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Fast 3D surface reconstruction by unambiguous compound phase coding

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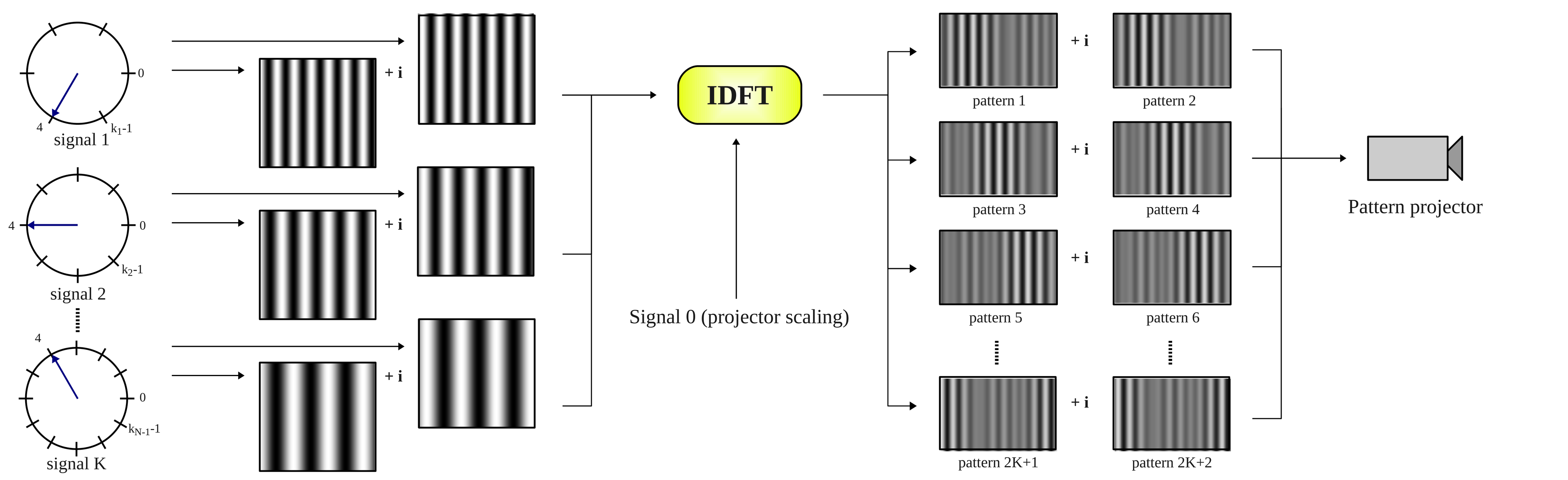
Research Goal

Multi-Period Phase Shift [1] ensures high quality and density of the code, but requires the projection of three times more patterns than classical phase shifting.

We introduce a novel coding strategy requiring a significantly lower number of structured light patterns while achieving comparable levels of accuracy.

Compound Phase Coding

Phases of the fringe vector are encoded as phases of a Fourier term at different frequencies. Each fringe exhibits a different period and all of them are coprime.



Given a phase code $\phi \in [0,1)^k$ we create a complex vector $\mathbf{x} \in \mathbb{C}^{k+1}$, where:

$$x_j = e^{-2\pi i \phi_j} \quad if\ 1 \le j \le k$$
$$x_j = 0 \quad otherwise$$

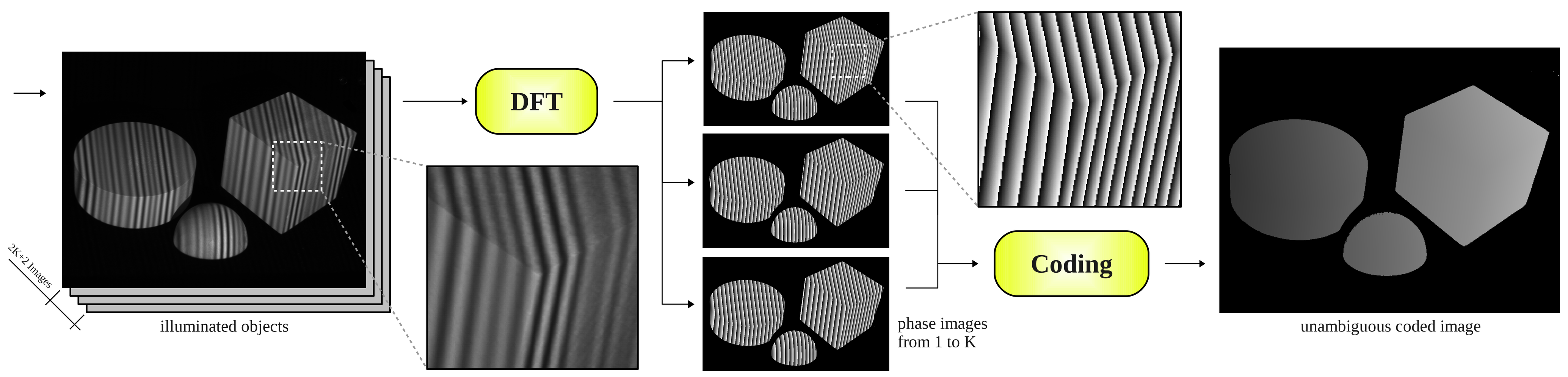
Given x_j for any $1 \le j \le k$ we can compute the phase ϕ_j as

