	1000 mm	2000 mm	3000 mm	5000 mm	7500 mm	10000 mm
Baseline 20 mm	0.04	0.16	0.37								
Baseline 50 mm			0.15	0.41	0.92	1.64					
Baseline 100 mm				0.20	0.46	0.82	3.27				
Baseline 150 mm					0.31	0.55	2.18	4.91			
Baseline 200 mm						0.41	1.64	3.68			
Baseline 300 mm							1.09	2.46	6.82		
Baseline 400 mm							0.82	1.84	5.12	11.51	
Baseline 500 mm								1.47	4.09	9.21	16.37
Baseline 600 mm								1.23	3.41	7.67	13.64
Baseline 700 mm									2.92	6.58	11.69
Baseline 800 mm									2.56	5.76	10.23
Baseline 900 mm									2.27	5.12	9.10

OK

100 mm
0.04

16.37
13.64
11.69
10.23
9.10

Methods & hardware
SfM-MVS

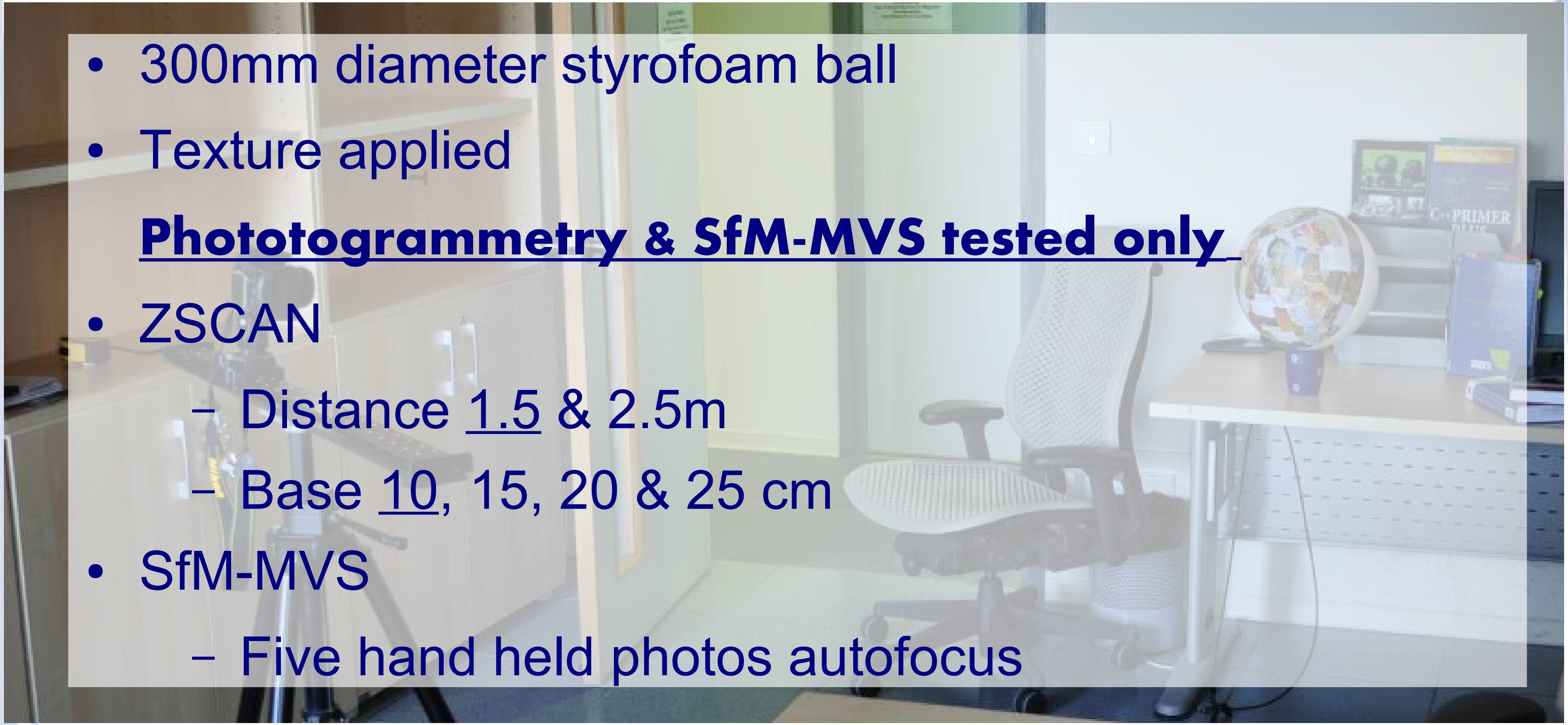
- Multiple un-calibrated hand held photos thought Bundler-CMVS & PMVS work flow
- Measure control points in point cloud
- Perform a scaled similarity transformation for global registration
  - If global registration not necessary, just scale model
- Black box - Difficult to amend or check process accuracy & precision

