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Review

Analysis and correction of axis error in periscope-type optical communication terminals

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ABSTRACT

Highly precise pointing is needed in satellite optical communication systems because of the extremely narrow laser beam. The axis error angles can cause large pointing error angles. In this paper, the matrixes of the axis error angles were given through geometric optics. And the models of pointing error angles caused by the axis error angles were built in the periscope-type optical communication terminals. The models show that the pointing error angle of azimuth axis increases quickly when the elevation angle θ_{EL} is approximate to 0° or 180°. The correction of axis' error has been performed and the pointing error angles have been corrected. This work provides the theory that can benefit the design and assembling of periscope-type optical communication terminals, and it can amend the pointing error angles caused by axis error angles during working. Besides, according to these models, some optical elements, whose position errors cause pointing error angles, can be researched by quantitative analysis.

Contents

1. Introduction

With the development of information, network technology, and the requirement of high data rate, long-distance communication technology become much stronger. Satellite optical communication technology can meet these requirements and provide higher quality link with a higher-capacity data, higher data rate, higher security, stronger anti-interference ability, larger link distance at lower size, weight and power [1–3] than satellite radio frequency communication. Therefore, more and more scientists from different countries are interested in optical communication technology. At present, many satellite optical communication terminals utilize the periscope as the coarse pointing apparatus (CPA) because its moment of inertia is smaller, its requirements for motor control is lower and its design of temperature control is easier than the gimbals-type CPA's [4,5].

For the satellite optical communication system, a narrow laser beam requires highly precise pointing. The pointing error will reduce the acquisition probability of the optical communication link [6,7], and even make the building of communication link unsuccessful [8].

Some papers on the pointing error in the optical communication terminal have been published. In references [9–11], the authors have analyzed the probability distribution of the pointing

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error in optical communication terminals, they did not give the influences of the individual components' error on pointing error. However, the influences of the individual components' error, especially some key components, are vital factors in the design and analysis of periscope-type CPA.

The axis error is one of the key factors which cause pointing error in the periscope-type CPA. It will deflect the beam axis from the machinery axis of CPA, and the relative location between them changes with pointing angles (azimuth angle θ_{Az} and elevation angle θ_{El}). Therefore, the pointing error angles brought by axis error angles of periscope-type CPA vary complexly, and it is very necessary to study the relationship between pointing error angles and axis error angles in periscope-type CPA.

In paper [12], a compensating algorithm of correcting the mirror errors has been provided, but the model of the mirror errors has not been given and it make the control system of the Fine Pointing Apparatus complex. In this paper, we create the models of axis error angles in the periscope-type CPA, and we utilize geometric optics and transformation of coordinates to build the models of the pointing error angles caused by axis error angles. For the first time, there are models used to describe the relationship between the axis error angles and pointing error angles. Through these models, the key error angle of azimuth axis and elevation axis can be reduced during assembling process of the periscope-type CPA. Also, the pointing error angles can be corrected by these models with precise axis error angles. Besides, these models offer an approach for researching influences of optical device's position error which can cause pointing error.

The paper is organized as follows. Section II defines three coordinate systems of the CPA. Section III builds the models of axis error angles. The relationship between azimuth axis' error and elevation axis' error is analyzed in Section IV. The correction test is performed in Section V. The conclusion is given in Section V.

2. Definition of coordinate system

It is very essential to analyze the relationship between axis error angles and pointing error angles in periscope-type CPA. At present, many satellite optical communication terminals utilize

