A Toolset for Automating 1mm Measurement Accuracy in Photogrammetry Surveys

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Key words: Bridge surveying, Photogrammetry

SUMMARY

The implementation of calibrated photogrammetry tags produced with optimal surface materials enables very precise engineering surveys (down to 1mm relative measurement accuracy) of water management infrastructure. Such photogrammetry tags create automatically detected control points within the model space that also provide the basis for very precise measurement control.

Each unique tag is coded within the photogrammetry software completely automating the typical manual work of adding control points, merging projects, and merging different datasets of the same project. The nuance presented here is using the coded tags around the surveyed object as the measurement system. Producing the tags with an optimized surface material enables the surveyor to mimic measurement standard conditions (lab conditions) in the field to systematically achieve sub-cm measurement accuracy.

The recipe for success for implementing this coded tag based measurement system as well as case studies of 3D surveys with 1mm measurement accuracy of stone infrastructure using Unmanned Aerial Vehicles (UAVs) and handheld cameras are presented here. The key elements to take into account for successful implementation of such surveys are the following:

1: Know your camera
2: Trust your measurement
3: Control your space
4: Understand your photogrammetry software

The correct implementation of photogrammetry tags with consumer grade measurement devices and consumer grade UAVs and cameras enables very precise and very fast photogrammetry based 3D models at a much lower cost compared to laser scanners and total stations.

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1. INTRODUCTION

The advent of consumer grade Unmanned Aerial Vehicles (UAVs) and multicopters weighing less than 2 kg has created a surge in new technologies specifically for surveying and inspection. In particular, photogrammetry has achieved a wide spread market and is now considered a standard survey and inspection tool within these industries' overall toolset. Here, we present a toolset consisting of consumer grade equipment to systematically automate precision photogrammertry workflows.

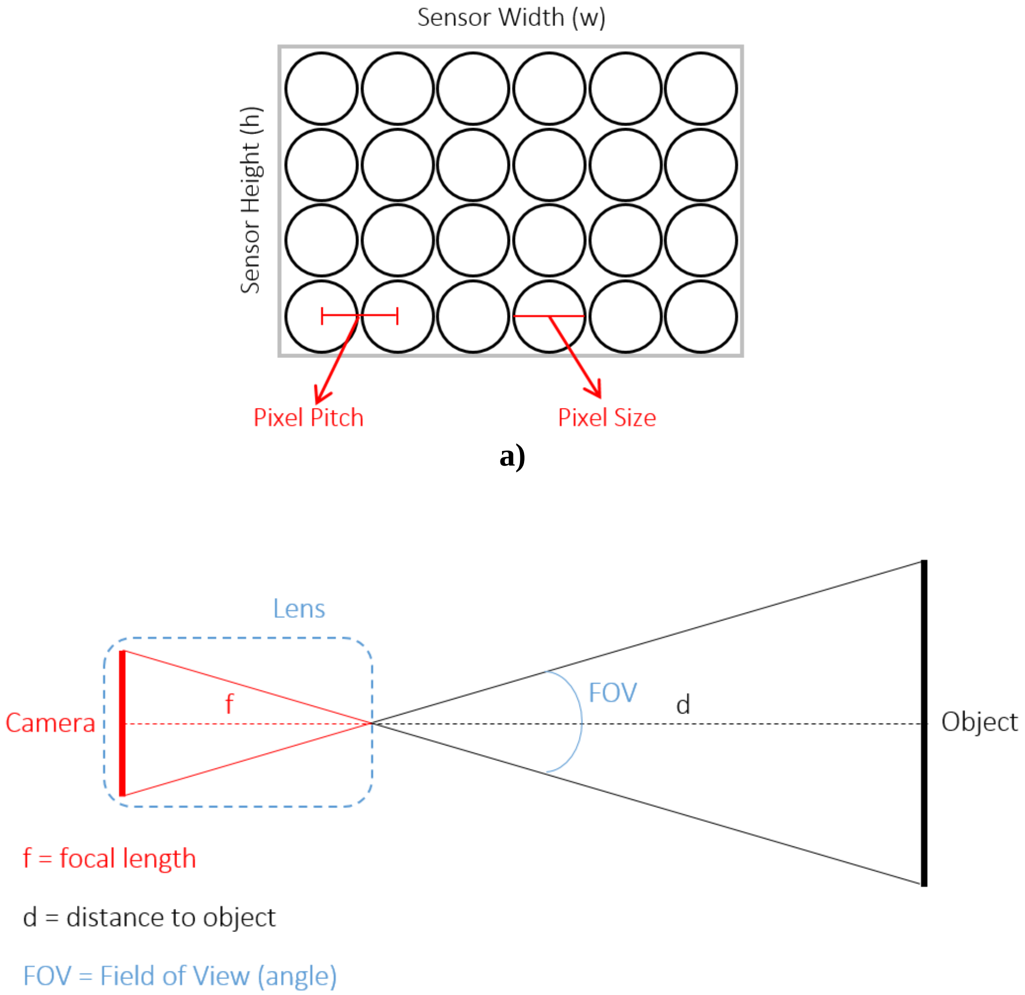
The four main aspects that one must consider in order to obtain down to 1mm accurate measurement photogrammetry models are listed here and will be described more in depth within this paper:

