2018 14TH INTERNATIONAL SCIENTIFIC-TECHNICAL CONFERENCE ON ACTUAL PROBLEMS OF ELECTRONIC INSTRUMENT ENGINEERING (APEIE) – 44894 PROCEEDINGS

APEIE – 2018

In 8 Volumes

Volume 1

Part 2

Novosibirsk
2018

ТРУДЫ XIV МЕЖДУНАРОДНОЙ НАУЧНО-ТЕХНИЧЕСКОЙ КОНФЕРЕНЦИИ АКТУАЛЬНЫЕ ПРОБЛЕМЫ ЭЛЕКТРОННОГО ПРИБОРОСТРОЕНИЯ

АПЭП – 2018

В 8 томах

Том 1

Часть 2

Новосибирск
2018

Decrease in the Error at Elimination of Phase Ambiguity by Method of Equivalent Wavelength

Vladimir. I. Guzhov, Sergey. P. Ilinykh, Grigory. A. Pozdnyakov
Novosibirsk State Technical University, Novosibirsk, Russia

***Abstract* – This article describes a method for reducing the phase error in a multifrequency method for eliminating phase ambiguity in digital, including holographic, measuring systems. The proposed method involves obtaining a series of interference patterns with different wavelengths and decoding them by the phase shift method. Reduction in error is ensured by combining the integer values of the phase obtained for an equivalent wavelength with the averaged values of the phase of the original wavelengths, which allows to eliminate the effect of accumulation of errors and, accordingly, to reduce the overall error in determining the phase. This allows us to extend the range of applicability of the method for eliminating phase ambiguity when several wavelengths are used. The method was tested by deciphering test patterns with a given noise level. The method showed stability to phase and amplitude noise.**

***Keywords* – interferogram, analysis, equivalent wavelength, phase ambiguity.**

I. INTRODUCTION

ELIMINATION OF PHASE ambiguity an important component of analysis algorithms of interferograms in digital interferential, including, holographic measuring systems. One of popular methods is expansion of dynamic range of phase unambiguity by synthesis of equivalent wavelength from two or more interferograms of the waves of a source of lighting received with different lengths [1]. A lack of such approach is increase in an error of definition of a phase in proportion to the relation of the initial and synthesized lengths of waves. Authors of article have offered a way of elimination of phase ambiguity which allows to eliminate this shortcoming.

II. PROBLEM DEFINITION

The two-frequency method of a holographic interferometry is that two holograms of the same object when lighting with different lengths of waves register in one photographic plate and. Equivalent wavelength is defined as [1]

$$\lambda_{eq} = \frac{\lambda_1 \lambda_2}{|\lambda_1 - \lambda_2|} . \quad (1)$$

The difference between lengths of the used waves is less, the more there will be an equivalent wavelength. From the metrological point of view use of a method of two frequencies is more preferable as lengths of waves decide on a smaller error, than corners or indexes of refraction. The main problem when using this method is the complexity of selection of lengths of waves of the laser radiation used for lighting.

This shortcoming is easily overcome when using projective methods in which it is possible to project easily sinusoidal pictures with various periods [2].

For this purpose we receive two series of sinusoidal pictures with various size of period λ_1 and λ_2 .

When using a method of step-by-step phase shift resultant values of a profile will change from 0 to the fringe width. The width of a strip determines object profile size in any units of measure (micrometers, millimeters) at the dynamic range of a phase from 0 to. 2π .

The size of a profile can be determined by the following expression

$$C \cdot h(x,y) = \left[\frac{\Phi(x,y)}{2\pi}\right]\lambda , \quad (2)$$

where – C the system constant depending on the optical scheme, and $\Phi(x,y)$ absolute value of a phase.

Expression which connects a phase - Φ , the width of a fringe and size of a profile $h(x,y)$ has an appearance

$$\Phi(x,y) = \left[C \cdot h(x,y) / \lambda\right] \cdot 2\pi , \quad (3)$$

If we do phase measurements with two lengths of waves λ_1 and λ_2, then the difference of two phases within the period will be defined by the following expression

$$\Delta\Phi_{12} = \Phi_1 - \Phi_2 = \left[C \cdot h(x,y) / \lambda_{12}^{eq}\right] \cdot 2\pi , \quad (4)$$

where - $\lambda_{12}^{eq} = \lambda_1 \lambda_2 / |\lambda_2 - \lambda_1|$ equivalent wavelength.

