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IEICE Communications Express, Vol.1, 1–6

Estimations for Train Speed based on Two-Frequency CW and Initial Experiments on Railway Environments

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Abstract:

Estimation methods based on two-frequency continuous wave modulation (2FCW) for the train speed which are not affected by idling and slide of wheels are presented. The initial experimental results on the railway environments are also shown. The proposed methods obtained stable estimation results even in the situation where there exists shielding objects. The nonlinear least square method with an unknown quantity had the smallest standard deviation in the environment where the height of ballast track bed was not changed. The nonlinear least square method with two unknowns had the smallest bias errors between the estimation results and GPS speedometer.

Keywords: Radar, 2FCW, Train speedometer

Classification: Sensing

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1 Introduction

The speed monitoring of the railway train is one of the most important factor for railroad safety. There are many methods to measure the speed of the trains. The speed of train is generally obtained from the rotation speed of a wheel of train [1]. It is also obtained by GPS [2]. The former is affected by the wheel sliding. The latter cannot obtain the speed of train in the situation where the upper side is shielded. In recent years, the speedometer based on radar technique using the Doppler frequency has been developed [3]. In these systems, the method which calculates the speed by using the Doppler frequency and the mounting angle of the antenna is generally adopted. However, the spread of Doppler frequency is a possible cause of error [4]. The pitching of the car during the acceleration and deceleration also cause bias errors as well as the mounting antenna angle error. In this paper, the speed measuring method based on 2FCW which are not affected by the spread of Doppler frequency, the mounting angle, and the pitching of the train is presented. The initial experimental results on the railway environments are also shown.

2 Methods

2.1 Speed estimation calculated by the mounting angle (method (a))

Fig.1 illustrates the relationship between the mounting antenna angle (a) and the spread of Doppler frequency observed in the situation (b), measured the relative velocity and range from each reflection point. The train velocity is calculated by the following equation (1)

$$V_g = \frac{1}{M}\sum_{m=0}^{M-1}\frac{V_m}{\cos(\varphi)} \qquad (1),$$

where m (m=0,1,2...M-1) and θ denote the number of Doppler frequencies that exceed the given threshold and the mounting antenna angle, respectively. This method calculates the speed by the Doppler frequency and the mounting antenna angle. Thus the method is generally adopted in previous research using unmodulated CW radar. However, the spread of Doppler frequency due to the beam width is possible to be the cause of error. The mounting antenna angle error and the pitching of the car during the acceleration and deceleration may also make bias errors, although the method itself is very simple.

2.2 A nonlinear least square method with an unknown quantity (method (b))

Two-frequency continuous wave modulation (2FCW) is a simple and common modulation technique which can obtain range information of the targets associated with the Doppler frequency [5]. If the beam width of azimuth is very narrow and the angle of each reflection point is assumed to depend on only range of the reflection point, the following equation (2) is obtained from the geometric relationship

$$\sin^2(\theta_m) + \cos^2(\theta_m) - 1 = \left(\frac{h}{R_m}\right)^2 + \left(\frac{V_m}{Vg}\right)^2 - 1 = 0 \qquad (2),$$

where h is antenna height which can be measured at the starting point. R_m and V_m are the range and relative velocity of each reflection point. θ_m indicate the angle of the reflection points. Therefore, we proposed the following equation (3) to obtain the train velocity.

$$Vg = \arg\min_{Vg}\left[\sum_{m=0}^{M-1}\left(\frac{h}{R_m}\right)^2 + \left(\frac{V_m}{Vg}\right)^2 - 1\right] \qquad (3)$$

This method is expected to mitigate errors due to the spread of Doppler frequency, the mounting antenna angle, the pitching of the car during the acceleration and deceleration. In other words, method (b) (as well as method(c) presented below) utilizes the broadband information associated with the spread of Doppler frequency to obtain the train velocity.

