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Performance evaluation and acceleration of Flynn phase unwrapping algorithm using wraps reduction algorithms

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ABSTRACT

Flynn phase unwrapping algorithm, probably, produces the best results in comparison to other methods, but it needs a long execution time. In this paper we suggest combining Flynn algorithm with wraps reduction algorithms in order to reduce its execution time and also improves its noise performance. Additionally, we propose a method that can be used to measure the success of phase unwrapping techniques. Computer simulation and experiments are used to verify the ideas proposed in this paper.

1. Introduction

Phase unwrapping plays a vital rule in numerous practical applications such as synthetic aperture radar (SAR) interferometry, adaptive optics, and medical imaging [1]. Other applications also include, but not limited to, MRI [2], 3D profile measurement [3] and optical interferometry [4].

A large number of phase unwrapping algorithms have been proposed in the literature [1]. These algorithms vary in terms of their noise performance, execution times and suitability for practical applications. Probably Flynn algorithm is one of the most well-known methods for its robustness but it is also one of the slowest methods [5–8].

In this paper, we propose the use of some of the wraps reduction algorithms [9–11,13,14] in order to reduce the execution time of the Flynn algorithm and improve its noise performance. Additionally, we introduce a new method to evaluate the noise performance of phase unwrapping techniques and we apply this method to Flynn algorithm.

The paper is organized as follows. The second section introduces accelerating Flynn algorithm using a frequency domain wraps reduction method [9]. The third section explains a new method to evaluate the noise performance of Flynn algorithm. The fourth section discusses accelerating Flynn algorithm using a spatial domain wraps reduction method [11]. The fifth section concludes the paper.

2. Accelerating Flynn algorithm by using shifting in the frequency domain wraps reduction technique

Flynn phase unwrapping algorithm is well known for its excellent performance, but it has a very high execution time [6,7]. Our investigations reveal that prepressing of wrapped phase maps using wraps reduction algorithms [9–11,13,14] and then unwrapping the resultant phase maps using Flynn algorithm reduces considerably the execution time and improves the noise performance of Flynn algorithm.

Qudeisat et al. have proposed the use of shifting in the frequency domain to reduce the number of wraps of an image [9]. The procedures of the algorithm can be combined with Flynn algorithm as explained using the following example.

Suppose we have the computer-simulated shape that is shown in Fig. 1(a) and it is produced using the MATLAB® *peaks* function. This shape is used in the literature for evaluating different phase unwrapping and fringe analysis techniques [9–11] and it is given by

$$\emptyset(x,y) = 3(1-x)^2\exp(-x^2-(y+1)^2) - 10\left(\frac{x}{5}-x^3-y^5\right) \times \exp(-x^2-y^2) - \frac{1}{3}\exp(-(x+1)^2-y^2) \quad (1)$$

where x and y are the sample indices for the x and y axes respectively. The peaks shape consists of 512×512 pixels and contains regions with both slow and rapid phase variations.

This shape phase modulates fringe patterns using the phase stepping algorithm, with a modulation index $\beta = 2$. A Gaussian noise with a variance of 8 and a mean of 0 is added to the four fringe patterns. The resultant images are shown in Figs. 1(b)–(e). A $\pi/2$ phase shift is introduced between successive fringe pattern images.

$$g_0(x,y) = \cos(2\pi f_o x + \beta\emptyset(x,y)) \quad (2a)$$

$$g_{90}(x,y) = \cos\left(2\pi f_o x + \beta\emptyset(x,y) + \frac{\pi}{2}\right) \quad (2b)$$

$$g_{180}(x,y) = \cos\left(2\pi f_o x + \beta\emptyset(x,y) + \pi\right) \quad (2c)$$

$$g_{270}(x,y) = \cos\left(2\pi f_o x + \beta\emptyset(x,y) + \frac{3\pi}{2}\right) \quad (2d)$$

