学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

EFFICIENT AND ACCURATE PHASE UNWRAPPING ALGORITHMS FOR NOISY IMAGES WITHIN FRINGE PATTERNS

(高雑音干渉縞に対する高効率高精度位相連結アルゴリズム)

Phase unwrapping is a crucial and challenging step to most data-processing chains based on phase information in many fields of research, such as magnetic resonance imaging, synthetic aperture radar interferometry and optical metrology. In all these research fields, the measured parameters are modulated in the form of 2D fringe pattern. To retrieve the phase information from the fringe pattern, Fourier domain filtering or phase shift technique can be used. The retrieved phase values, which are wrapped phase, are the distribution of principal values ranging from $-\pi$ to π. Thus, phase unwrapping procedure is needed to get back the unknown multiple of 2π to each pixel. This is why many algorithms have been proposed for phase unwrapping. However, there is no agreement between the current phase unwrapping algorithms for different applications, due to the existence of disturbance in the measured phase data. In the case that there is no disturbance in the phase data, the unwrapped phase can be obtained by integrating the phase gradients over the whole data samples, which is independent from the integration path. However, there are several sources of errors. Firstly, phase aliasing occurs when the true phase changes by more than one cycle (2π rad) between samples, which was caused by long baselines, objects discontinuities or high deformation. The second source is noise, which may be caused by speckle noise, electronic noise and/or fringe breaks. Those defected points in the measured phase images are called singular points (SPs). To exclude these invalid areas from unwrapping process and get precise unwrapped phase results can be a time-consuming process.

For this purpose, we proposed two novel phase unwrapping algorithms for noisy phase images. The first algorithm is called rotational and direct compensators for phase unwrapping (RC+DC). The RC+DC algorithm is a new phase unwrapping approach for noisy wrapped phase maps of continuous objects to improve the accuracy and computational time requirements of phase unwrapping using a rotational compensator (RC) method. The RC method uses local phase information to compensate the singularity parts of phase map caused by existence of SPs. It computes the compensators through superposing the effect of each SP by adding an integral of isotropic singular function along any loops. However, the RC method has a drawback of undesired phase error because the RC should be applied to the regular region with no SPs as well as to the singular region. In addition, the RC method required high computational time cost when the measured phase data contains many SPs. Therefore, the proposed algorithm (RC+DC) aims to overcome the disadvantages of the RC method. It uses direct compensator (DC) for adjoining SP pairs, and uses RC for other pairs. The adjoining pair is a dipole which consists of two SPs with opposite signs, separated by one pixel horizontally or vertically. The RC+DC method is fast, however, its accuracy is not guaranteed. Its accuracy is depending on reducing

the times for using the RC technique that increases the phase distortion in the unwrapped results.

The second proposed algorithm is based on singularity compensation for cluster regions of SPs; it aims to improve the performance of phase unwrapping using a localized compensator (LC) method regards the memory shortage and computational time requirements. The LC method regularizes the inconsistencies in local areas, which are clusters, around the SPs by integrating the solution of Poisson’s equation for each cluster to evaluate the compensators. In terms of accuracy, the method using LC is superior to the other methods. Despite this, LC method has a major disadvantage of computational cost since this method requires long time cost to compute the compensators. Hence, to overcome the drawbacks, we use a new way to produce the compensator values. The proposed algorithm (Modified LC) is tested on both computer-simulated and experimental noisy phase data. The results show that the proposed algorithm is faster compared to the original algorithm with LC, meanwhile it keeps the same level of accuracy of the unwrapped results.

As a summary, the proposed phase unwrapping algorithms (RC+DC, and Modified LC) have been evaluated extensively using a set of simulated and experimental phase data obtained from various optical applications. In addition, these proposed algorithms are also compared to existing phase unwrapping methods, such as the method by Goldstein et al. and least-squares method with discrete cosine transforms ... etc. The results show that the proposed algorithms give better performances regards the accuracy and computational time cost.

Keywords: Interferometric measurements, 3D shape measurements, Holographic data, Fringe analysis, Phase extraction, Phase unwrapping, Image processing