2.3 A nonlinear least square method with two unknown quantity (method (c))

In this research, radar transmits the radio waves toward the ballast track bed. In the nonlinear least square method with one unknown quantity, the height of the antenna is not changed. On the other hand, it is possible that the height of ballast track bed may vary. That means that the height of antenna h in the equation (3) changes. Particularly in regions with heavy snowfalls, the change of the height of antenna should be taken into consideration. Therefore, we propose the following equation (4) to obtain the train velocity.

$$(Vg, h) = \arg\min_{Vg,h}\left[\sum_{m=0}^{M-1}\left(\frac{h}{R_m}\right)^2 + \left(\frac{V_m}{Vg}\right)^2 - 1\right] \qquad (4)$$

In the equation (4), the unknown quantities are the antenna height h as well as the train velocity Vg.

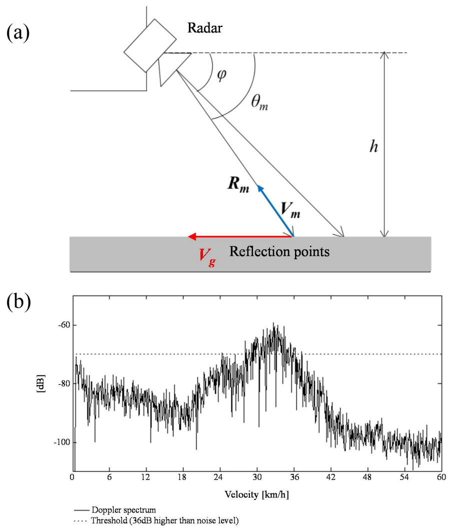

Fig.1 The Doppler frequencies (relative velocities) obtained by 2FCW radar in the situation where the antenna is mounted being tilted by φ ((a) Relative velocities and corresponding range of reflection points, (b) Doppler spectrum).

3 Experimental results

The specification of 2FCW radar using in the experiments is as follows. The two frequencies are 24.090GHz and 24.165GHz, respectively. The frequency difference is 75.0MHz that corresponds to the range of 1.99m where the radar can be measured the target range without ambiguity. The switching time interval of the frequencies is 50us. The sampling rate of A/D converter is 10 kHz. The antenna height *h* at the starting point is 0.835m. The beam widths of antenna are 7.5deg in azimuth and 3.0deg in elevation. The coherent processing interval (CPI) is 307msec.

Fig.2 shows the estimation results of train velocity for 390 seconds. Fig.2 (a) shows the results by method (a). The blue dots indicate the velocity estimation results by GPS speedometer for the reference. The bias between method (a) and GPS of about 1km/h is identified through the whole observation time especially in high speed region. The bias through the whole observation time is possible to be caused by the mounting angle error, the spread of Doppler frequency, and the pitching of the car.