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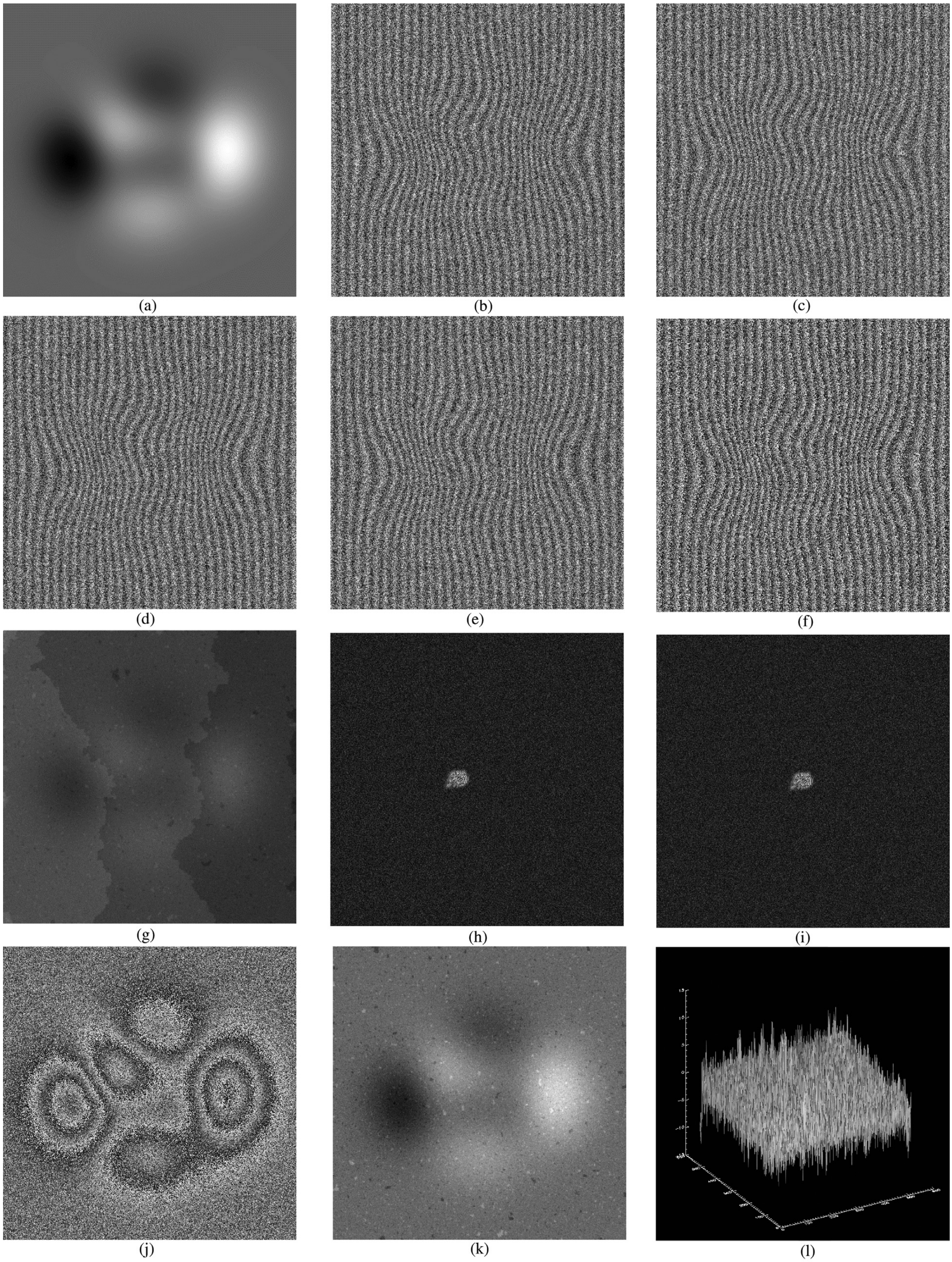

Fig. 1. (a) A computer-generated shape with the size of 512 × 512 pixels. (b)–(e) Fringe patterns produced using phase stepping algorithm. (f) Wrapped phase map produced using phase stepping algorithm. (g) The unwrapped phase map produced using Flynn algorithm. (h) The spectrum of the wrapped phase map in (f). (i) The spectrum is shifted using the algorithm in [9] to the origin of the image. (j) Wraps reduced using the algorithm in [9]. (k) The image in (j) is unwrapped using Flynn algorithm. (l) The mathematical difference between the images in (a) and (k).