$$\phi_j = frac\left(1 + \frac{1}{2\pi} arg(\Re(x_j), \Im(x_j))\right)$$

Each x_j represents a sinusoidal component with frequency $j/(k+1)$. Hence we can reconstruct the intensity sequence of that coordinate by computing the IDFT of **x**, obtaining $\mathbf{y} \in \mathbb{C}^{k+1}$, where:

$$y_n = \frac{1}{k+1} \sum_{j=0}^{k} x_j e^{2\pi i \frac{j}{k+1} n}, \quad n = 0, \ldots, k$$

We can then project separately the real and imaginary part of this vector and uniquely encode the x_i projector coordinate.

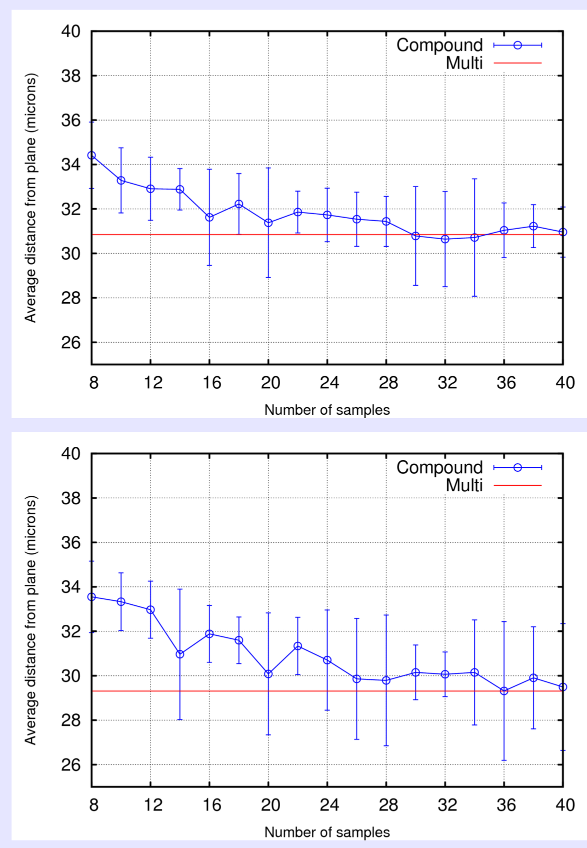


Experimental Results

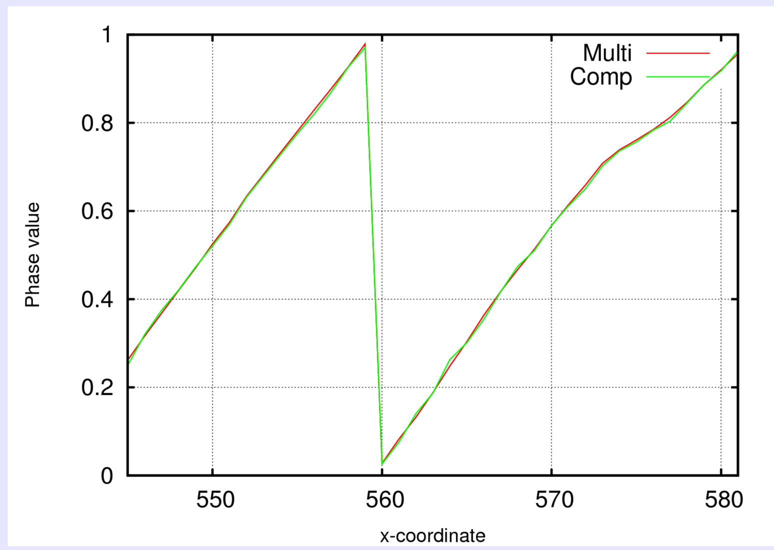
- We performed several experiments with real-world data.
- We compare our measurements with those given by the Multi-Period method.