Test models / scenarios

- Artificial mathematical surface
- Simple facade
- Complex scene with a large 3D object


Sphere
Artificial surface as reference

0.4mm pixel size – accuracy {0.8mm}



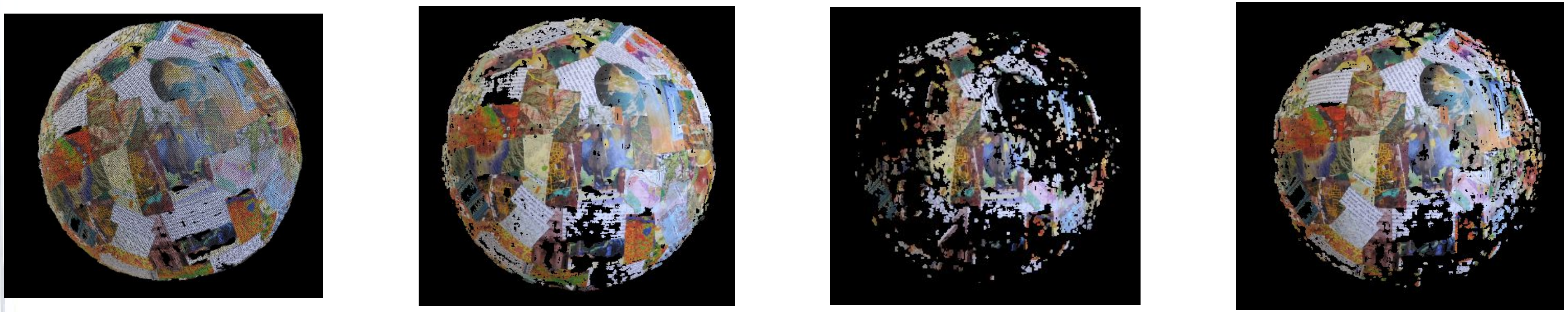
- 300mm diameter styrofoam ball
- Texture applied

Phototogrammetry & SfM-MVS tested only

- ZSCAN
  - Distance 1.5 & 2.5m
  - Base 10, 15, 20 & 25 cm
- SfM-MVS
  - Five hand held photos autofocus

Sphere
What was compared

- ZSCAN triplet with parallel axis @ 1.5m with 10cm base [ZS]
- Same triplet with SfM-MVS [PMVS3]
- Five hand held photos, convergent geometry, autofocus ON, @1.5m [PMVS5]



ZSCAN models @ 1.5m with 0.20, 0.30, 0.40, 0.50 m bases, respectively

Sphere
Precision assessment

Comparison against the best-fit sphere, diameter being calculated from point cloud