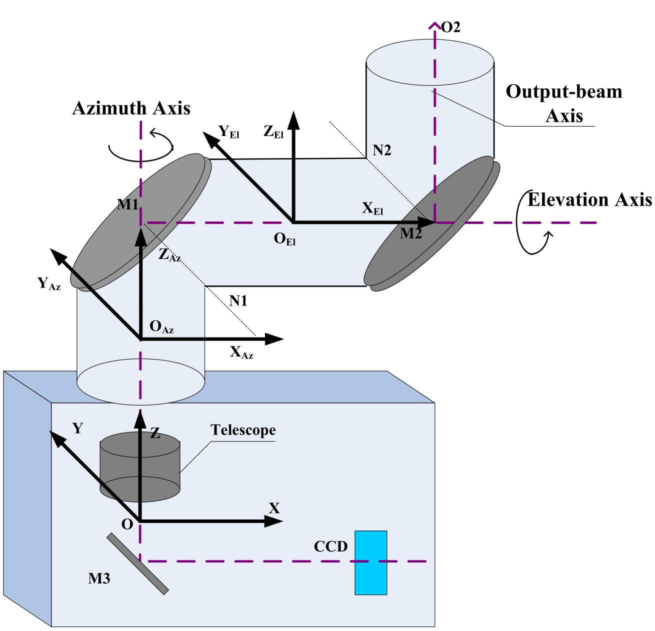

Fig. 1. Coordinate system in the CPA.

the periscope as the CPA. The periscope-type CPA is different from gimbals-type CPA in which the beam axis is fixed on the machinery axis. In the periscope-type CPA, the relative position between the beam axis and the machinery axis changes with azimuth angle θ_{Az} and elevation angle θ_{El}. Therefore, spherical trigonometry which is utilized in gimbals-type CPA cannot be utilized in periscope-type CPA [13–15]. In this paper, the geometric optics is used to research the influence of axis error angles on pointing error angles in periscope-type satellite optical communication terminals. Here, it is necessary to define three coordinate systems in the CPA before building the model.

2.1. Basic coordinate system of the terminals

As shown in Fig. 1, the coordinate system *XYZ* is the basic coordinate system of the terminals. The vector along optical axis of the telescope is the *Z* of the coordinate system *XYZ*. Then the vector from the center of mirror *M*3 to the center of CCD C1 is the *X*. *Y* can be defined by the right hand. When the azimuth axis angle is 0°, the elevation axis parallels to the vector *X*, and when the elevation axis angle is 0°, the output beam axis parallels to the vector Z.

2.2. Coordinate system of the azimuth axis

As shown in Fig. 1, the vector along azimuth axis is the Z_{Az} of the coordinate system $X_{Az}Y_{Az}Z_{Az}$. Then the vector along elevation axis is the X_{Az} of the coordinate system $X_{Az}Y_{Az}Z_{Az}$. And Y_{Az} can be defined by the right hand. When the azimuth axis angle is 0°, the elevation axis parallels to the vector *X*. The coordinate system $X_{Az}Y_{Az}Z_{Az}$ is the basic coordinate system, around which the CPA turns.

2.3. Coordinate system of the elevation axis

As shown in Fig. 1, when the azimuth plane mirror and the elevation plane mirror parallel to each other, the vector along the output beam axis is the Z_{El} of the coordinate system of the elevation axis. Then the vector along elevation axis is the X_{El} of the coordinate system $X_{El}Y_{El}Z_{El}$, and the Y_{El} can be defined by the right hand. The same as the coordinate system of the azimuth axis, the coordinate system $X_{El}Y_{El}Z_{El}$ is the basic coordinate system, around which the CPA turns.

Ideally, the coordinate axes with the same name in the base coordinate system of the terminals and the coordinate systems of the axis strictly parallel to each other (X_{Az} parallels to *X*, Y_{Az} parallels to *Y*, Z_{Az} parallels to *Z*, and X_{El} parallels to *X*, Y_{El} parallels to *Y*, Z_{El} parallels to *Z*). However, because of axis error angles, they are not parallel to each other anymore. Due to axis error angles, the coordinate system $X_{Az}Y_{Az}Z_{Az}$ and $X_{El}Y_{El}Z_{El}$ deviate from the basic coordinate system of the terminals.

3. Building model of pointing error due to axis error angles

3.1. Model of the error angles of azimuth axis

Due to the limitation of machining and assembly precision, there are azimuth axis' error angles in the periscope-type CPA. These error angles deviate the coordinate system of the azimuth axis from the basic coordinate system of the terminal. As shown in Fig. 2, the coordinate system *XYZ* is the basic coordinate system of the terminal and the coordinate system $X_{Az}Y_{Az}Z_{Az}$ is the coordinate system of the azimuth axis. The *XYZ* could be transformed to $X_{Az}Y_{Az}Z_{Az}$, and the angles are brought by the error angles of azimuth axis. Here, ϕ_{Az_z}, ϕ_{Az_yz} and ϕ_{Az_xy} are the error