1: Know your camera
2: Trust your measurement
3: Control your space
4: Understand how your photogrammetry software works

The two most commonly reported metrics in a calibrated photogrammetry surveys are pixel resolution (most commonly referred to as Ground Sampling Distance (GSD)), which determines the overall visual accuracy of the model, and the measurement accuracy, which can be presented in several ways. Even though the GSD has an effect on determining the baseline for measurement accuracy, GSD and measurement accuracy are controlled and determined completely independent of one another. The GSD is determined by the visual properties relating to the camera, distance from object, and focal length. Measurement accuracy is determined by the measurement system used within the model space.

2. KNOW YOUR CAMERA

The main input for photogrammetry based surveys and inspections are images. In this case, we are presenting results based on standard RGB imagery from consumer cameras. The camera's physical properties as well as the image distance from the model object are the key factors in calculating the GSD. In Figure 1, the key parameters for the GSD calculation are defined.



a)

b)

Figure 1: The camera’s physical properties used for calculating GSD.

With these parameters defined, it is possible to now calculate a camera system's GSD with the common formula below:

$$GSD_w = \frac{d \times SensorWidth}{f \times ImageWidth}$$

$$GSD_h = \frac{d \times SensorHeight}{f \times ImageHeight}$$

In common practice, one then selects the higher of the two values for determining the GSD. In this project, a consumer grade **Sony a5000** camera with an APS-C sensor was used with a 10 mm lens. This camera system's corresponding properties for photogrammetry applications are listed here:

Image Width:	5466 px
Image Height:	3632 px
Sensor Width:	23.5 mm
Sensor Height:	15.6 mm
Focal Length:	10 mm

Using the calculations from above, we can calculate that a maximum distance of **2.33 m** from the model object is necessary in order to maintain a GSD of **1 mm**.

3. TRUST YOUR MEASUREMENT

It can be very challenging for human beings to verify measurements in the real world, especially as the measurements get smaller across larger spaces. For this reason, we rely on certified equipment such as laser distance measurement tools, Total Stations, and laser scanners to precisely measure the world around us. Even though such devices are certified for accuracy, it is still the responsibility of the user to maintain the boundary conditions necessary to provide best accuracy while applying the proper techniques in the field.

For this work, we used a Leica Disto 810 for measuring at 1 mm accuracy.

- when it has to be right

Leica Geosystems

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Calibration Certificate Silver

Calibration Certificate Silver with measurement values issued by Manufacturer

LCA766669b

Product	LEICA DISTO D810 touch (US)	**Serial No. / Certificate no.**	5034240425
Article No.	799097	**Inspection Date**	2013-10-23

Compliance

The Calibration Certificate Silver with measurement values issued by Manufacturer corresponds to the Producer Inspection Certificate M in accordance with DIN 55 350 Part 18-4.2.2.