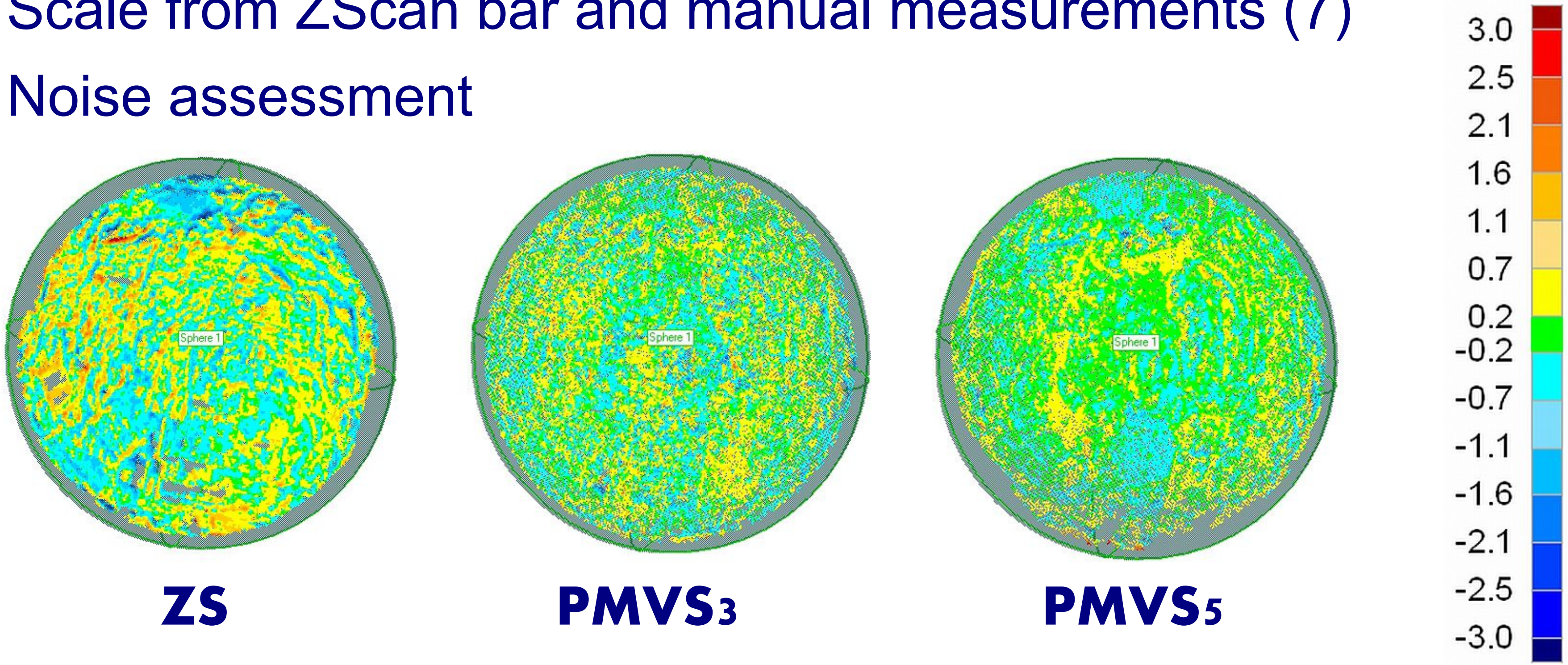
- Scale from ZScan bar and manual measurements (7)
- Noise assessment

	ZS	PMVS3	PMVS5
Diameter (mm)	301.599	301.789	302.544
# of points	35232	28747	28493
Max Distance (mm)	6.548	2.574	5.325
Mean Absolute Distance (mm)	0.456	0.275	0.175
STD Distance (mm)	0.600	0.375	0.262

Sphere
Precision assessment

Comparison against the best-fit sphere, diameter being calculated from point cloud

