The Elimination of the Phase Ambiguity in Projective Methods

V.I. Guzhov, S.P. Ilinykh, A.R. Vagizov, R.A. Kuznetsov
Novosibirsk State Technical University

Abstract: **The algorithm eliminate the phase ambiguity in projection method of measurements of the surface topography. The method involves the projection of the object arrays with different period. The full difference of stroke are determined on the basis of the analysis of the trajectory of the measured signals.**

***Keywords*: projection; interference; data processing algorithms; unwrapping phase.**

I. INTRODUCTION

In a number of practical tasks along with the traditional contact methods of measurement of the surface shape are widely used optical methods. Especially relevant is the application of these methods in such areas, where there is a need for non-invasive method of measurements of the surface shape, and in most cases the measured surface is not fixed on the measuring device.

The main method, which is used in the optical systems for measuring the surface form a three-dimensional objects, is the method of the projection of the bands [1-3].

Field brightness $I(x,y)$ is of the form

$$I(x,y) = A(x,y) + B(x,y)\cos(\Phi(x,y)) , \quad (1)$$

where - $A(x,y)$ is the average brightness, $B(x,y)$ - amplitude strips, $\Phi(x,y)$ - complete phase.

$$\Phi(x,y) = \phi(x,y) + 2\pi N(x,y) , \quad (2)$$

where $N(x,y)$ is the number of whole periods 2π laid in full optical phase difference (full phase) - $\Phi(x,y)$, $\phi(x,y)$ - local phase corresponding to the fractional part of the full phase $\Phi(x,y)$.

Instead of the phase difference of interfering waves Φ it is convenient to introduce into consideration the proportional her value of the difference of the optical (optical path difference) - Λ. Complete the difference of the connected with the complete phase as follows:

$$\Lambda = \frac{\lambda}{2\pi}\Phi = \frac{\lambda}{2\pi}(\phi + 2\pi N) = \delta + \lambda N , \quad (3)$$

where δ is the local the difference of the corresponding local phase ϕ.

The definition of a number of periods is called the elimination of the phase ambiguity [4]. This problem is difficult in the presence of noise. For the first time for the solution of this problem Guzhov V.I. and Solodkin Y.U. (1991) approach was proposed, in which the absolute value of the phase is calculated directly. The approach is based on the Chinese Reminder Theorem [5]. Сущность подхода состоит в том, что измеренные значения локальных фаз переводят в локальные разности хода, которые выражают в виде целых значений с необходимым числом знаков, соответствующих необходимой точности измерения. Полные разности хода - находят путем решение целочисленной системы сравнений:

The essence of the approach lies in the fact that the measured values of local phases ϕ are transferred to a local differential of the path δ, which is expressed in the form of integer values with the necessary number of digits, corresponding to the required accuracy of the measurement. The full difference path - Λ find the way of solution of the integral system of comparisons:

$$\begin{cases} \Lambda \equiv \delta_1 \bmod m_1 \\ \Lambda \equiv \delta_2 \bmod m_2 \end{cases} . \quad (4)$$

The maximum length of the trajectory $L_{\max} = m_1 \times m_2 - 1$ sets the dynamic range of an unambiguous definition Λ.

In order to find solutions of the system comparisons (4) is used approach based on the application of the extended Euclidean algorithm [6].

Note the shortcomings of this approach. To find the solutions required to fulfill a large number of operations, which, considering the large number of pixels in an image 10^6-10^7 and more, leads to unreasonably long time in the calculations. You need to introduce the results of the measurements to an integral mind, which imposes certain restrictions on the dynamic range of measurements. In addition, the algorithm is sensitive to errors of determination of the local phase.

II. PROPOSED METHODS AND SOLUTIONS

The authors proposed a simple algorithm of definition of the full differential phase that does not have these shortcomings. Let us imagine the solution of the system of comparison, as a path in the complex plane. When you change the phase point (δ_1, δ_2) will move along the diagonals of the trajectory (see *Figure* 1).

