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THE INFLUENCE OF THE FINITE RESOLUTION OF AZIMUTH ANGLE AND RANGE ON SYNTHESIZED 2-DIMENSIONAL HORIZONTAL VELOCITY IN A BISTATIC DOPPLER RADAR SYSTEM

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1. INTRODUCTION

The bistatic Doppler radar system invented and developed by J. Wurman (1993) has many excellent features. The most prominent is that a single transmitter illuminates the whole system, and thus all the Doppler signals processed are scattered from the same point at the same instant. In addition, the system is much cheaper than a conventional multi-Doppler radar system.

This paper investigated the accuracy of the synthesized Doppler velocity obtained with a system composed of a transmitter/receiver (T/R) and a receiver (R) from a geometric perspective.

Figure 14 in Wurman (1993) presented the horizontal distribution of the standard deviations of synthesized horizontal winds, without giving an explicit mathematical expression for the distribution. According to our calculations, the mean square error of the synthesized Doppler velocity takes a minimum value when the scattering angle α is approximately 100 degrees, and is less than 2 times this minimum value for the range 52 <α <142 degrees.

In the synthesis procedure, two Doppler velocities and two vectors determine the horizontal 2-dimensional Doppler velocity. The vectors are obtained if the positions of T/R, R, and a scatterer are specified. Of these, the positions of T/R and R can be determined much more precisely than that of the scatterer by using GPS. The position of the scatterer is determined by two kinds of information: azimuth angle information at T/R and range information at R. Their resolutions are essentially limited by beam width and pulse length, respectively. This finite resolution brings error into the position of a scatterer resulting in a non-negligible error in the synthesized Doppler velocity. The purpose of this paper was to evaluate the influence of this finite resolution.

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2. TYPE-1 AND -2 ERRORS

The synthesis of the Doppler velocity is expressed by the equation:

$$\mathbf{V} = V_t \mathbf{q_t} + V_b ' \mathbf{q}_b ' \qquad (1)$$

where V_t and $V_b '$ are the Doppler velocities obtained at T/R and R, respectively. Note that $V_b '$ is related to V_b, the real Doppler velocity, by R, through the following relation (Protat and Zawadzki, 1999).

$$V_b ' = \cos(\alpha / 2) V_b \qquad (2)$$

The vectors $\mathbf{q_t}$ and $\mathbf{q}_b '$ can be determined uniquely if the locations of T/R, R, and the scatterer are specified.

The precision of the above two Doppler velocities is restricted by the rotation speed of the antenna and the number of pulses from which the Doppler velocity is calculated. We call the error associated with the finite resolution of the Doppler velocity type-1 error. This is expressed as

$$\delta \mathbf{V}_1 = \delta V_t \mathbf{q_t} + \delta V_b \text{'} \mathbf{q}_b \text{'} \tag{3}$$

The mean square value of the type-1 error is given by

$$\overline{(\delta \mathbf{V}_1 \bullet \delta \mathbf{V}_1)} = \overline{\delta V_t^{\,2}}(\mathbf{q_t} \bullet \mathbf{q_t}) + \overline{\delta V_b^{\,\prime 2}}(\mathbf{q}_b \text{'} \bullet \mathbf{q}_b \text{'})$$
$$= \sigma_v^{\,2}[(\mathbf{q_t} \bullet \mathbf{q_t}) + (\mathbf{q}_b \text{'} \bullet \mathbf{q}_b \text{'})]$$
$$= \sigma_v^{\,2} 2 \frac{3+\cos(\alpha)}{\sin^2(\alpha)} \tag{4}$$

The error due to the finite resolution of an azimuth angle and range is called type-2 error and is given by

$$\delta \mathbf{V}_2 = V_t \delta \mathbf{q_t} + V_b \text{'} \delta \mathbf{q}_b \text{'} \tag{5}$$

The root mean square of this error is represented by

$$\overline{(\delta \mathbf{V}_2 \bullet \delta \mathbf{V}_2)} = V_t^{\,2}\overline{(\delta \mathbf{q_t} \bullet \delta \mathbf{q_t})}$$
$$2 V_t V_b \text{'} \overline{(\delta \mathbf{q_t} \bullet \delta \mathbf{q}_b \text{'})} + V_b^{\,\prime 2}\, \overline{(\delta \mathbf{q}_b \text{'} \bullet \delta \mathbf{q}_b \text{'})} \tag{6}$$

As the correlations of the error vectors in (6) are expressed by the root mean square error of the azimuth angles and range, (6) can be rewritten as

$$\overline{(\delta \mathbf{V}_2 \bullet \delta \mathbf{V}_2)} = (\sigma_\theta)^2 f(\alpha, r_1, r_2, V_t, V_b \text{'})$$
$$+ (\sigma_S)^2 g(\alpha, r_1, r_2, V_t, V_b \text{'}) \tag{7}$$

In (7), *f* and *g* are complex functions of the scattering angle α, the distance from T/R to the scatterer (r_1), the distance from R to the scatterer (r_2), and two Doppler velocities. σ_θ and σ_S are the standard deviations of the azimuth angles and range at R.