- Scale from ZScan bar and manual measurements (7)
- Noise assessment



Sphere
Accuracy assessment

Comparison against the 300mm diameter sphere

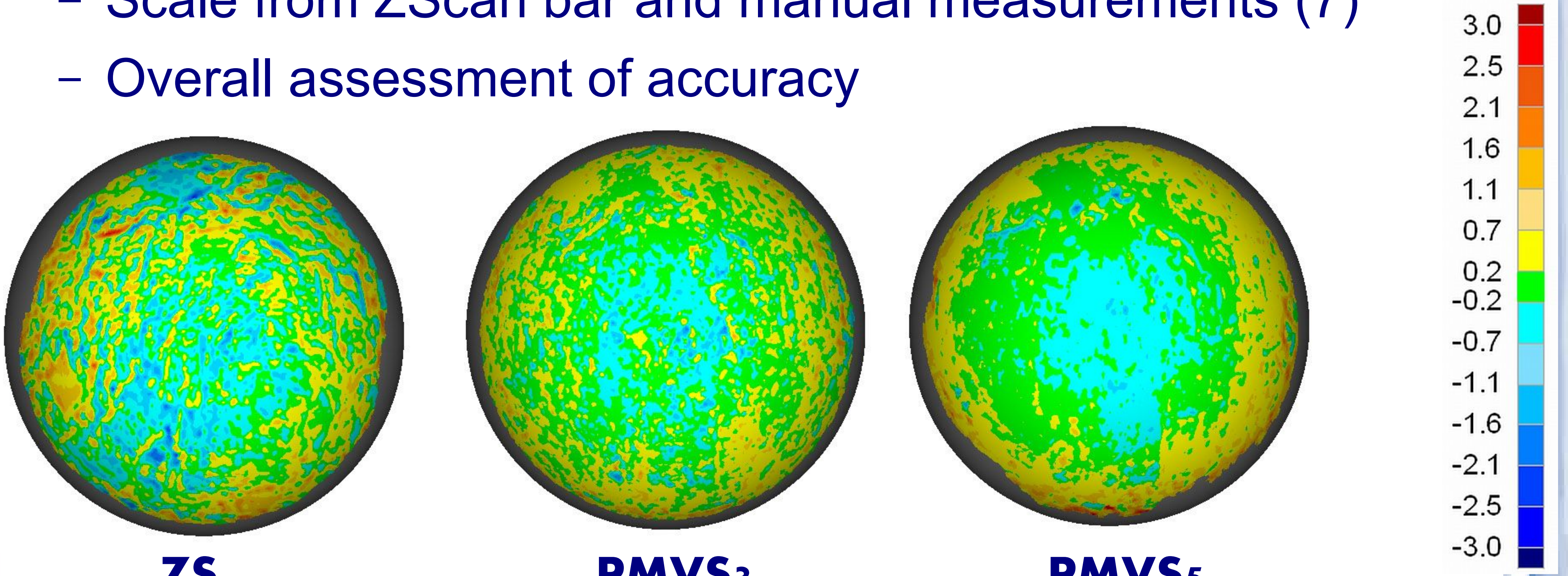
- Scale from ZScan bar and manual measurements (7)
- Overall assessment of accuracy

	ZS	PMVS3	PMVS5
Max distance (mm)	4.478	2.685	6.011
Mean Absolute Difference (mm)	0.477	0.323	0.284
Mean distance (mm)	0.026	0.058	0.053
RMS (mm)	0.645	0.610	0.384
Standard deviation (mm)	0.620	0.422	0.382
Accuracy (%) (<2σ or <1.6mm)	99.61	99.83	99.95
Completeness (%) on half sphere	58	68	67

Sphere
Accuracy assessment

Comparison against the 300mm diameter sphere

- Scale from ZScan bar and manual measurements (7)
- Overall assessment of accuracy



ZS **PMVS3** **PMVS5**

Facade
Object description

13.0 x 5.5 m
Narrow road: <5.0m object to photo distance

- Large homogeneous areas - unfavourable to IBM
- Flat object – difficult to recover focal length with self calibration
- TLS data from a single station, used as reference (~10.3 Mpoints), reduced to 4.3 Mpoints

Facade
Photography

Typical photo (4288x2848 pix)
At ~5m distance
Ground pixel size 1.1 mm

ZSCAN

- 13 triplets for ZSCAN

Hand held

- 39 vertical photos
- 36 oblique photos

… out of which 4 point clouds were created

Facade
Point clouds

- 13 triplets (39 photos) solved with ZSCAN using bundle adjustment **[ZS]**
- The aforementioned photos solved with SfM-MVS **[PMVStr]**
- 39 hand held photos solved with SfM-MVS **[PMVSvr]**
- The afore mentioned 39 photos with additional 36 oblique photos (75 in total) **[PMVSall]**