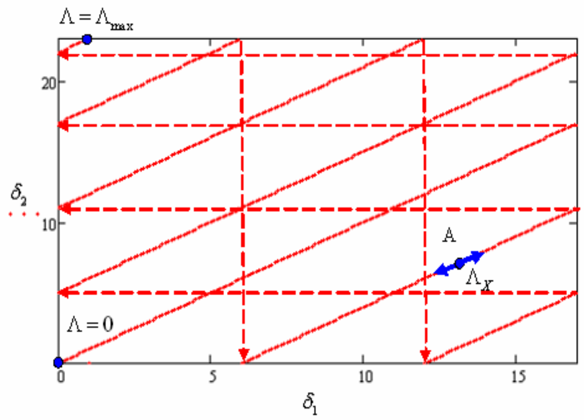


Figure 1. The trajectory of motion of the point (A) with change of phase

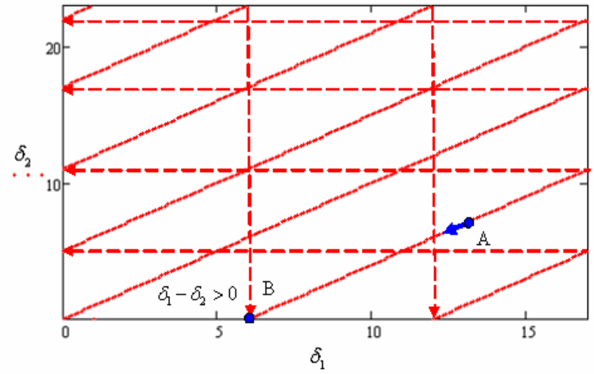


Figure 2. The point lying on the bottom diagonal

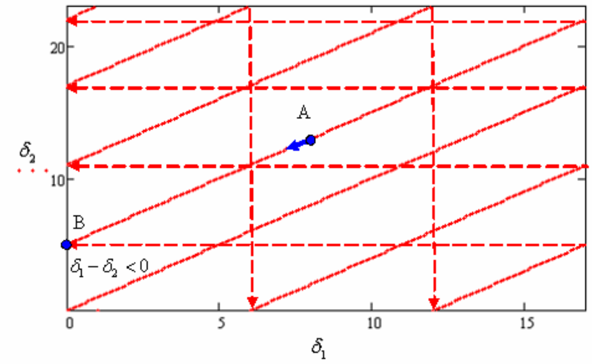


Figure 3. Point is at the top of the diagonal

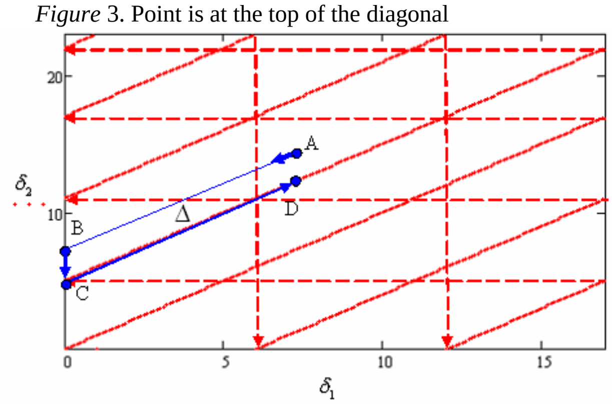
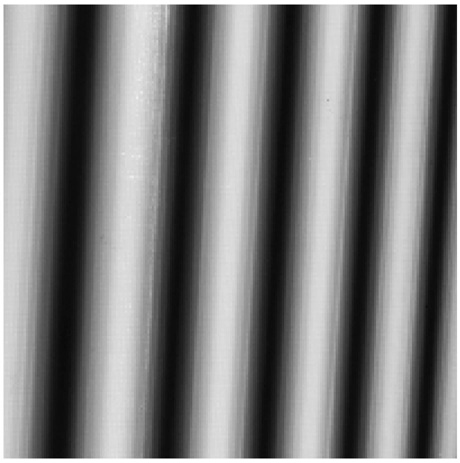
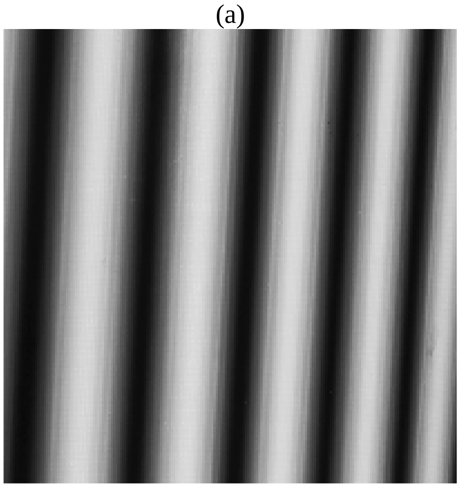


