Optoelectronic System for Roll Angles Measuring of Maneuvering Objects Based on Anamorphosis Effect

I A Konyakhin, A D Merson and D Y Zubenko
Dept. of Optic-electronics Devices and Systems, Institute of Fine Mechanic and Optics, 14 Sablinskaya Str., St.-Petersburg, Russian Federation 197101
E-mail: oeps@grv.ifmo.ru

Abstract. The objects mutual displacement measurement is an important task, particularly, the measuring of roll angles. New method for roll angles measuring of maneuvering objects based on anamorphosis effect is developed. Optical scheme for whole measurement system and for anamorphosis element is proposed. Equation for the static characteristic of the system and its graphical representation are showed.

1. Introduction
One of the major problems today is a objects mutual displacement measurement. In instrument making it is a control of geometrical parameters of the products and of their spatial position, in construction – it is a control of separate elements and of whole construction, in a robotics and navigation - location determination of any objects in the certain fixed coordinate system. There are contact and contactless methods of the mutual displacement measurement. Obviously contactless methods are exactly most perspective since they allow to measure displacement of the object inaccessible to direct contact - for example at the high altitude, at heats, etc. The methods of mutual displacement measurement of the objects can be divided into linear displacement measurement methods and a roll angles measurement methods. In this paper the method for mutual rotation angles measurement of two objects around an imagine axis between them is offered.

2. Existing roll angles measurement system
One of the applications of these methods is a roll angles measurement of two satellites during the docking. The existing one control system is implemented as shown on figure 1.

Two radiation sources are placed on the first satellite and a receiving system is placed on the second. Radiation sources images are rendered on the CCD-matrix receiving system is based on. Then sources images coordinates are measured and thus roll angle $\varphi$ is calculated. But there is a couple of disadvantages in such approach. Those are insufficient accuracy and influence of distance changes between objects[2].
3. Roll angles measurement system based on anamorphosis effect

Disadvantages of existing method can be avoided with using of anamorphosis based system. Optical scheme of such system is shown on the figure 2.

Figure 2. The optical scheme of roll angles measurement system based on anamorphosis effect.

Autocollimator 1 installed on the first object, includes radiation source 2, aperture-mark 4, objective 6 and semireflection mirror 5. Receiving channel includes CCD-matrix 7 and a digital video-processing system. Reflector 8,9 installed on the second object, includes anamorphosis system 8 and retroreflector 9.

This system works as follows. Collimated beam formed from the mark 4 by the autocollimator objective 6, is guided to the reflector 8,9. One half of the beam pass through anamorphosis telescopic system 8 and retroreflector 9 in forward trace, whereas another half – in backward trace after retroreflector. Objective 6 projects mark image transformed by the anamorphosis telescopic system 8 to the CCD-matrix 7 through which image goes to the digital video-processing system.

Mark is a square with diagonals lies in a meridional plane and a saggital plane. Aperture the mark formed by is shown on figure 3a. Aperture image in autocollimator objective focal plane is shown on figure 3b.
Figure 3. (a) Square mark. (b) Mark image in autocollimator objective focal plane.

Anamorphosis telescopic system 8 shown on figure 4 consists of two wedges 8, 8'. Wedges are installed one-by-one so that incident rays angles $\varepsilon_1, \varepsilon_3$ and refracted rays angles $\varepsilon'_1, \varepsilon'_3$ on the first edge of wedges equals to zero and angles of the beam deflection after wedges has opposite sign ($\beta$ and $-\beta$).

Figure 4. Anamorphosis telescopic system.

As result of mark image processing we get parameters $\bar{X}$ and $\bar{Y}$. Roll angle $\varphi$ then

$$\varphi = \frac{1}{2} \arccos \left( \frac{\bar{Y} - \bar{X}}{\bar{Y} + \bar{X}} \right) \left( \frac{A+1}{A-1} \right),$$

where the anamorphosis coefficient of telescopic anamorphosis system is

$$A = \frac{1 - \sin^2 \theta}{1 - n^2 \sin^2 \theta}.$$

When controlled object being rotated, reflector 8,9 rotates along with it. The form and size of the mark image being changed because of anamorphosis system principal profile rotation. Figure 5 shows the mark image on different roll angles of the object.
During image processing the video-processing system measures value
\[ \eta = \vec{Y} - \vec{X} = (A - 1) \cdot \cos 2\varphi \]

The system sensitivity is
\[ \frac{d\eta}{d\varphi} = -2 \cdot (A - 1) \cdot \sin 2\varphi \]

The static characteristic of whole measurement system for \( A = 2 \) is shown on figure 6.

**Figure 6.** The static characteristic of the anamorphosis based measurement system.

4. Conclusion
The new method for roll angles measurement based on anamorphosis effect is developed. The use of this method allows to increase measurement accuracy and to avoid of distance influence. This method can be used in many different technological fields, for example – in the space technology.

References
[1] A. L. Andreev, I. A. Konikahine and E. D. Pankov 1995 Problems of designing of optico-electronic systems for determination of a mutual position in the space of objects or their elements *The Optical Journal. (J. of Optical Technology)* 8 8-12