Facade
Comparison method

- PMVStr, PMVSvr & PMVSall models were scaled using 7 measured distances on the object
- All models were aligned with the TLS model using ICP
- Final analysis was done using commercial (point-to-surface) and in-house (point-to-point) software with similar results

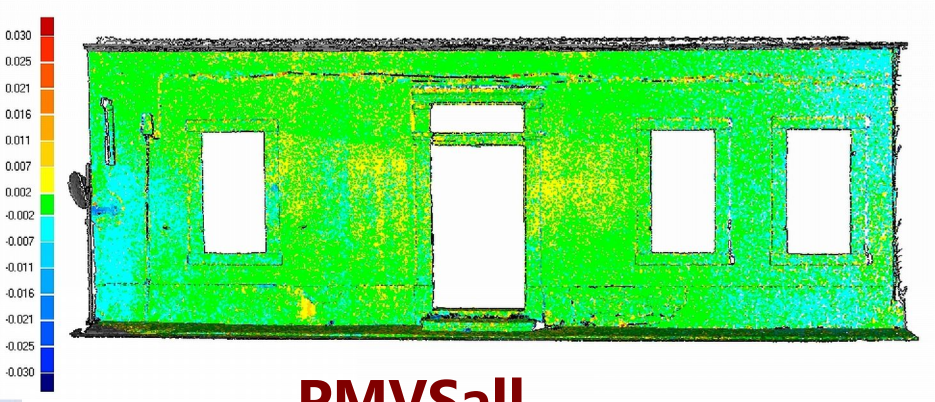
Facade
Analytic Comparison

	PMVSall	PMVSvr	PMVStr	ZS
# of points	3842824	2481292	3133604	1585216
Mean reprojection error [pix]	0.70	0.49	0.40	-
STD focal length [pix]	2.95	3.21	2.55	-
MAD (m)	0.0016	0.0015	0.0020	0.0078
Mean (m)	0.0001	0.0003	0.0001	0.0005
STD (m)	0.0026	0.0023	0.0031	0.0100

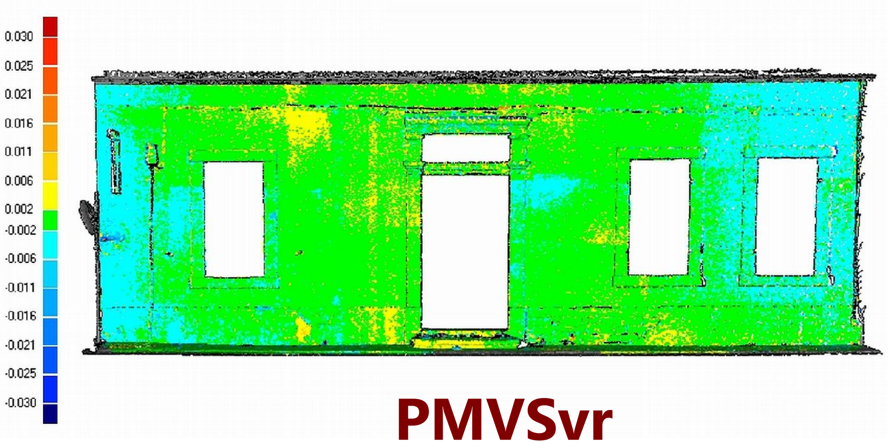
- ZSCAN {accuracy} @6.0m with 0.6m base is **3.41mm**
- STDs of SfM-MVS is comparable to TLS data, if not better

System Performance	
Accuracy of single measurement	
Position*	6 mm
Distance*	4 mm
Angle (horizontal/vertical)	60 µrad / 60 µ
Modeled surface precision/noise**	2 mm
Target acquisition***	2 mm std. dev
Dual-axis compensator	Selectable on/ accuracy 1.5"

