High-Resolution Fringe Pattern Phase Extraction, Placing a Focus on Real-Time 3D Imaging

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Abstract

The idea behind the research is to deal with real-time 3D imaging that may extensively be referred to the fields of medical science and engineering in general. It is to note that most effective non-contact measurement techniques can include the structured light patterns, provided in the surface of object for the purpose of acquiring its 3D depth. The traditional structured light pattern can now be known as the fringe pattern. In this study, the conventional approaches, realized in the fringe pattern analysis with applications to 3D imaging such as wavelet and Fourier transform are efficiently investigated. In addition to the frequency estimation algorithm in most of these approaches, additional unwrapping algorithm is needed to extract the phase, coherently. Considering problems regarding phase unwrapping of fringe algorithm surveyed in the literatures, a state-of-the-art approach is here organized to be proposed. In the aforementioned proposed approach, the key characteristics of the same conventional algorithms such as the frequency estimation and the Itoh algorithm are synchronously realized. At the end, the results carried out through the simulation programs have revealed that the proposed approach is able to extract image phase of simulated fringe patterns and correspondingly realistic patterns with high quality. Another advantage of this investigated approach is considered as its real-time application, while a significant part of operations might be executed in parallel.

Keywords: High-Resolution Fringe Patterns; 3D Imaging; Itoh Algorithm; Wavelet Transformation.

1. Introduction

Due to the fact that optical measurement approaches have the merit of being the precise outcomes in the areas of medical science and engineering, it is coherent to realize it first with respect to other related ones via more reliable image processing tools. There are high-resolution optical noncontacts measuring approaches that can be effective techniques to calculate the exact depth of objects, as long as their surface is not taken into real consideration. In one such case, the most effective noncontact measuring techniques can include the structured light patterns that are provided for an object to derive its depth. In fact, the most common type of structured light pattern can now be recognized as the fringe pattern. It is to note that non-contact measuring approaches may be exploited, in order to obtain the depth distribution of such an object. It is carried out via fringe pattern through a number of sequential steps. Now, the fringes acquired from interferometer or reticulated projector is provided for the surface of the object to be considered, while the image acquired from an axis except projection axis is to be used. Hereinafter, the projected fringe pattern transforms as its phase is modulated through the distribution of object depth. Therefore, image of transformed fringe pattern can be demodulated or analyzed via a potential fringe analysis approach to be able to extract the phase distribution of the pattern. In conclusion, the depth distribution of the object is to obtain though the extracted demodulated phase distribution, coherently.

The fringe pattern analysis approaches including Fourier fringe analysis can generally be divided into two key steps that can be listed as the extraction of wrapped phase and phase unwrapping, as well. It should be noted that the first step of the phase of the fringe pattern to be extracted is to use the Fourier or wavelet transform. There are some necessary filters to be applied to the frequency domain, while phase that is generated in the aforementioned step is wrapped. These are to be eliminated by using the phase unwrapping approach, which is the second phase of the fringe pattern analysis approach. It can be shown that the processing time is to be considerable because of the existence of noise, in wrapped phase mapping. With this goal, optimizing the approaches is prominent so that noise is removed and, in turn, the processing time is decreased.

It is reasonable to note that despite unwrapped phase that is directly extracted by these approaches, most of them suffer from drawbacks, which can now be addressed. Furthermore, the Fourier transform approach is efficient in surfaces that have the uniform phase variations. Due to the fact that the measured surface has severe and abrupt changes, the frequency of fringe pattern should be more than these variations. Therefore, considering the Fourier

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transform approach from such a pattern and extracting the desired frequency to be named as the phase though the inverse of the Fourier transform approach can be problematic. Now, as long as the feature of imaging speed is important to consider, the approach is applicable, while it merely utilizes one fringe pattern and Fourier analysis [1]-[3]. It is obvious that the applications of the same approaches are measuring surface vibration through high speed imaging. By executing this one, the phase can be extracted in wrapped form and subsequently the phase unwrapping approach can be employed to interpret the validated phase information.