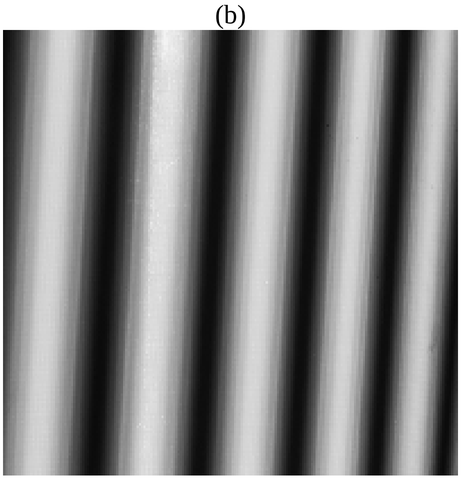
Figure 4. Correction of the position of the point, which is out of the diagonal



(a)



(b)

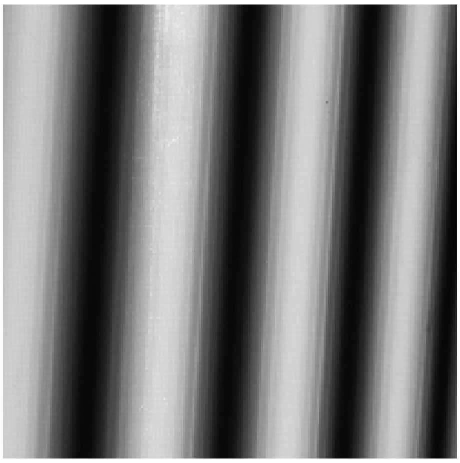


(c)

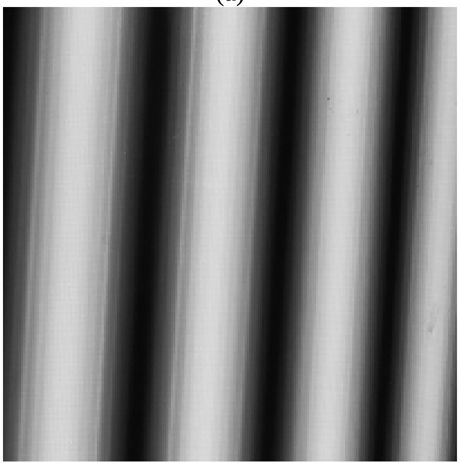
Figure 5. Projection image c period $T = 17$.

(a) -without the shift, (b) - with the grid shift for the period $T/3$, c) - with the grid shift for the period $2T/3$.

