About the Level of Minimum Signal/Background Ratio in PSI Surface Reconstruction

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Introduction

This document gives some results of the impact of noise and interference contrast to the PSI surface reconstruction. The impact of noise to the face reconstruction will be added in the next version of the document.

Only two mentioned factors (noise and interference contrast) were taken into consideration. Because many other factors influence the measurement, all numbers given in this document should be considered as boundary values. Actual results will be equal or worse.

Conclusion

The following conclusions could be done from the results presented below.

1. Whether we use 8 bit or 12 bit camera image, the ratio noise/signal remains the same.
2. Noise level remains the same for any combination of camera exposure and LED luminosity as long as image brightness remains constant.
3. In case of no noise the level of reflected signal can be reduced to a few percentages. If we use 12 bit image, even less then 1% can be enough.
4. Real camera noise sigma is about 1.7%, if the brightness of raw image is a half of the range.
5. The lower level of useful signal should be near 12.5% if the noise sigma is 1.7%.
6. If we increase the level of useful signal by involving camera bits 9-12, we increase the noise. So this method will not help if the level of signal is below the threshold of 12.5%.

Camera Noise for 8 and 12 bit images

Camera model SMX-15Mx can produce 8 and 12-bit images. Noise measurement for 8 bit images was done in [1]. The theory of noise measurement is given in [2].

An experiment was done to measure 12 bit noise under the same conditions.

Experiment setup (general experiment setup is given in [1]):

Device: MAX QS+

s/n: 14002

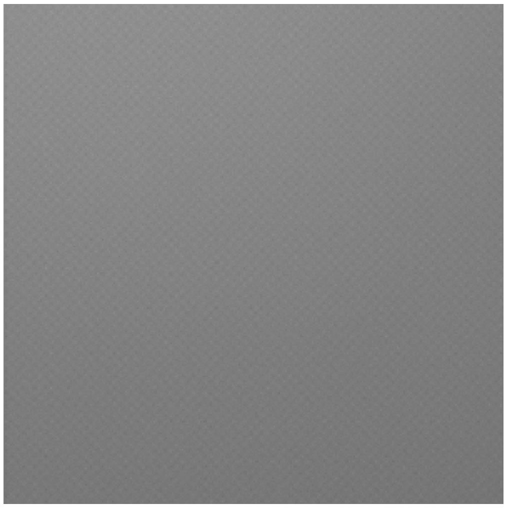
Camera: SMX-15Mx,

s/n 7606,

Viewport:

```
StartX: 1040
StartY: 716
Width: 512
Height: 512
```

Camera image looks like the following:



Experiment results:

The table below presents a comparative study of 8 and 12 bit image noise.

#	\# of bits	LED (1-255)	Exposure (ms)	Avg. image brightness	Noise sigma	Noise sigma, % of avg.	Comments
1	8	4	189	127.18	2.18	1.714	
2	8	22	6.92	128.01	2.18	1.704	MaxInspect LED value
3	8	127	1.29	126.15	2.17	1.722	
4	8	255	0.76	129.65	2.20	1.697	
5	12	4	189	2065.11	34.75	1.683	
6	12	22	6.92	2055.80	34.65	1.69	MaxInspect LED value
7	12	127	1.29	2025.72	34.39	1.70	
8	12	255	0.76	2079.56	34.85	1.676	

As can be seen from the table, noise level as % of image mean doesn't depend on frame depth (# of bits), LED current and exposure. This can be illustrated with the following table.

	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
12 bit image	0	0	0	0												
					7	6	5	4	3	2	1	0				
8 bit image																
Legend		noiseless bit					signal/noise bit						noise bit			

Section conclusion. Number of noisless bits remains the same for 8 and 12-bit images. The expansion of dynamic range to 12 bit increases the number of noisy bits. Number of bits not impacted by noise holds unchanged.

Dependents of PSI Measuremet on the number of noisless bits

As shown in the previous section, the number of noisless bits remains constant, whether we use 8 or 12 bits. In this section we determine the upper noise bound, that doesn't impact PSI measurement.

Image intencity at any point can be described with the formula.

$I = I_{bkg} + I_0 * A(t, x, y)$, where $-1 <= A(t, x, y) <= 1$

Let $I_{-1} = I_{bkg} - I_0$, $I_1 = I_{bkg} + I_0$

In case $I_{bkg} = I_0$ we have a full contrast image, if $I_{bkg} > I_0$, the contrast will be less then 1. In the latest case we can cast the image to the interval [I_{-1}, I_1], all significant information is concentrated here.

Futher we consider 12 bit noised images. Images are created in the following way. A sphere of radius 5 mm is used as an object. Interferograms for this object are simulated with a Python script as 12 bit images. Noise is then added to the image. Noise characteristics corrspond to the real noise measured in the previous section. A phase-shift procedure is also simulated to generate sequences of frames (raw data).

