PHASE EXTRACTION METHODS FOR CROSSED FRINGE PATTERNS

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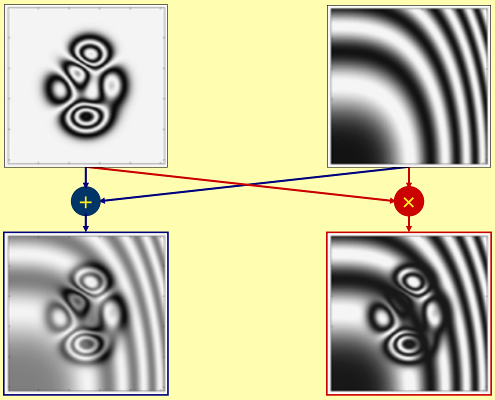
Abstract

In several optical techniques, two (or more) simultaneous events can be analyzed by coding their information in a crossed fringe pattern. In this work, two phase extraction methods for the processing of crossed fringe patterns are presented, and compared with previously established methods.

Introduction: What is a crossed fringe pattern?

Depending on the optical technique used, the resulting crossed fringe patterns are formed by either the multiplicative or the additive superposition of the separate fringe patterns.



ADDITIVE
Fringe projection
Ronchi test with square grid
Experimental-mechanic system

MULTIPLICATIVE
Photoelasticity
Deflectometry moiré with square grid

Problem: Demodulation of Crossed Fringe Pattern

The phase extraction is complex because:

- ➔ two, instead of one, phase informations must be estimated and,
- ➔ these phase informations are spatially superposed.

Previous solutions

Multichannel Fourier Transform (FT)

- ❖ FT in crossed fringe patterns has been applied in an experimental mechanics systems and in a fringe projection technique.
- ❖ It is necessary to introduce a high-frequency carrier.
- ❖ The two side-lobes must be processes separately in the frequency space.
- ❖ The propierties of the bandpass filter must be carefully selected.

Spatial Carrier Phase Shift (SCPS)

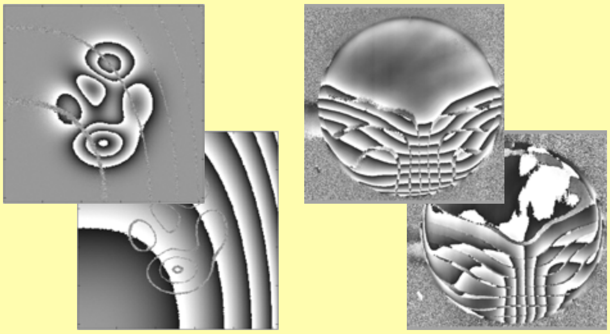
- ❖ It Is a phase-shifting technique applied to sequential pixels
- ❖ Requires the introduction of a carrier with a specific selected frequency.
- ❖ Although the phase obtained is noisy, the application of a low-pass phase filter permits the obtention of "acceptable" phase maps.

Proposed solution 1: Modified phase-shifting method (PS)

➔ The system must be able to apply phase shifts in two different directions

➔ For **Additive** superposition fringe patterns a standard phase-shift method is able to extract correctly the phase data, however, for **Multiplicative** superposition fringe patterns, the spatial overlapping of the low intensity zones results in low-modulation areas where the phase information is lost !

➔ We solve this problem by acquiring two times each phase map, but shifting by π the low-modulation zones between acquisitions. The "bad" zones are suppressed by calculating the contrast of this two phase maps, using either a **weighted average method** or a **maximum contrast method**.



Demonstration of the low-modulation problem with simulated and real data

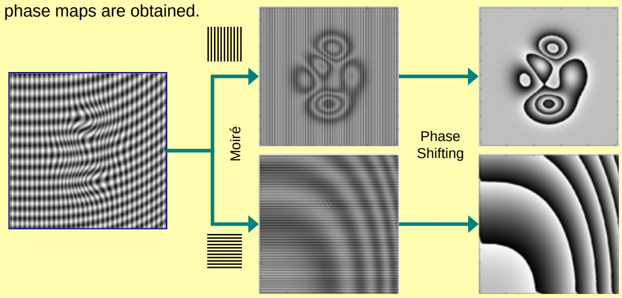
Proposed solution 2: Digital Multiplicative Moiré (DMM)

➔ It is necessary to introduce a high-frequency-carrier in the fringe pattern.

➔ The method is based in making a moiré effect between the fringe pattern and a computer generated grating. The moiré fringes are selected with a low-pass filter

➔ Two computer gratings must be generated with a direction and frequency similar to the carriers introduced in the fringe patterns.

➔ By numerically displacing the gratings and using a phase-shifting algorithm, the phase maps are obtained.

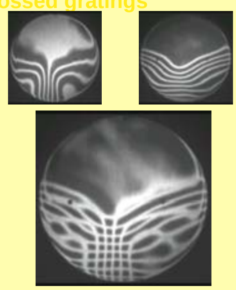


Comparative Analysis of The Methods

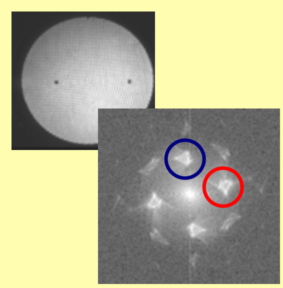
	PS	DMM	FT	SCPS
Nº of images required	≥ 12 *	1	1	1
Spatial carrier required	NO	YES	YES	YES
Extra-memory requirements	≥ 5 *	2	2	0
Approx. execution time (sec.)	6.3	7.4	5.3	3.5
Sensibility to harmonics	+ or □ *	□ –	–	□
Accuracy with superposition				
additive	+	□	□	□
multiplicative	+	□	□	–

Legend: + = High, □ = Medium, – = Low.
* = Depends on the phase shifting algorithm used.

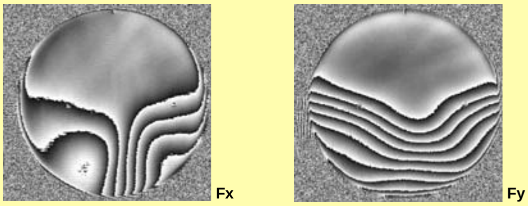
Example: Progressive ophthalmic lens characterization by moiré deflectometry with crossed gratings



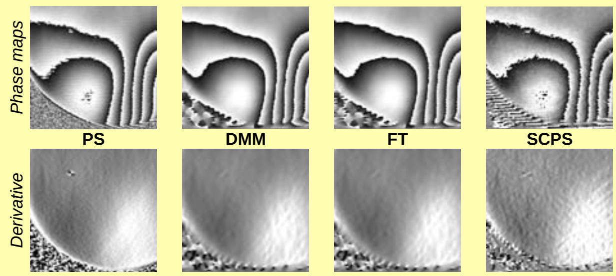
Note the relation between the deflectograms obtained with Ronchi gratings and with crossed gratings.



The carrier frequency must be high-enough to separate the two phase informations



Phase maps obtained with the modified phase-shifting method. Fx and Fy are proportional to the ray light deflection caused by the lens. (grating period 0.1mm)



Comparison of the informations obtained with the different methods