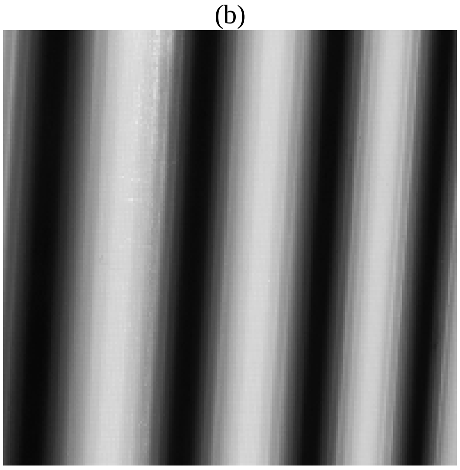
(b)



(a)

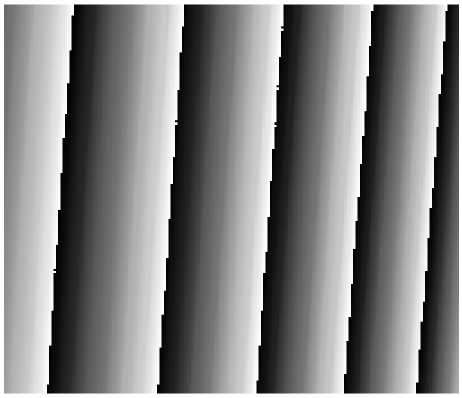


(b)

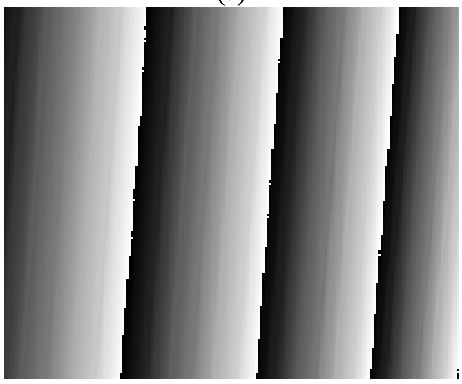


(c)

Figure 6. Projection image c period $T = 23$.
(a) -without the shift, (b) - with the grid shift for the period $T/3$, c) - with the grid shift for the period $2T/3$.



(a)



(b)

Figure 7. Local differential of path ((a) - period $T = 17$, (b) - period $T = 23$)

Figure 8 shows the trajectory of local differences.

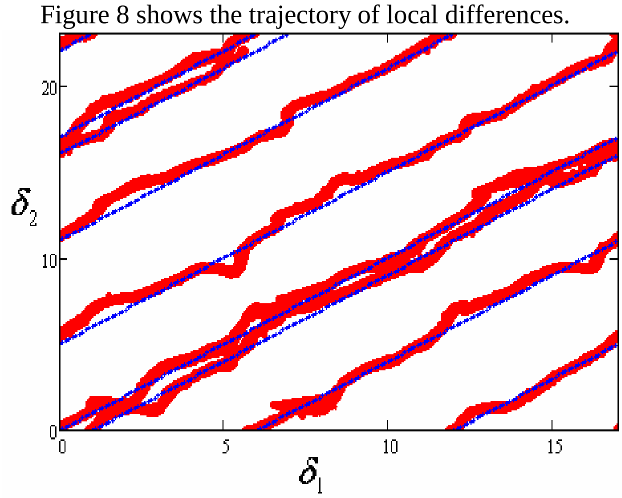


Figure 8. The trajectory of local differences

Complete the difference of the calculated according to the formula

$$\Lambda_X = \Lambda_n + \delta_1 \quad (7)$$

if point is located on the bottom diagonal and according to the formula

$$\Lambda_X = \Lambda_n + \delta_2 \quad (8)$$

if point is located at the top of the diagonal.