It is highly likely that another fringe analysis approach in this area can be taken into consideration as the wavelet transformation, which is the efficient choice for the non-uniform surfaces. In sequel, the aforementioned wavelet transformation may be carried out, whilst one the fringe pattern and the noise effect on the extracted phase that is less than Fourier approach can be resulted [4]-[5].

The lengthy processing time is known as the disadvantage of this approach that is a consequence of wavelet transformation. Besides, derived outputs in edges of image have errors which might be problematic in some applications. Among approaches concerning the wavelet transform is to be utilized, the phase estimation and the frequency estimation ones might be addressed. The phase extracted by the phase estimation approach is wrapped and needs the phase unwrapping algorithm. The phase estimation approach is more precise than the Fourier transform one in the fringe pattern analysis, while it is consuming more execution time. Yet, both cases need the phase unwrapping algorithm as the extracted phase can be wrapped.

Cusack et al and Karout et al have all proposed their potential algorithms [6]-[7]. It should be noted that the normal image may include thousands of phase discontinuities. Some of them are intrinsic, while some others are consequence of noise or phase extraction algorithm. Distinguishing intrinsic discontinuities and those resulted from noise is challenging which makes phase unwrapping more complicated. Moreover, accumulator nature of this procedure makes it even more difficult. In cases such as Frequency Estimation method there is no need for phase unwrapping as phase is directly extracted unwrapped [8]-[10].

Right now researchers in medical and engineering fields complain about inappropriate efficiency of current phase unwrapping techniques [11]. The researchers have even tried to collect a group of existing phase unwrapping algorithms to separately exploit their advantages for a set of applications [12]-[13]. So far, nobody knows why phase unwrapping algorithms (even powerful ones) demonstrate low performance in some cases [14]. The most evident and essential drawback of recent phase unwrapping algorithms is lack of generality. In other words, each phase unwrapping algorithm cannot be employed for unwrapping of all types of wrapped phases. In this study, firstly, a novel and powerful algorithm is proposed to analyze various types of fringe algorithms which is applicable to inclined surface objects. Afterwards, performance of proposed algorithm is compared to conventional algorithms.

2. The Proposed Approach

The behavior of proposed approach is determined using a method different from other fringe pattern analysis methods and does not need complicated calculations. In this algorithm a composition of characteristics of conventional methods is exploited. The following subsections elaborate on proposed method.

2.1 The Main Idea

As mentioned before, most fringe pattern analysis methods extract the phase in wrapped form and require a phase unwrapping algorithm; however, they may face various problems in unwrapping step which are mentioned in [14]. The proposed method to address this problem is supervising phase unwrapping operation through comparing main wrapped phase pattern with a proper pattern. The unwrapping procedure continues similar to other algorithms; whereas, in case of confronting any discontinuities, corresponding pixels are compared to similar ones in reference pattern. If the same discontinuity exists in reference pattern, it will be considered in unwrapping operation; otherwise it will be considered as fake discontinuity and would be ignored and the algorithm continues. Fake discontinuities are neglected as they might be noise and may threaten unwrapping operation of whole image.

Using valid reference pattern means using another method in parallel which necessarily meet following requirements:

- Small processing time.
- Avoiding destruction of output image as a result of noise in input image (in some methods the output image might be completely destroyed by an unwanted noise).
- Unimportance of output precision.

In almost all current methods if the noise variance exceeds a certain value, the output image will be completely lost. Even in conditions where destructive effect of noise is reduced, the processing time increases. On the other hand the output of this method is merely used for comparison in case of suspicious pixels; so, there is no need for a perfect output with high precision.

The traditional idea that is realized to deal with frequency estimation method or phase gradient method has a number of problems that are all solved through the proposed approach, which is entirely illustrated in Fig. 1, listed as: this approach is only potentially suitable for generating reference output [15]. Its output does not have sufficient precision in most cases and additionally, it does not need phase unwrapping algorithm after phase extraction. As a result the noise does not significantly affect the output, though it has improper output. Ignoring its large processing time, this method is a good candidate for reference pattern. Thus, the estimation frequency might be reduced which considerably reduces processing time. Although this attempt destroys output image, experiments have demonstrated that the information of this image is sufficient for a reference pattern. It is still necessary to have tradeoff between number of frequencies and generated output.

