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Velocity correction of the Janus configuration laser Doppler velocimeter

Nie Xiaoming *, Zhou Jian, Long Xingwu

Department of Optoelectronic Engineering, College of Optoelectronic Science and Engineering, National University of Defense Technology, Changsha 410073, China

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ABSTRACT

The error of laser Doppler velocimeter (LDV) based on Janus configuration is analyzed as the vehicle inclines. Analysis shows that the error of the Janus configuration LDV depends on the vertical velocity to horizontal velocity ratio (VHR) only. But the measurement accuracy of the Janus configuration LDV will be not high enough to meet the requirement of vehicle self-contained navigation system, if the VHR of the vehicle is overlarge in powerful rough ground. The error of the Janus configuration LDV is corrected through an inclinometer whose precision of angle needed is only 2%. Simulation shows that the error of the Janus configuration LDV after correction can be limited below 0.1% even as the VHR reaches 0.3 and pitch angle is 15°.

1. Introduction

Since Yeh and Cummins demonstrated the possibility of obtaining the fluid velocity through laser Doppler frequency shift [1], LDV has enjoyed widespread use including biomedicine, mechanics, astronautics, and acoustic for the advantages of fast dynamic response, wide dynamic range, good linearity, non-contact measurement and high resolution [2–6]. Recently, our attempts using an LDV to offer velocity parameter for the vehicle self-contained navigation system (VSNS) have been reported [8]. On the occasion that the vehicle pitches while moving, the velocity error of conventional LDV occurs. A Janus configuration LDV is proposed in order to decrease the influence of vehicle inclination [9,10]. The LDV system producing forward and backward beams is called a Janus configuration LDV. Janus configuration has been employed in acoustic Doppler logs conventionally [7]. Due to the Janus configuration, the influence of the vehicle pitching is eliminated. However, the measurement accuracy of the Janus configuration LDV will be not high enough to meet the requirement of VSNS, if the vertical velocity to horizontal velocity ratio (VHR) of the vehicle is overlarge in powerful rough ground. In the paper, the error of the Janus configuration LDV is analyzed as the vehicle inclines. Moreover, the measured velocity of the Janus configuration LDV is corrected with the help of an inclinometer whose precision of angle needed is only 2% while the VHR of the vehicle is overlarge. The layout of this paper is as follows. It is briefly introduced in Section 2 that the basic principle of the LDV system based on Janus configuration and the velocity error while the vehicle inclines and shakes. In Section 3, the velocity correction and the simulation results are presented. Section 4 is the conclusion of the paper.

2. Principle and velocity error of the LDV

2.1. Principle of the single-beam LDV

The diagram of the single-beam LDV is shown in Fig. 1. When the beam of the LDV emitted to the ground, the frequency of the scatted light is shifted compared with the emitted light.

The shifted frequency is called Doppler frequency, which is given by [11]:

$$f_D = 2\frac{|\vec{v}\cdot\vec{e}|}{\lambda} = 2\frac{v\cdot\cos\alpha}{\lambda} \quad (1)$$

where v is the velocity of the vehicle, λ is the wavelength of the light, α is the angle between the velocity of the vehicle

* Corresponding author. Tel.: +86 15116340851; fax: +86 073184576314.
E-mail address: thudpim@gmail.com (X. Nie).

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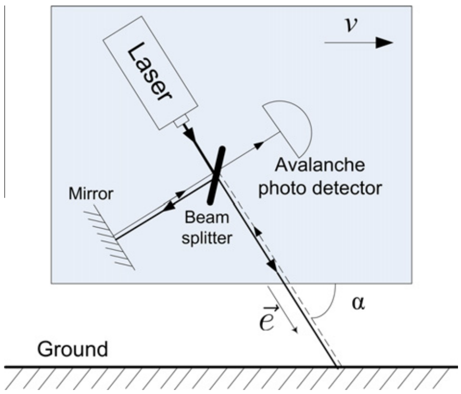

Fig. 1. Diagram of the single-beam LDV.

and the emitted light. From Eq. (1), we can see that the Doppler frequency depends on not only the velocity of the vehicle but also emitted angle. When the vehicle inclines, there will be a velocity error of the LDV. So a system of LDV based on Janus configuration is proposed in order to decrease the influence of the pitch angle.

2.2. Principle of the Janus configuration LDV

The diagram of the Janus configuration LDV is shown in Fig. 2. There are two single-beam LDVs. One's beam is emitted towards the moving direction and the other one's beam is emitted towards the anti-direction of moving. The emitted angles of both LDV are equal.