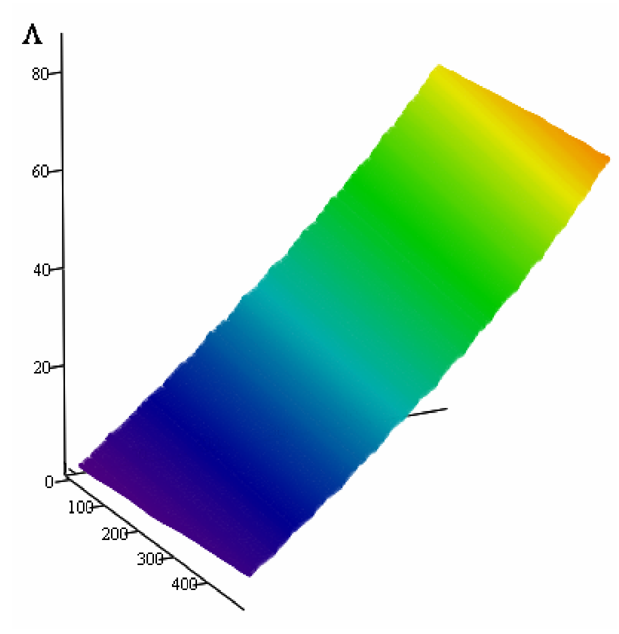


Figure 9. The difference of the path

III. EXPEREMENTS

For practical verification of the proposed technology was used projection system, consisting of the projector (800x600 pixels) and the camera (1600x1200 pixels). The size of the projection image was 2x2 meters. The grating grooves were perpendicular conquers to the plane, which passed through optical axes of illumination system and recording optical system. The optical axes of recording and illumination systems intersected in one point in the object's area. The angle between axes of recording and illumination systems was 10º. The distance between the object's plane and the target's plane was 3 *m*. The arrangement fastened to unmovable platform. The figures of 5.6 shows the projection of the image, obtained with various shifts projection grid for the (0, $T/3$, $2T/3$), where T - the period of the grid $T=17$ (*Figure* 5) and $T=23$ (*Figure* 6). *Figure* 7 shows the local difference of course, the corresponding periods of the projection grids $T=17$ (*Figure* 7a) and $T=23$ (*Figure* 7б).

Figure 9 shows the result of calculating the difference of the progress on the proposed algorithm.

IV. CONCLUSION

We presented a simple algorithm elimination phase ambiguity, which does not require the submission of the initial data in the general form. The algorithm requires a small amount of computation and resistant to measurement errors local phases.

REFERENCES

[1] B. Curless and M. Levoy. through spacetime analysis. In Better optical triangulation ICCV'95, pp. 987–994, 1995

[2] C. Chen, Y. Hung, C. Chiang, and J.Wu. Range data acquisition using color structured and stereo vision lighting Image and Vision Computing, 15(6):445–456, 1997.

[3] C. Guan, L. Hassebrook, and D. Lau, "Composite structured light pattern for three-dimensional video," Opt. Express 11, 406-417 (2003)

[4] V.I. Guzhov, S.P. Ilinykh. Computer interferometry. - Novosibirsk. Publishing office of NSTU, 2004, 252p.

[5] H. Zhao, W. Chen, and Y. Tan, "Phase-unwrapping algorithm for the measurement of threedimensional object shapes," Appl. Opt. 33, 4497–4500 (1994).

[6] T. R. Judge and P. J. Bryanston-Cross "A review of phase unwrapping techniques in fringe analysis," Opt. Lasers Eng. 21, 199–239 (1994)

[7] Zolotaryov V.V., Ovechkin G.V. Error-correcting coding. Methods and algrorithms. Reference. - Moscow. Publishing office «Hot line-telecom», 2004, 126 p.

Vladimir Guzhov is dean of the faculty of Automatics and Computer Engineering in Novosibirsk State Technical University, professor, doctor of technical sciences. He is the author of 120 science papers including 4 patents. The science interests and competence field is program systems, high accuracy measurements.

E-mail: vig@edu.nstu.ru

Sergey Ilinykh is assistant-professor inNovosibirsk State Technical University, professor, PhD. He is the author of 50 science papers including 4 patents and 1 high school-book. The science interests and competence field is, program systems, laser systems.

E-mail: i sp51@yandex.ru

Alexander Vagizov is undergraduate student in Novosibirsk State Technical University. The science interests and competence field is optical measurement systems, high accuracy measurements. E-mail: famas-yandex.ru