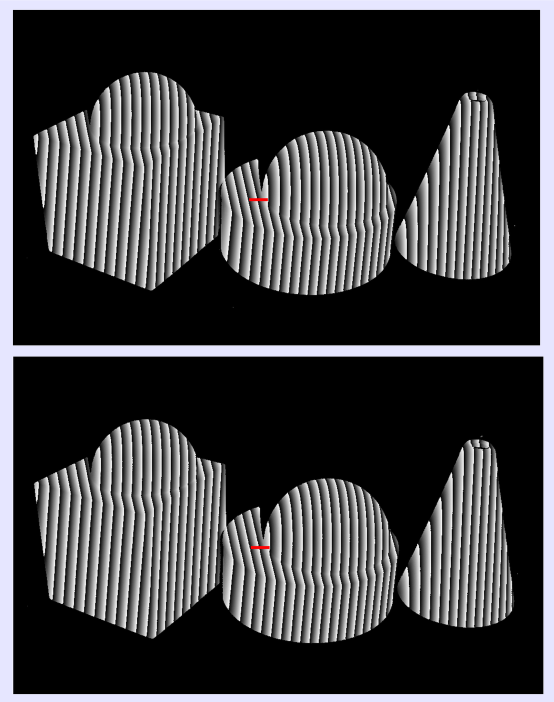
Planar target accuracy comparison

- Periods of 7, 11 and 13 pixels (top graph) and periods of 9, 11 and 13 (bottom graph);
- The ground truth was approximated with the best fitting plane (in the least squares sense);
- Standard deviation for Multi-Period appears as dashed red lines;
- Vertical bars are standard deviations in the measurement of the error for the compound technique.



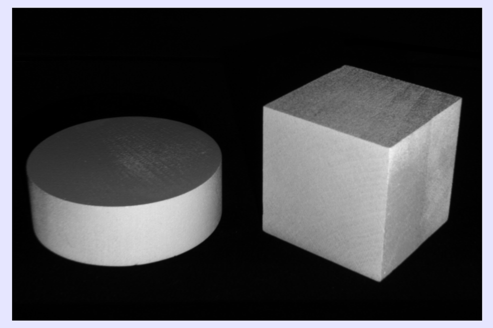
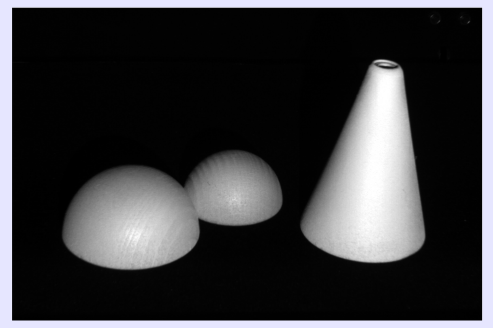
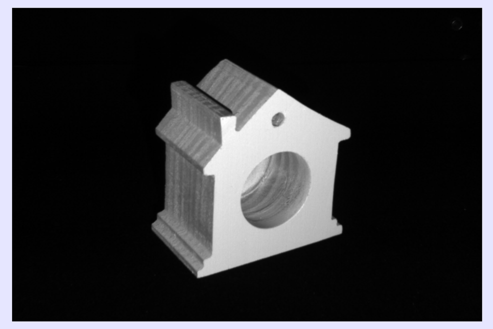
Phase images extracted by Multi-Period (top image) and our technique (bottom image).





Generic objects measurements

- Multi-Period has been tested with 34 samples to obtain the best quality;
- Distances are in microns and objects are 5 to 10 cm wide;
- For each experiment we evaluate the number of points acquired (first row), the average deviation (second row) and the average distance (third row).

Multi	Comp 8	Comp 16
109347	108306	109034
0.025	0.089	0.063
-	32.00	25.09
46749	46263	46505
0.030	0.085	0.067
-	21.15	16.19
37457	36880	37133
0.036	0.088	0.068
-	23.26	20.87

Conclusions

- We propose a novel compound phase coding technique that requires the projection of as few as 8 projected patterns.
- Experimental results assess the ability to obtain complete and accurate reconstruction.
- The time / quality trade-off can be easily controlled by adding more patterns; the method reaches the performance of other state-of-the-art approaches when feeded with a comparable quantity of data.

[1] E. Lilienblum and B. Michaelis. "Optical 3d surface reconstruction by a multi-period phase shift method. JCP, 2(2):73-83, 2007