Certificate

We hereby certify that the product described has been tested with the following result:

☒ **Compliance**	The test results are within the specification of the product.
☐ Non-Compliance	The test results are not within the specification of the product.

The test equipment used is traceable to national standards or to recognized procedures.
This is established by our Quality Management System, audited and certified to ISO 9001 by an independent national accreditation authority.

Test Equipment

Distance	Leica ADM 1442
Inclination	Leica NIVEL210, WEISS 150 HAT

Test results

	Distance			
Reference value (m)	0.0564	0.7837	2.3636	7.8475
Calibration value* (m)	0.0561	0.7835	2.3633	7.8480
Deviation (mm)	-0.3	-0.2	-0.3	0.5

* with statistical confidence level of ± 2 sigma; temperature of 23°C (± 3°C); target plate albedo 1

	Inclination			
Reference value (°)	-45.000	0.000	45.000	90.000
Calibration value* (°)	-45.007	0.000	45.045	90.035
Deviation (°)	-0.007	0.000	0.045	0.035

* with statistical confidence level of ± 2 sigma; temperature of 23°C (± 3°C)

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Figure 2: Calibration certificate for a Leica Disto 810

The Calibration Certificate of Figure 2 shows that a "target plate albedo 1" was used to calibrate the device. This now becomes the baseline for providing a measurement system around our model object. By creating diffuse reflective surfaces for targeting our DISTO device, we can achieve optimal surface conditions for precise measurements.

4. AUTOMATED TAGGING

An important practice when performing precision photogrammetry is the use of coded targets (also known as tags or markers) that can be automatically registered in the photogrammetry software. Figure 3 shows an example of Chilitags[1] as they are automatically detected and registered within the photogrammetry software. Coded targets are commonly used for automating the photogrammetry workflow and provide the following benefits: automatically generate tie points, automatically locate Ground Control Points, reduce time for manual processing steps, and seamlessly merge sub-projects.

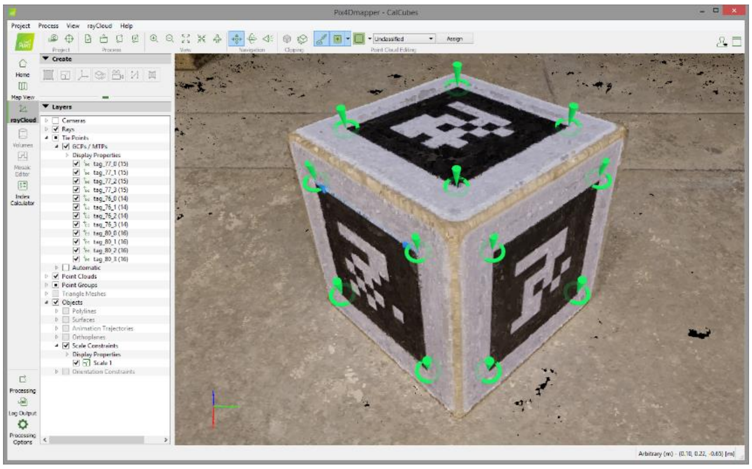


Figure 3: Automatically detected coded targets within the Pix4D[2] software.

This concept is not new, but the nuance presented here is using the coded tags around the surveyed object as the measurement system. Producing the tags with an optimized surface material enables the surveyor to mimic measurement standard conditions (lab conditions) in the field to systematically achieve sub-cm measurement accuracy. The combination of precisely locating the coded targets' corners while using an optimized surface material for precise measurements with the DISTO device enables 1 mm measurement precision for terrestrial photogrammetry projects.

5. CONTROL YOUR SPACE

The idea of ”controlling your space” is that much of the infrastructure being modelled with photogrammetry is not optimal for pulling precise measurements due to surfaces materials, shapes, or inaccessibility. By implementing coded targets printed on diffuse reflective surfaces around the infrastructure to be scanned, we create predictable points for pulling precise measurements independent of the conditions of the model space. Figure 4 shows an example of 4 cubes being placed around a stone bridge creating a precise measurement system within the model space. The points used for measurements are then automatically recognized within the photogrammetry software for model calibration.