2.2 The Basic Flowchart of the Proposed Algorithm

The basic flowchart of the proposed algorithm is given in the form of Fig. 1. In this procedure, fringe pattern projected on the object is simultaneously processed by two methods. In the first one, the image of projected fringe pattern is unwrapped using a conventional method with low computational load. In fact, this takes place based on the core of phase gradient method and Itoh algorithm. Furthermore, in the second method, the phase of the same image is derived via frequency estimation method and then it is wrapped manually and intentionally (it is done using atan function in MATLAB). The image obtained by this method is called reference pattern whose information is utilized in the first method. In this flowchart DIFF1 denotes the difference between two adjacent pixels in projected fringe pattern after filtering operation; while, DIFF2 is the difference between the same pixels in reference pattern. As mentioned, when first method is being executed and it faces discontinuity, the similar pixels in reference pattern are checked. The observed discontinuity is valid if there is a discontinuity in its corresponding pixels in reference pattern.

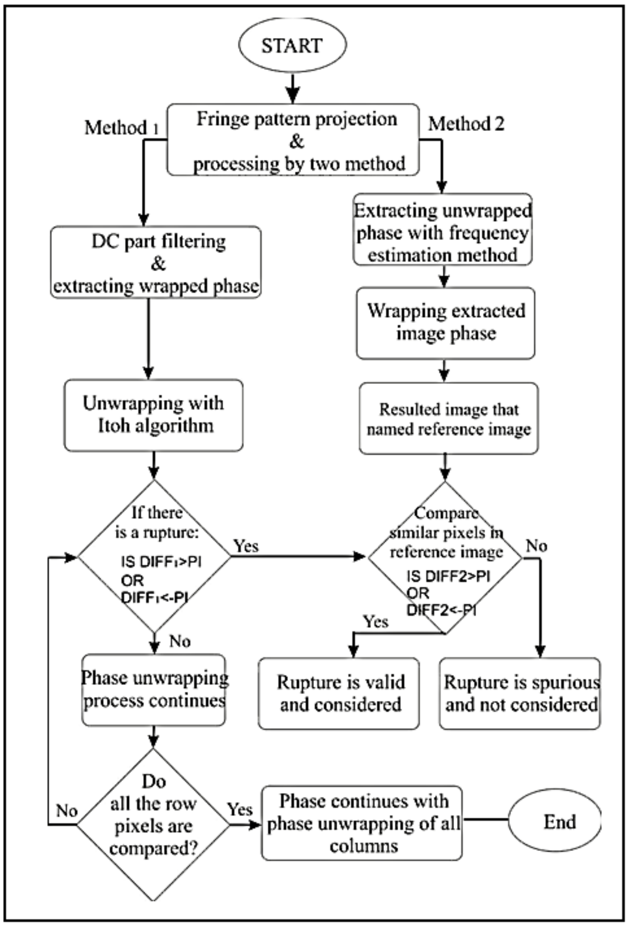


Fig. 1. The schematic diagram of the proposed algorithm