As a result of two phase measurements with different lengths of waves it is possible to receive only the values defined within the period from 0 to for φ_1 and φ_2 . The absolute phase 1, is connected with the relation $\varphi = \Phi \ (\mathrm{mod}\ 2\pi)$. Using this expression from (4) it is possible to receive

$$\begin{aligned} \Delta\phi_{12} &= \Delta\Phi_{12} (\mathrm{mod}\ 2\pi) = \\ &= \left[\Phi_1 - \Phi_2\right] (\mathrm{mod}\ 2\pi) = \left[\varphi_1 - \varphi_2\right] (\mathrm{mod}\ 2\pi) = . \quad (5) \\ &= \left\{\left[C \cdot h(x,y) / \lambda_{12}^{eq}\right] \cdot 2\pi\right\} (\mathrm{mod}\ 2\pi) \end{aligned}$$

The work is supported by the Russian Foundation for Basic Research (grant № 18-08-00580).

978-1-5386-7054-5/18/$31.00 ©2018 IEEE

Thus, if to synthesize equivalent wavelength λ_{12}^{eq}, then the period of the interferential fringe corresponding to it will be more, than the measured range, then a problem of elimination of phase ambiguity will be solved within the range determined by equivalent wavelength.

Expression (5) is as follows:

- determine the phase difference;
- если, то к $\varphi_1 - \varphi_2$ добавляем.
- we define the difference of phases $\varphi_1 - \varphi_2$;
- if $(\varphi_1 - \varphi_2) < 0$, then to we add 2π.

Let the fringe width (the period size) be expressed in pixels. If to take phase distributions of points $\lambda_1 = 60$ and $\lambda_2 = 90$, then equivalent wavelength will be $\lambda_{12}^{eq} = \lambda_1\lambda_2 / |\lambda_2 - \lambda_1| = 60 \cdot 90 / (90 - 60) = 180$ points (fig. 1).

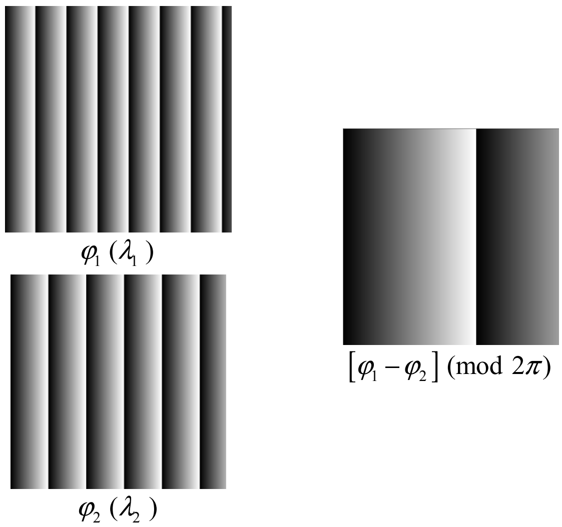

Fig. 1. Full phase recovery using an equivalent wavelength.

The algorithm is rather simple therefore now it is the most widespread algorithm of expansion of range of phase measurements. The algorithm well works if the initial phases defined within the period are defined precisely. However, if phases decide on some mistake, the error of definition of a profile sharply increases. At precision measurements it limits a method scope.

III. OFFERED THE ALGORITHM

Let us have four interferential pictures with phase shift between them 0, 90, 180 and 270 degrees (fig. 2 at the left) with a margin error 20% of value of amplitude of a sinusoid. The error is modelled by addition of casual noise to value of a sinusoidal picture.

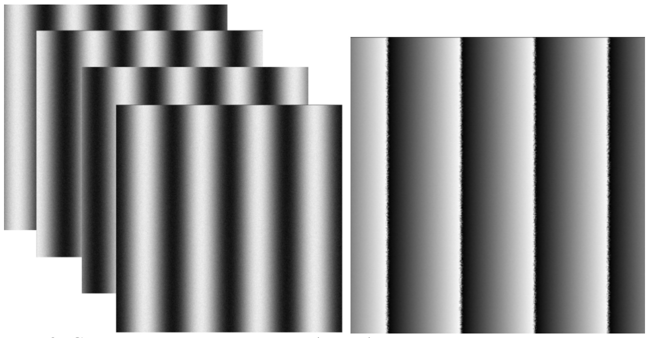

Рис. 2. Синусоидальные картины (слева) и восстановленное по ним фазовое распределение в диапазоне от 0 до 2π (справа).

On sinusoidal pictures it is fixable phase distribution (fig. 2 on the right) method of step-by-step phase shift by means of expression

$$\phi(x, y) = \arctan\frac{I_4 - I_2}{I_1 - I_3}. \qquad (6)$$

At 20% of casual noise of amplitude of the set sinusoids the error of definition of a phase will make about 6.64% from at a sinusoid with the period of 60 and 7.2% at a sinusoid with the period 90. (fig. 3). Decrease in an error when determining a phase is explained by the filtering properties of expression (6). For this formula of interpretation decrease in an error makes about 3 times.