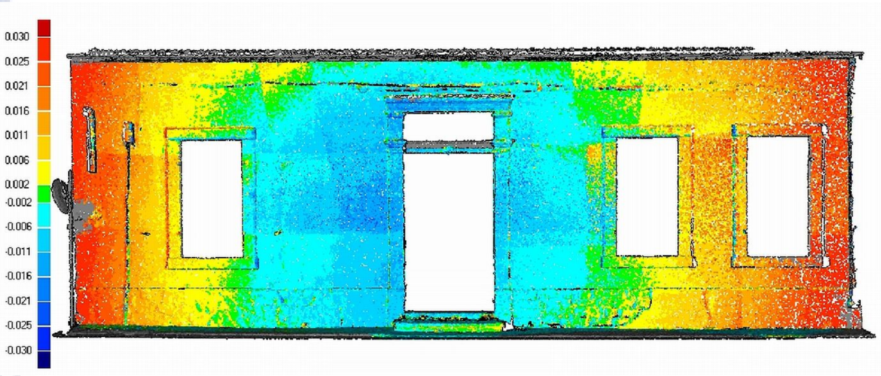
Facade
Visual Comparison



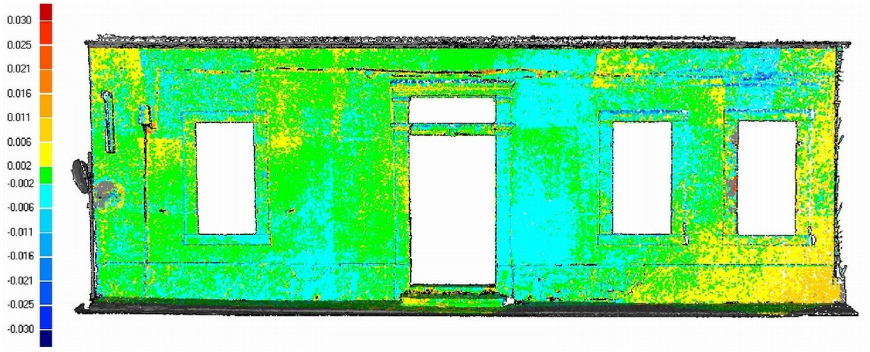
PMVSall



PMVSvr



ZS