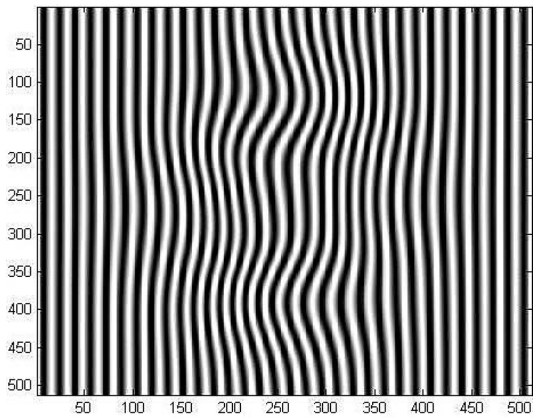
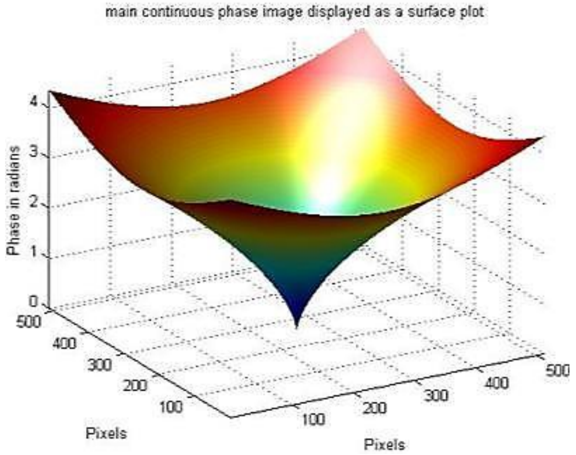


Fig. 2. The fringe pattern of the main image without the noise.

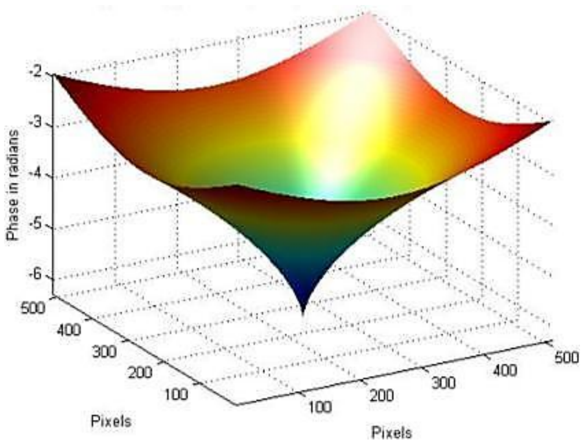
3. The Simulation Results

The proposed approach is now carried out through a simulation program, as long as the first condition is given by including the noise variance to be equaled to 0.5 in the fringe pattern. For this purpose, an image with the undergoing phase relation is provided and its fringe pattern is simulated via the Gaussian distribution. The simulated fringe pattern is now illustrated in Fig. 2, where after processing of this one via the noisy image by the proposed approach, an image that is similar to the input image and without any deficiencies is also provided. Now, in order to illustrate the applicability of the proposed approach, the same image of Fig. 2 with similar noise variance is processed under the some conventional algorithms including the phase estimation, the frequency estimation and finally the first and the second Itoh methods. The proposed approach is in fact carried out, where the phase

Variation of the image is considerable. The main image, which has a relatively large slope and also the image provided by the proposed approach, is illustrated in Fig. 3.



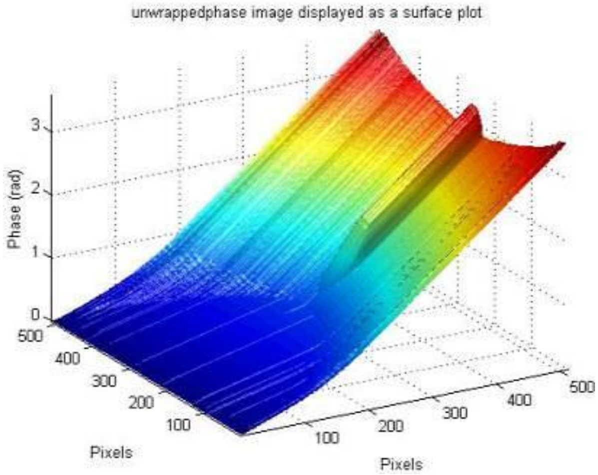
(a)



