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Local correlation in dynamic speckle

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Abstract

We propose the use of an operation named local correlation to account for localized features that are obscured in the usual global correlation operation. It consists in the use of an explicit window function with two free parameters: location and width. Some simulations are shown and this operation is applied to an example in the field of dynamic speckle.

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1. Introduction

Cross correlation and autocorrelation have proved to be valuable tools in Fourier optics. This is particularly noticeable in the field of pattern recognition, where the invention of the Van-der Lugt [1,2] filter in 1963 showed that these operations were very sensitive and could discriminate very well optical patterns, being this high discrimination capability its main practical drawback.

The most interesting properties of correlation are that autocorrelation is maximal at the lag origin and that cross correlation between two functions is maximized when the two functions differ only in a multiplicative constant (it is, they are similar) [3].

The first mentioned property provides an origin to lean against, thus permitting the meaningful averaging of different instances of the function. This fact has been successfully exploited in astronomic speckle interferometry to recover images blurred by atmospheric turbulence [4].

The second enables its use for pattern recognition. So, high values of the (normalized) correlation function indicate that the functions being correlated are similar or proportional.

Because of its definition, correlation extends to the whole interval between minus and plus infinite

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for the integrated independent variable. So, if two functions show local similarities but differ in other regions, the global operation does not show neither a clear indication nor the location of the further.

Some (many) functions of practical interest exhibit these local similarities and it is of considerable interest to detect them. Consider the example of stereoscopic depth perception. Comparison between the images recorded by the left and right eyes or cameras must be inherently performed on a local basis. The location of the similar areas is also of the same importance.

Step wise stationary functions [5] show correlations that may change from one region to another of the domain.

Autocorrelation is related to the Fourier Power Spectrum by the Wiener Kintchine Theorem [6].

Vander Lugt [1,2] and Goodman [7] filter for optical pattern recognition has been extensively studied and is based on these properties. Geometric correlators, restricted to only positive real functions have also been optically implemented [7,8].

Three-dimensional information of a spatially incoherent source from the spectral content of a speckle pattern is also based in local correlations [9].

Spatial and time domain speckle size and lifetime are usually defined in terms of the FWHM of the autocorrelation function of its corresponding intensity fluctuations.

The use of autocorrelation to measure the spacing of fringes in speckled images usually leads to a substantial reduction of noise [10], but as some fringe systems are periodic functions windowing is required.

As there are many situations where phenomena of short extent (spatial, temporal or both) coexist or are followed by others with a different scale, it is convenient to be able to recognize its presence by the use of a more local tool than the usual correlation operation. Ordinary correlation, being a global operation (i.e. involving all the function), pools all these results and the global behavior masks any of the local features.

We propose the use of a local operation. It is characterized by the product of the function to be studied multiplied by a window function (chosen to be the same in all the cases in every measurement). In the following we are going to choose mostly a Gaussian window. That window requires the definition of two free parameters, namely the width and the location. The autocorrelation variable, namely the lag, adds another dimension to the representation.

The location of the window identifies which region is currently investigated. It sets to a low value or zero all the other regions that are not required in that calculation and highlights the region of interest. The width of the window measures the spread where the searched correlation is expected to be significant.

Windows appear unavoidably in numerical calculations and in experiments due to the inherently finite size of computational and optical elements. So, (implicit) local correlations are a commonplace. It has been used or implicitly proposed in several ways in the past [3,8]. An astigmatic optical processor for local (in one direction) pattern recognition was proposed in the past by one of us [11].

The following section deals with some properties of local correlation deduced from its definition, then we show some numerical simulations to illustrate the concept and a possible application in the field of dynamic speckle.

2. Definition of the local correlation

We propose to define the local correlation (LC) between two functions $f(t)$ and $g(t)$ as the function

$$\mathrm{LC}(f, g; w; t_0, \sigma)(t) = \int_{-\infty}^{\infty} \hat{f}^*(\tau)\hat{g}(t+\tau)\,\mathrm{d}\tau, \qquad (1)$$

where t is the lag, $*$ is conjugation, and

$$\hat{f}(t) = f(t)w((t-t_0)/\sigma), \quad \hat{g}(t) = g(t)w((t-t_0)/\sigma)$$

with $w((t-t_0)/\sigma)$, the window function, located (equationed) at t_0, and of width σ. In numerical calculations on actual signals the implicit and unavoidable window is a rectangular function dictated by the finite length of the domain of the function f.