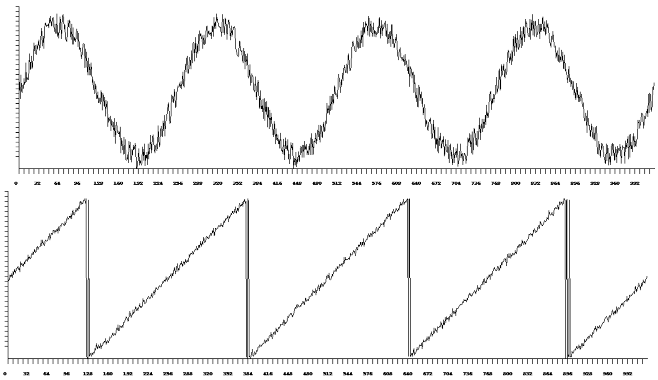

Fig. 3. The schedule on the central section of one sinusoid with the period of 256 points and 20% noise and phase distribution in the range from 0 to 2π.

Choosing the different period of sinusoids it is possible to receive distribution of phases with various periods. From two sinusoidal sets with the period of 60 and 90 pixels (all field 1024) we will receive two phase distributions φ_1 and φ_2 by which it is possible to determine $\varphi_{12} = \varphi_1 - \varphi_2$, if $\varphi_{12} < 0$, then to φ_{12} it is added 2π (fig. 4). The period φ_{12} is equal to the period of equivalent wavelength - 180 pixels.

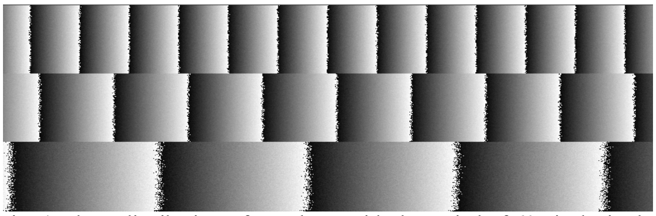

Fig. 4. Phase distributions: from above with the period of 60 pixels, in the center with the period equal to the equivalent wavelength of 90 pixels, from below with the period equal to the equivalent wavelength of 180 points.

The phase φ_{12} is formed by the difference of phases φ_1 and φ_2, her error increases twice in comparison with errors of these phases respectively.

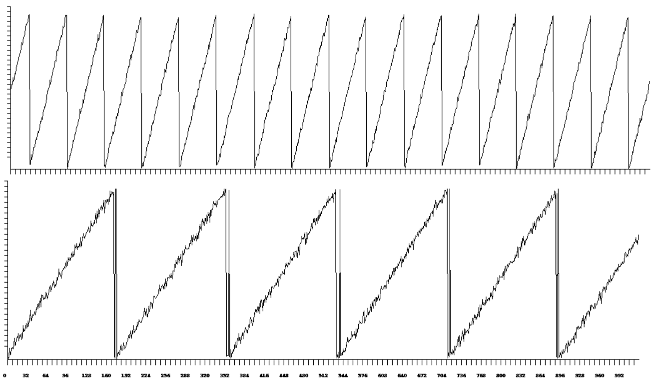

Fig. 5. Schedules on a line of phase distributions: with the period of 60 pixels (above), with the period equal to the equivalent wavelength of 180 points (below).

The profile of the measured surface can be defined as (7)

$$C \cdot h(x,y) = [\varphi_{12}]\lambda_{eq},. \quad (7)$$

Thus, the value of an error when determining a profile of an object grows in proportion to increase in equivalent wavelength.

From the schedule of the phase distribution corresponding to the equivalent wavelength (the lower part of fig. 5) it is visible that the error increases upon transition through zero. She can be reduced if to consider error size

$$\begin{aligned} &\varphi_{12} = \varphi_1 - \varphi_2, \\ &if \;\; \varphi_{12} < -\pi \cdot noise/3 \Rightarrow \varphi_{12} = \varphi_{12} + 2\pi \end{aligned}, \quad (8)$$

where *noise* - noise level at a task of a sinusoidal picture. The size of noise shares on 3 as when determining a phase approximately noise size is so reduced.

Accuracy of measurements is inversely proportional to wave length. Therefore calculations with a big equivalent wave give a big error. These measurements can be used for deployment of a phase in the opposite direction for other lengths of waves with the smaller period. Therefore it is possible to offer the following algorithm at which loss of accuracy doesn't happen.

We will define an object profile by expression (7) and we will subtract from him the profile received at the minimum wavelength (fig. 6).

