Fast 3D surface reconstruction by unambiguous compound phase coding

Andrea Albarelli, Emanuele Rodolà, Samuel Rota Bulò and Andrea Torsello

Dipartimento di Informatica - Università Ca' Foscari di Venezia, Italy

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 \( \psi \in [0, 1) \) we create a complex vector \( x \in \mathbb{C}^{k+1} \), where:

\[
x_j = e^{2\pi i \psi} \quad \text{if } 1 \leq j \leq k
\]

\[
x_j = 0 \quad \text{otherwise}
\]

Given \( x \) for any \( 1 \leq j \leq k \) we can compute the phase \( \psi_j \) as

\[
\psi_j = \frac{1}{k+1} \sum_{n=0}^{k} \angle \{ \Re(x_n), \Im(x_n) \}
\]

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 \( y \in \mathbb{C}^{k+1} \), where:

\[
y_n = \frac{1}{k+1} \sum_{j=0}^{k} x_j e^{2\pi i j n/(k+1)}, \quad n = 0, \ldots, k
\]

We can then project separately the real and imaginary part of this vector and uniquely encode the \( x_j \) 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.

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).

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 fed with a comparable quantity of data.