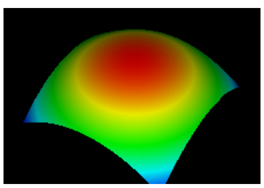
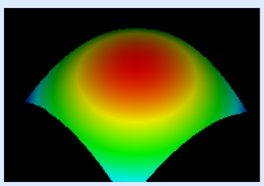
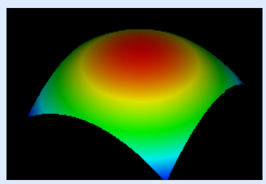
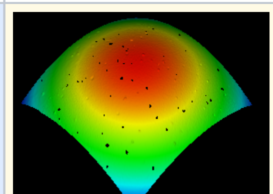
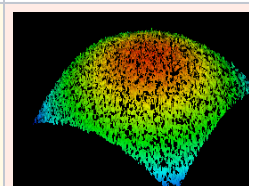
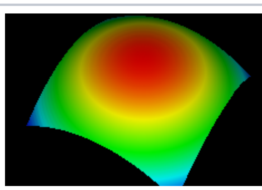
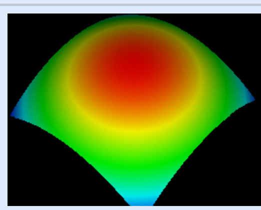
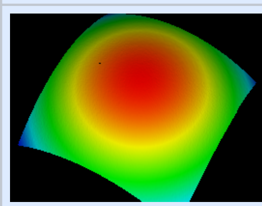
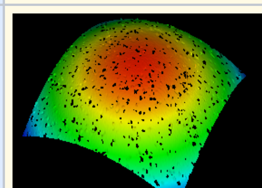
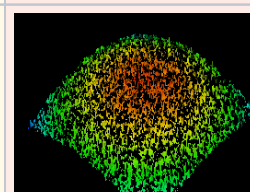
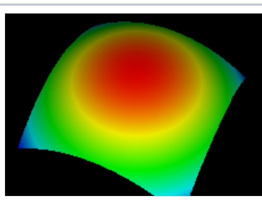
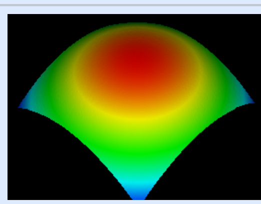
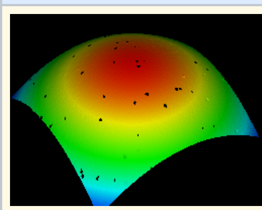
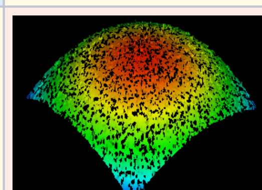
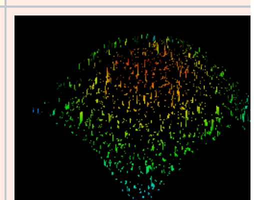
Note. Measured valus of I_0 for a sphere artifact and for flat standard are about 0.35.

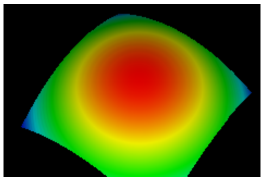
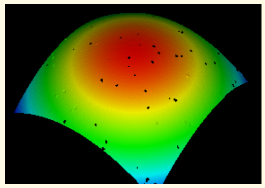
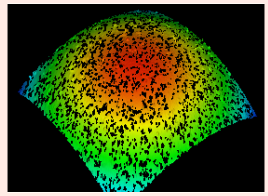
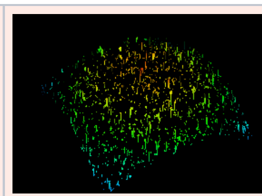
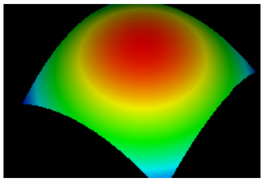
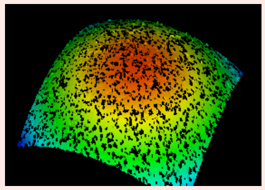
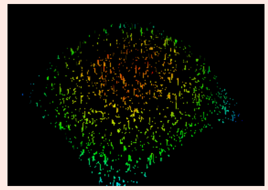
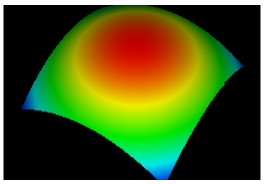
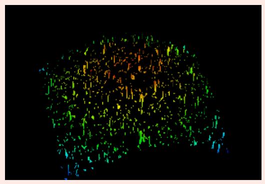
12-bit images are downcusted to 8 bit with gradual shift from highest to lowest bits. The custing procedure throw out heigher bits (that are constants for a certain level of I_0), and on every step increases the number of lower noisy bits. I_{bkg} is initially set to 2048. Results are summerised in tables below.

Table. Shifting scheme

#	I_0	I_{-1}	I_1	Range	# of noiseless bits	Noise/I_0ratio	11	10	9	8	7	6	5	4	3	2	1	0
1	2048 (100%)	0	4096	4096	6.5	0.017	X	X	X	X	X	X	X	X				
2	1024 (50%)	1024	3072	2048	5.5	0.034		X	X	X	X	X	X	X	X			
3	512 (25%)	1536	2056	1024	4.5	0.068			X	X	X	X	X	X	X	X		
4	256 (12.5%)	1792	2304	512	3.5	0.135				X	X	X	X	X	X	X	X	
5	128 (6.25%)	1920	2176	256	2.5	0.270					X	X	X	X	X	X	X	X

The following table presents simulation results. Rows represents the level of signal, columns - level of noise. Table cells contain 3D images of reconstructed surface, that are quite illustrative in this case.

noise => signal (I_0)	0.	0.017	0.034	0.068	0.136
0.49					
0.35 (actual value for sphere artifact)					
0.25					

0.125					
0.062					
0.04 (mini-interferometer concept)					

The following conclusions can be done from images, without additional calculations:

1. The level of signal for actual 1.7% noise should be at least 12.5%.
2. Level of signal of 4% with noise 1.7% gives the same results as full-contrast image with 27% noise.

References

1. Noise comparison of smx15m5m, Basler acA3800-14um, and smx16e2 cameras. Sumix, 2016
2. EMVA Standard 1288. Standard for Characterization of Image Sensors and Cameras. Release 3.0. November 29, 2010. Issued by European Machine Vision Association www.emva.org