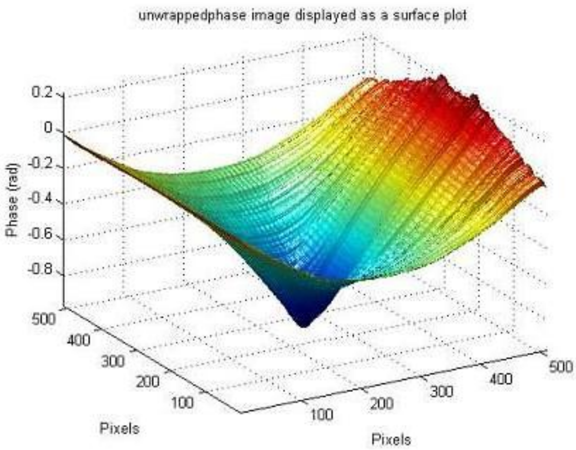
(b)

Fig. 3. a) The main image, which has the relatively large slope, b) the image provided by the proposed algorithm.

Figures 4 and 5 depict the results, as long as the frequency estimation algorithm is executed in two conditions in Fig. 4 including (a) with the small number of frequency samples and (b) with the large number of frequency samples. As it can be seen in Fig. 4(a), the output image is completely distorted and cannot be interpreted while in Fig. 4(b), it is somehow interpretable. Experiments have revealed that through the proposed method, both images would be acceptable and similar and desired results might be achieved; nevertheless, condition (a) is selected in the proposed approach owing to its small execution time. Figure 5 illustrates the results of image given in Fig. 3 with the phase estimation approach including Fig. 5(a) indicates the output image and Fig. 5(b) indicates the difference between main image and output image.

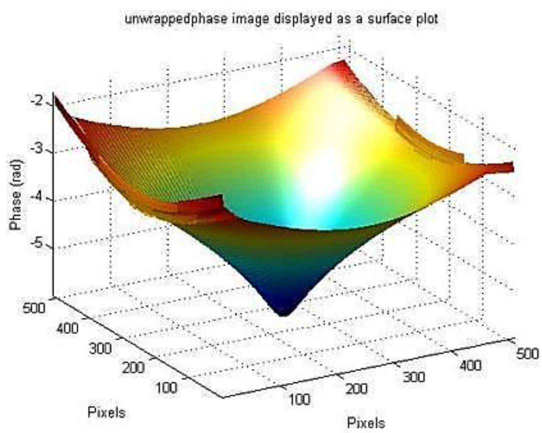


(a)

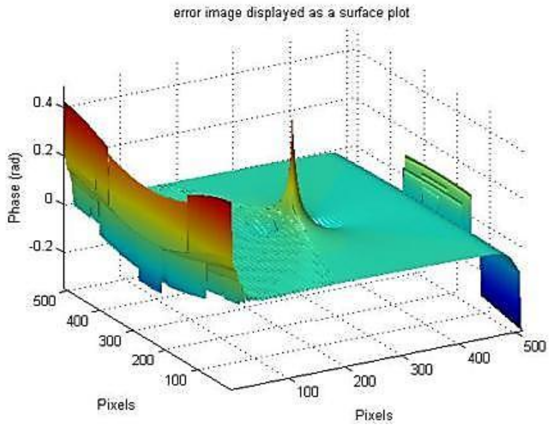


(b)

Fig. 4. The results of image illustrated in Fig. 3 with the frequency estimation approach a) with the small number of frequency samples, b) with the large number of frequency samples.



(a)



(b)

Fig. 5. The results of image illustrated in Fig. 3 with the phase estimation approach a) output image, b) difference between main image and output image.

4. Conclusions

An approach is proposed in this research to solve the problems concerning the unwrapping of phase extracted though the fringe pattern. The proposed approach is realized based on a number of traditional algorithms to be correspondingly taken into account including the frequency estimation approach and the corresponding Itoh approach. In fact, the key suggestions of the research are to present the new tools for processing of the fringe pattern; nonetheless, a number of other issues might be investigated in future research. The proposed one does not have an acceptable performance in case of images with higher than average noise. It might be improved by changing two utilized parallel methods. Furthermore, the performance of algorithm can increased by using other mother wavelets as the known Morlet mother wavelet is now exploited in the proposed approach.

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