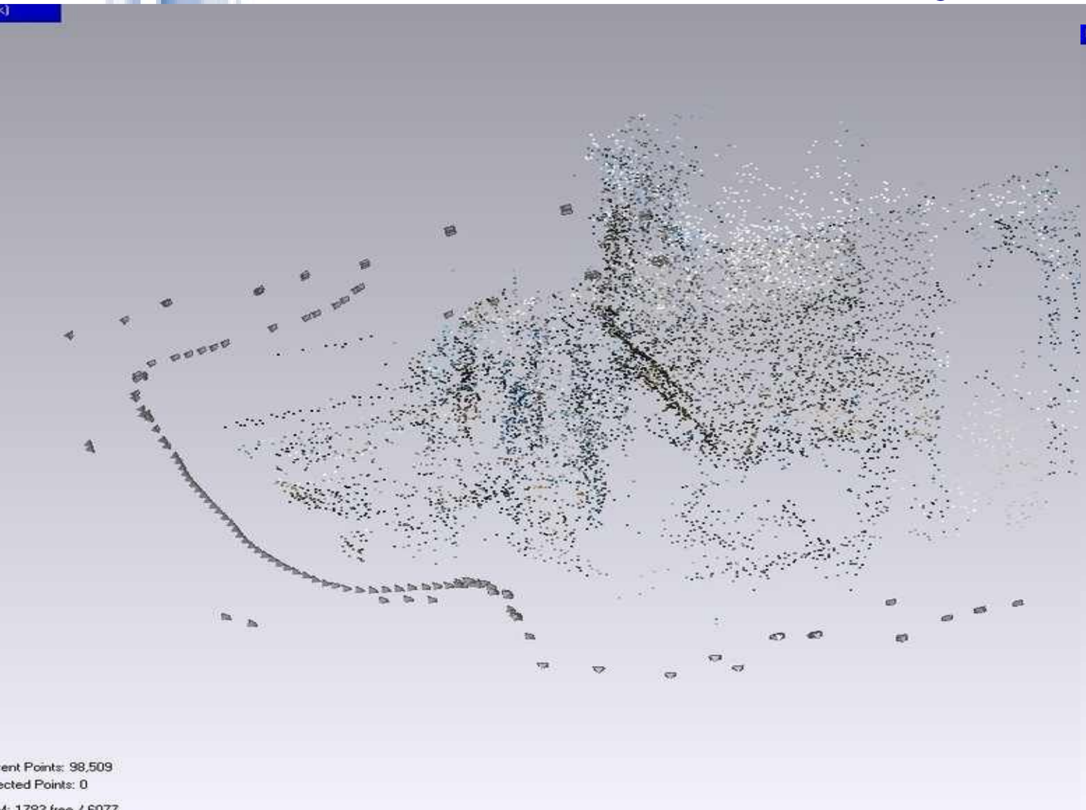
PMVStr

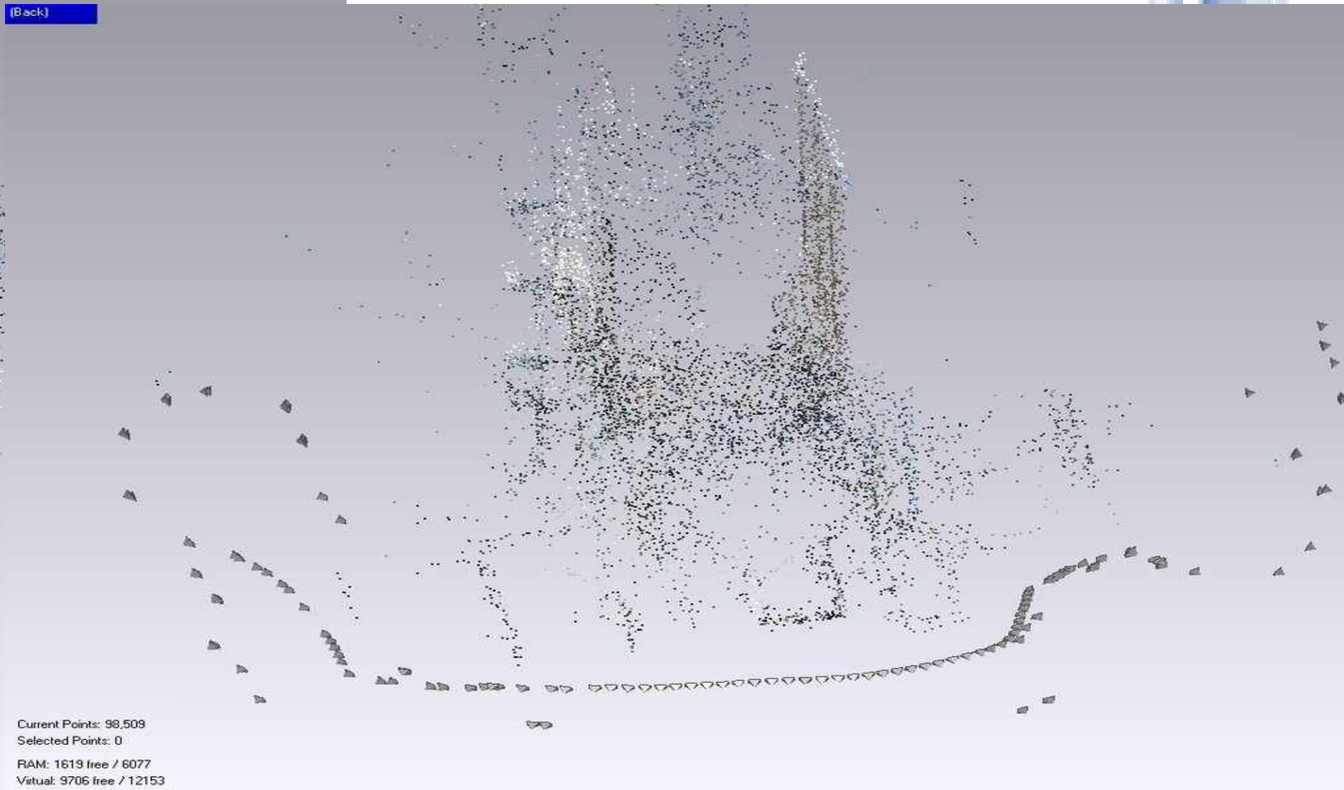
Complex Scene
EAC's facilities after explosion