The Doppler frequencies of the two LDVs can be obtained as

$$f_{D1} = 2\frac{|\vec{v}_x \cdot \vec{e}_1 + \vec{v}_z \cdot \vec{e}_1|}{\lambda} = 2\frac{v_x \cos(\alpha - \Delta\alpha) - v_z \sin(\alpha - \Delta\alpha)}{\lambda} \quad (2)$$

$$f_{D2} = 2\frac{|\vec{v}_x \cdot \vec{e}_2 + \vec{v}_z \cdot \vec{e}_2|}{\lambda} = 2\frac{v_x \cos(\alpha + \Delta\alpha) + v_z \sin(\alpha + \Delta\alpha)}{\lambda} \quad (3)$$

where v_x and v_z is the horizontal and vertical velocity of the vehicle respectively; $\Delta\alpha$ is the pitch angle of the vehicle.

From Eqs. (2) and (3), we can obtain

$$\Delta\alpha = a\tan\left[\frac{(f_{D1} + f_{D2})k\tan\alpha + (f_{D1} - f_{D2})}{(f_{D1} + f_{D2})\tan\alpha - (f_{D1} - f_{D2})k}\right] \quad (4)$$

$$v_x = \frac{\lambda(f_{D1} + f_{D2})}{4\cos\alpha\cos\Delta\alpha} - v_z \tan\Delta\alpha \quad (5)$$

where $k = v_z/v_x$ is the VHR.

If $v_z \ll v_x$ Eqs. (4) and (5) can be simplified to

$$\Delta\alpha' = a\tan\left[\frac{f_{D1} - f_{D2}}{(f_{D1} + f_{D2})\tan\alpha}\right] \quad (6)$$

$$v'_x = \frac{\lambda(f_{D1} + f_{D2})}{4\cos\alpha\cos\Delta\alpha'} \quad (7)$$

v'_x will be taken as the result of the velocimeter. Therefore the velocity error is immediately calculated

$$\beta = \frac{v'_x - v_x}{v_x} = \left(\frac{\cos\Delta\alpha}{\cos\Delta\alpha'} - 1\right) + k\cdot\frac{\sin\Delta\alpha}{\cos\Delta\alpha'} \quad (8)$$

For further calculation the following simplification is applied

$$M = \frac{f_{D1} - f_{D2}}{f_{D1} + f_{D2}} \quad (9)$$

According to Eq. (4), M can be resolved as

$$M = \frac{(\tan\Delta\alpha - k)\tan\alpha}{1 + k\cdot\tan\Delta\alpha} \quad (10)$$

With respect to Eqs. (6) and (10), $\Delta\alpha'$ is calculated as

$$\Delta\alpha' = a\tan\left(\frac{M}{\tan\alpha}\right) = a\tan\left(\frac{\tan\Delta\alpha - k}{1 + k\cdot\tan\Delta\alpha}\right) \quad (11)$$

Substitute Eq. (11) into Eq. (8), the velocity error is further simplified as

$$\beta = \sqrt{1 + k^2} - 1 \quad (12)$$

This is the relative error of velocity of the Janus configuration LDV. As can be seen from Eq. (12), the velocity error β obviously only depends on the VHR and is insensitive with the pitch angle.

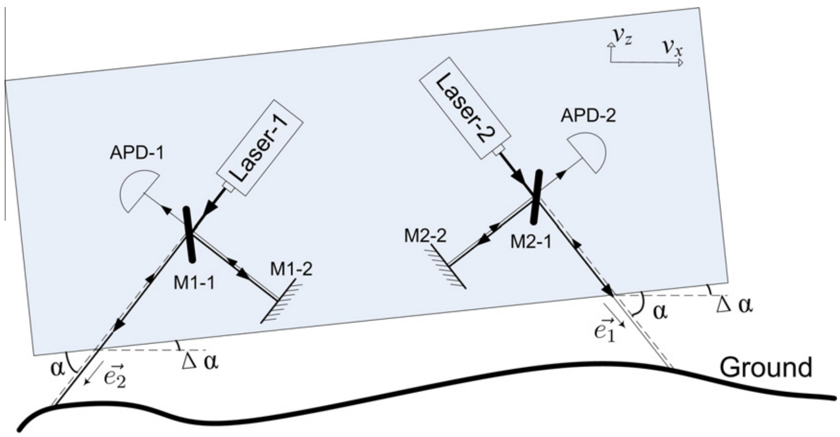

Fig. 2. Diagram of the Janus configuration LDV.