3. EVALUATION OF ERRORS

This section evaluates type-1 and type-2 errors. Usually, the beam width of a Doppler radar is around 1 degree. Therefore, we assume that σ_θ is 0.5 degrees. The resolution of range is determined by the pulse repetition frequency and the number of gates between the pulses, but is essentially limited by the pulse width. Here we assume that σ_S is 100 m. The functions *f* and *g* depend on the magnitude of the two Doppler velocities. In this paper, we assumed them to be 20 m/s everywhere. Fig. 1 depicts the horizontal distribution of the standard deviation of the synthesized Doppler velocities. The left half of the figure gives the contribution of the type-1 error. This may be popular in the bistatic community. The right half gives the distribution of the error from errors of both types. In the right half of the figure, it is clear that precision is decreased around R. This occurs because at points close to R, the direction of the scatterer seen from R changes considerably with even small differences in azimuth angle and range.

4. CONCLUSION

At points close to the receiver, the finite resolution of azimuth angle and range information results in non-negligible errors in the synthesized Doppler velocities compared with the errors associated with the Doppler velocity measurement error.

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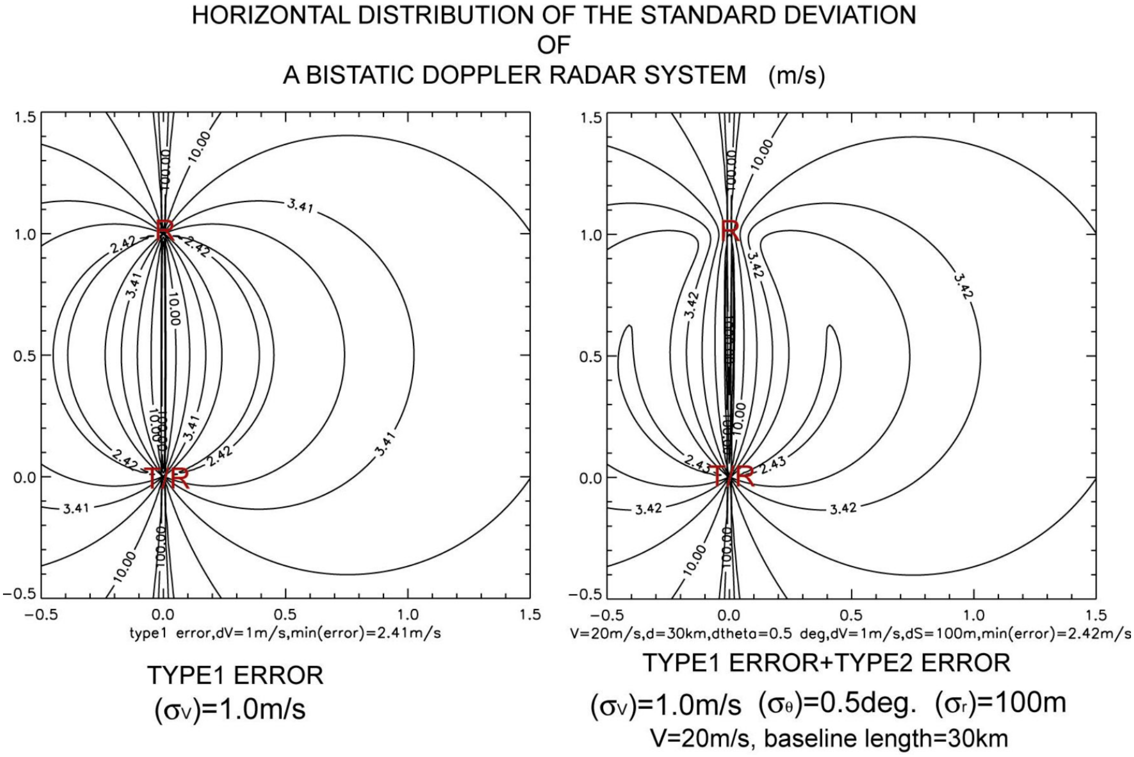

Figure 1. The horizontal distribution of the standard deviation of the synthesized 2-dimensional horizontal Doppler velocities is given. The figure on the left side shows only type-1 error. The figure on the right side depicts the total error distribution. T/R is the transmitter/receiver (traditional Doppler radar) and R represents the bistatic receiver. The coordinate is normalized with respect to the length of the base line that is assumed to be 30 km.