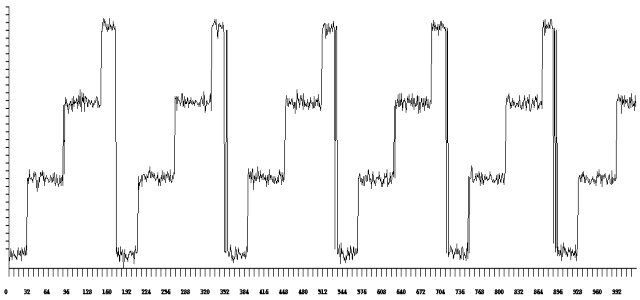

Fig. 6. The difference of a profile with the period equal to equivalent wavelength in 180 points and a profile with the period of 60 pixels.

From the figure 6 it is visible that the platforms corresponding to addition of transitions through the period have rather strong noise. For lack of noise of the platform have to be straight lines. For this purpose whole from division of a difference of a profile is enough to take of the next on. Then to increase this size on $\pi \cdot \lambda_1$. As a result we will receive the direct platforms corresponding to transitions through the period (fig. 7).

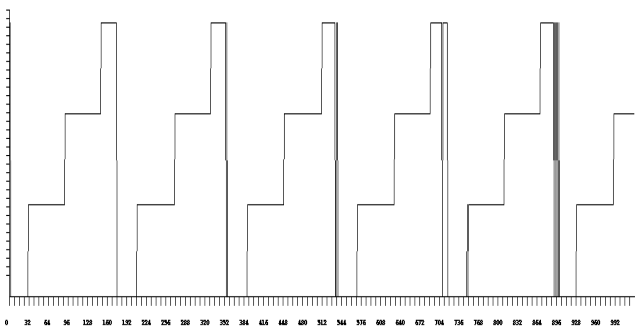

Fig. 7. The difference of a profile with the period equal to the equivalent wavelength of 180 points and a profile with the period of 60 pixels without computing errors.

Adding to him value of a profile at the minimum period we will receive (fig.8). At a large number of strips the best results are yielded by an algorithm of elimination of phase ambiguity, with interferential strips the periods of which are coprime [3]. Significant increase in area of phase unambiguity is possible when using several phase pictures with various periods.

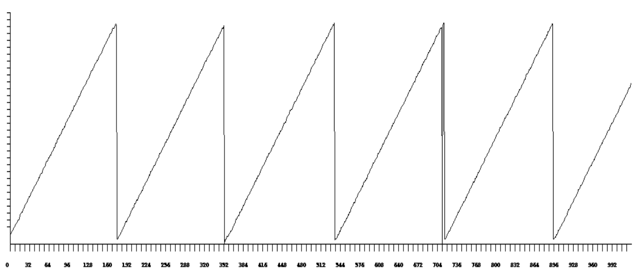

Fig. 8. A profile with the period equal to equivalent wavelength and with the minimum error.

IV. Conclusion

The new way of definition of a phase at a multifrequency method of elimination of phase ambiguity is presented. The way is based on combination of integer values of a phase of the initial lengths of waves received for equivalent wavelength with average values of a phase that allows to eliminate effect of accumulation of an error and to respectively lower the general error of definition of a phase.

REFERENCES

[1] De S.T., Kozachok A.G., Loginov A.V., Solodkin YU.N. Izmerenie parametrov rel'efa poverhnostej metodom dvuhdlinnovolnovoj holograficheskoj interferometrii. // Golograficheskie izmeritel'nye sistemy: Sb. nauchnyh trudov. – NEHTI. – Novosibirsk. – 1976. – pp.23 – 29. (in Russian).

[2] WangY., Zhang S. Superfast multifrequency phase-shifting technique with optimal pulse width modulation. – Optics Express. – 2011. – Vol. 19, No. 6, pp.5149 – 5155

[3] Guzhov V.I. Metody izmereniya 3D profilya ob"ektov. Fazovye metody.: Ucheb.posobie. – Novosibirsk: Izd-vo NGTU, 2016. – 83p. (in Russian).

Vladimir Guzhov is professor of SSOD department of faculty of Automatic equipment and computer facilities in Novosibirsk State Technical University, the Doctor of Engineering. He is an author more than 200 scientific works. Area of scientific interests: program systems, high-precision measurements.

Sergey Ilinykh is associate professor department of faculty of Automatic equipment and computer facilities in Novosibirsk State Technical University, Candidate of Technical Sciences, the associate professor. He is an author more than 130 scientific works, including 1 textbook of NGTU and 4 patents. Area of scientific interests: development of analysis algorithms of images in optical measuring systems.

Grigory Pozdnyakov is the graduate student of SSOD department of faculty of Automatic equipment and computer facilities in Novosibirsk State Technical University.