- Metal constructions, of high complexity
- Distance ~ 17-35m
- Height 26m
- TLS vs SfM-MVS, due to fast acquisition
- Variable illumination conditions at each side of the object - camera set to auto

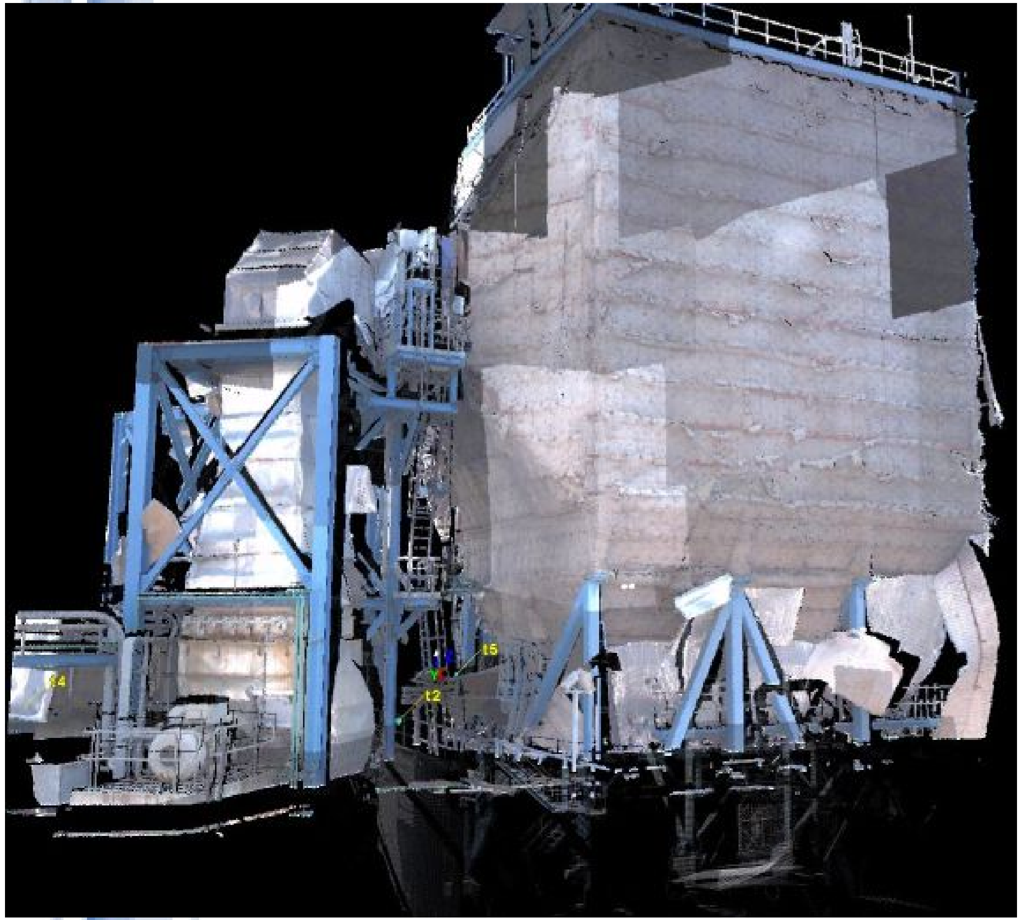
Complex Scene
Photography

- Selected positions & 3 sec auto acquisition while moving
- Auto focus ON, Sony a320 20-80mm zoom lens





Complex Scene
Qualitative assessment only



Conclusions & Discussion

- Accuracy of SfM-MVS methods is better to 'traditional' photogrammetry
- TLS & SfM-MVS accuracy comparable in facade
- TLS is better in complex scenes (simplicity, noise)
- Versatility of IBM allows accommodation of smaller objects with higher accuracy
- IBMs are still slower to final result, but cheaper
- IBMs have better colour/texture quality

… so it depends on the application, people & hardware available

… while the combination is always an option

Thank you for your attention

www.photogrammetric-vision.weebly.com