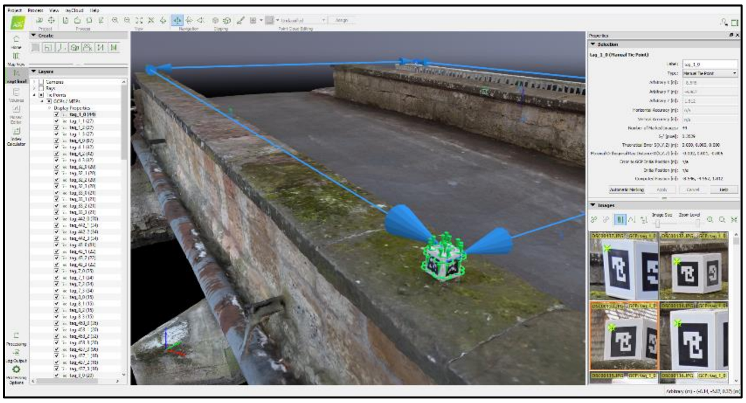


Figure 4: Use of coded targets on aluminum cubes to create a predictable measurement space around the model object.

6. FIELD RESULTS

6.1 Stone Wall

A photogrammetry model of the stone wall in Figure 5 was contracted with the goal of finding the combiner stones that provide the mechanical stabilisation of such a wall. These stones are single stones that traverse both sides of the stone preventing wall collapse over time. In order, to locate these stones, it was necessary to first, create a 1 mm accurate survey model of the structure and second, create calibrated, mirrored orthophotos of the two sides for a precise overlay of both sides of the wall in order to ”see through” the wall and determine which stones traverse the entire structure.

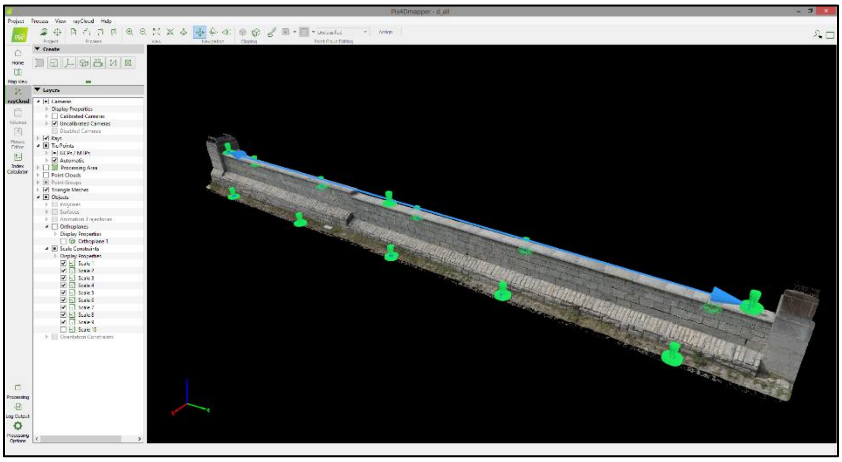
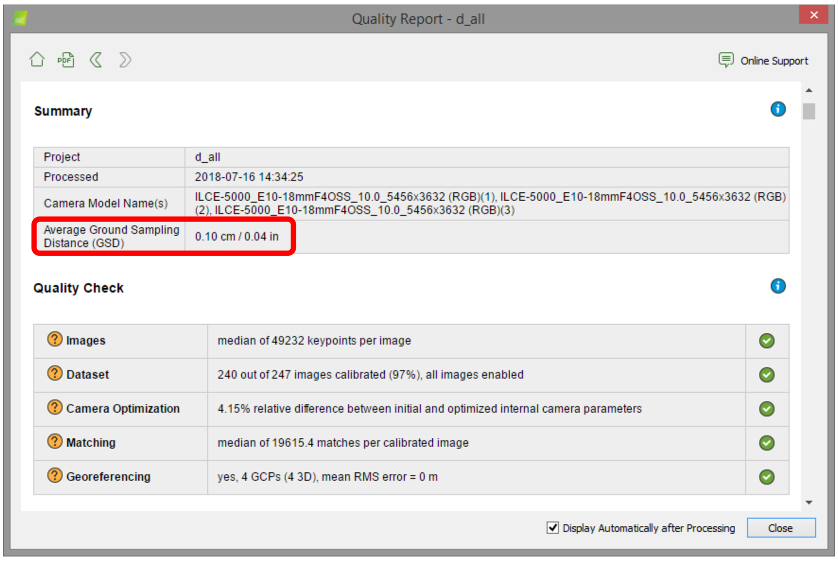