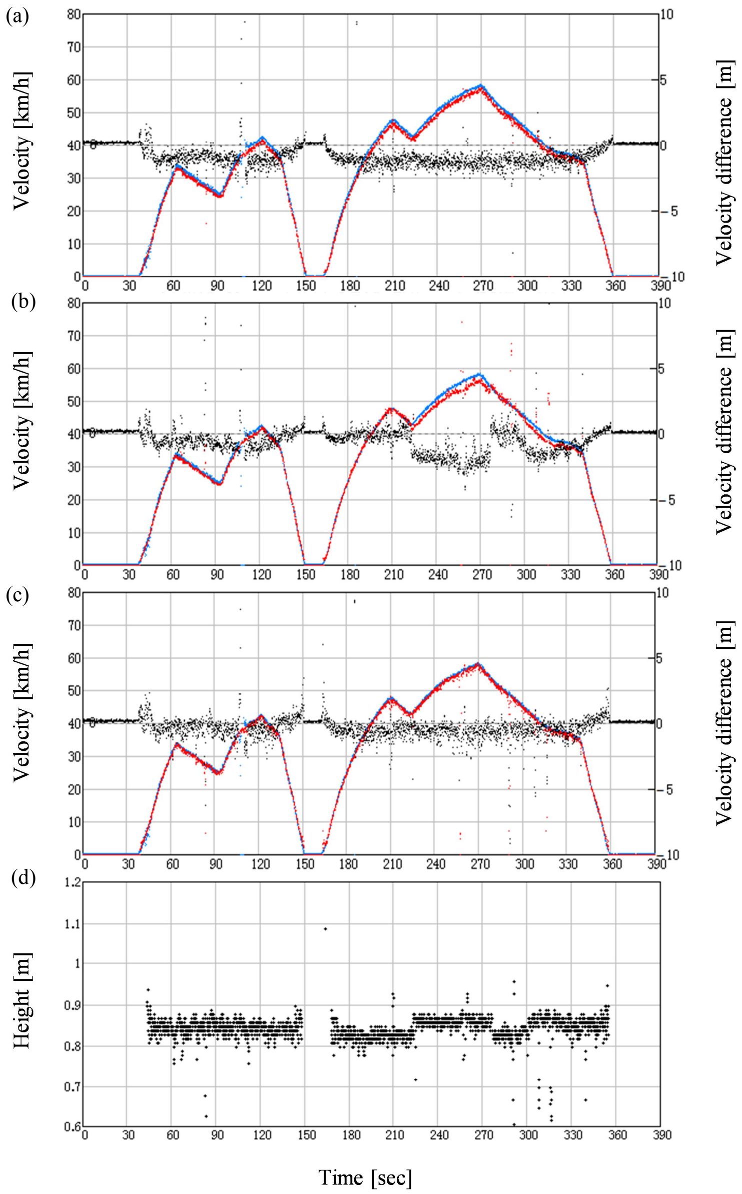

Fig.2 The estimation results by proposed methods for 390s ((a) velocity estimation by method (a), (b) velocity estimation by method (b), (c) velocity estimation by method(c), (d) estimation of the antenna height by method (c)).

(a)

(b)

Fig.3 The ballast conditions of the experiments ((a) the ballast condition at the time of 212s, (b) the ballast condition at the time of 245s).

Fig.2 (b) shows the results by method (b). The results by method (b) seem to have the smallest standard deviation and the bias errors from GPS compared to the other methods except the time from 225s to 275s and from 300s to 320s. During the time from 225s to 275s and from 300s to 320s, bias errors of about 2km/h are identified.

Fig.2 (c) shows the results by method (c). The results by method (c) have relatively small bias errors through the whole observation time. The results by method (c) seem to have the bias errors having smallest variation with time in the three methods. Fig.2 (d) shows the estimation results of the antenna height *h* by method (c). The result indicates that the antenna height during the time from 225s to 275s and from 300s to320s is 4cm higher than the other observation periods. In other words, the result indicates that the ballast of corresponding area is 4cm lower than other area. Figs.3 (a) and (b) show the ballast condition at the time of 212s and 245s, respectively. From fig.3, the ballast at 245s seems to be low compared to that at 212s. That also supports the results by method (c). Method (c) calculated the train velocity having small bias errors in the corresponding area and it also detected the change of the antenna height. In method (b), the antenna height *h* is assumed not to be changed. The results also indicate that method (b) obtains a good standard deviation and the smallest bias errors in the environment where the height of ballast is not changed from the setting value which is measured at the starting point.

4 Conclusion

In this paper, we presented the estimation methods for train speed based on 2FCW, which can estimate the target ranges associated with the Doppler frequencies. And then we also show the initial experimental results on railway environments. The estimation method by only the mounting antenna angle (method (a)) is a very simple. In principle, however, this method is possible to have the bias error associated with the error of mounting angle, pitching of the car, and the spread of Doppler frequency. The nonlinear least square method with one unknown quantity (method (b)) produced the smallest standard deviation in the three methods and the bias error also takes small value in the environment where the antenna height is not changed from the predetermined antenna height. The nonlinear least square method with two unknown quantity (method (c)) produced relatively small bias error through the whole observation time including the situation where the antenna height is changed. From the results described above, the followings are one of the efficient ways to operate the speedometer. The train velocity is obtained from the method (b), when the antenna height from the method (c) is not changed. When the antenna height is changed, the velocity from the method (c) should be referenced during corresponding time.