Figure 5: Final mesh of the stone wall within Pix4D. Note the control points in green, which were automatically detected in the software, and the scale constraint across the top of the wall.

Figures 6 and 7 show the GSD and measurements results of the photogrammetry model, where a GSD of **1 mm** was achieved and a measurement accuracy sigma of **0.6 mm** over 27.160 m.



Summary

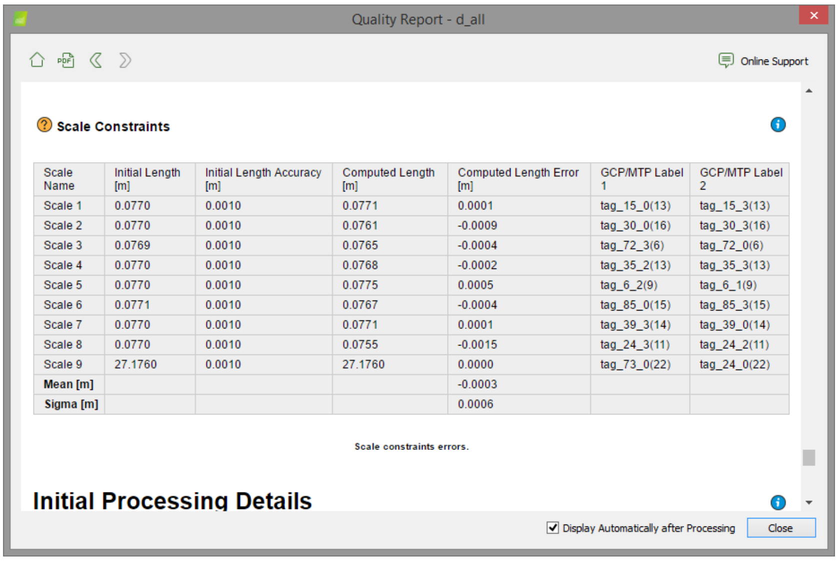
Project	d_all
Processed	2018-07-16 14:34:25
Camera Model Name(s)	ILCE-5000_E10-18mmF4OSS_10.0_5456x3632 (RGB)(1), ILCE-5000_E10-18mmF4OSS_10.0_5456x3632 (RGB)(2), ILCE-5000_E10-18mmF4OSS_10.0_5456x3632 (RGB)(3)
Average Ground Sampling Distance (GSD)	0.10 cm / 0.04 in

Quality Check

Images	median of 49232 keypoints per image	✓
Dataset	240 out of 247 images calibrated (97%), all images enabled	✓
Camera Optimization	4.15% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 19615.4 matches per calibrated image	✓
Georeferencing	yes, 4 GCPs (4 3D), mean RMS error = 0 m	✓

☑ Display Automatically after Processing

Figure 6: Quality Report of the photogrammetry model.



Scale Constraints

Scale Name	Initial Length [m]	Initial Length Accuracy [m]	Computed Length [m]	Computed Length Error [m]	GCP/MTP Label 1	GCP/MTP Label 2
Scale 1	0.0770	0.0010	0.0771	0.0001	tag_15_0(13)	tag_15_3(13)
Scale 2	0.0770	0.0010	0.0761	-0.0009	tag_30_0(16)	tag_30_3(16)
Scale 3	0.0769	0.0010	0.0765	-0.0004	tag_72_3(6)	tag_72_0(6)
Scale 4	0.0770	0.0010	0.0768	-0.0002	tag_35_2(13)	tag_35_3(13)
Scale 5	0.0770	0.0010	0.0775	0.0005	tag_6_2(9)	tag_6_1(9)
Scale 6	0.0771	0.0010	0.0767	-0.0004	tag_85_0(15)	tag_85_3(15)
Scale 7	0.0770	0.0010	0.0771	0.0001	tag_39_3(14)	tag_39_0(14)
Scale 8	0.0770	0.0010	0.0755	-0.0015	tag_24_3(11)	tag_24_2(11)
Scale 9	27.1760	0.0010	27.1760	0.0000	tag_73_0(22)	tag_24_0(22)
Mean [m]				-0.0003		
Sigma [m]				0.0006		

Scale constraints errors.

Initial Processing Details

Figure 7: Quality Report of the photogrammetry model showing the errors of the compiled length measurements and scale constraints.

6.2 Stone Bridge

A photogrammetry survey of the stone bridge in Figure 8 as part of a renovation project. The following results were achieved: GSD = **1.3 mm** ; Measurement accuracy = **±1 mm**.

Figure 8: Final mesh of a stone bridge

6.3 Dam Inspection

A photogrammetry survey of the dam in Figure 9 as part of a renovation project. The following results were achieved: GSD = 1.7 mm ; Measurement accuracy = ±1.2 mm.

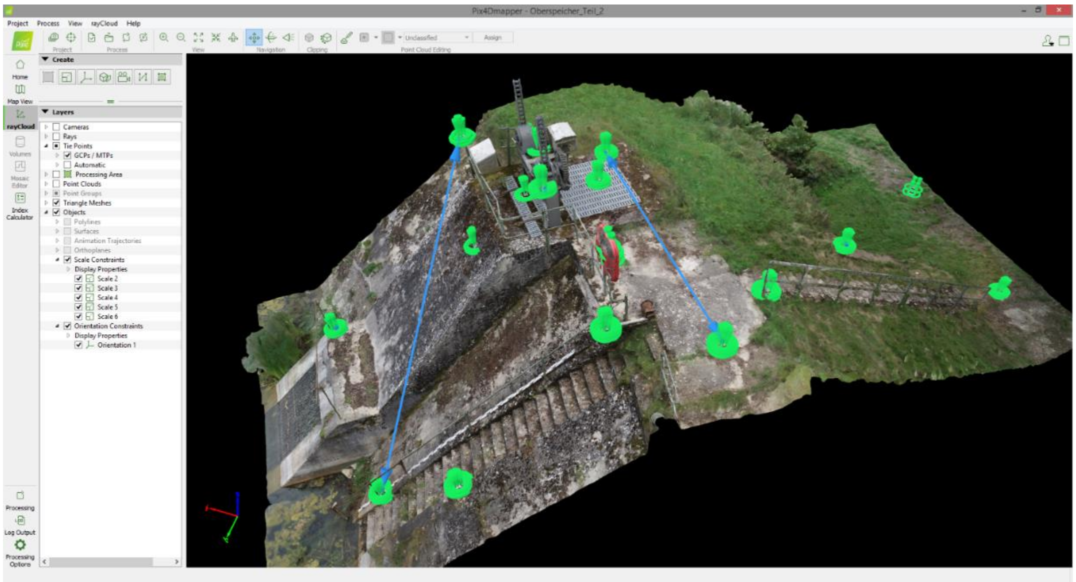


Figure 9: Photogrammetry model of a dam within Pix4D. All green control points were automatically detected using coded targets.

REFERENCES

[1] Chilitags: Robust Fiducial Markers for Augmented Reality. Q. Bonnard, S. Lemaignan, G. Zufferey, A. Mazzei, S. Cuendet, N. Li, P. Dillenbourg. CHILI, EPFL, Switzerland. http://chili.epfl.ch/software. 2013.

[2] www.pix4d.com

BIOGRAPHICAL NOTES

Dr. Ken Varner has a background in semiconductor measurement physics and has spent the last several years applying photogrammetry as a precision measurement tool in the built environment. With several patents in the aerial inspection space, Ken's focus is on automated precision of aerial inspection workflows.

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