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A Consideration of Interference Prevention Technique for Doppler Weather Radars

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1. Introduction

Doppler weather radar is a type of radar used to locate precipitation, calculate its motion, and estimate its type (rain, snow, hail, etc.). Modern weather radars are mostly pulse-Doppler radars, capable of detecting the motion of rain droplets in addition to the intensity of the precipitation. Data obtained from weather radars can be analyzed to determine the structure of storms and their potential to cause severe weather s uch as local short-term rainfall. In recent years, the installation places of the Doppler weather radars are increased in order to predict more exactly the local short-term rainfall. However, Doppler weather radars which are installed closely cause interference to each other. As a result, the correct meteorological data are no longer obtained from the radars. From now on, the number of the radars will increase because of more localization of short-term rainfall. Therefore, the evaluation of conventional interference prevention techniques and improvement of the techniques are indispensable for stable and reliable operation of the radars. In this paper, clarifying the characteristics of the conventional interference detection and correction algorithm in Doppler weather radars, we propose a novel algorithm and show through computer simulation that it is more effective than the conventional one.

2. Analytical Model

Figure 1 shows the block diagram of Doppler weather radar. Assume that there are two pulse waves incident on the radar antenna. One is a desired wave which is an echo from particles (raindrops) in the air, thus being a Rayleigh scattering wave, and the other is interference from the adjacent weather radars, so being a stable pulse wave. The received pulse signals, which are complex-valued, become the input data to the interference detector. They are expressed here as $inIQ(n)$ ($n = 1, 2, \ldots, N$; N: the number of hits). After the interference detection and correction is performed in the interference detector, we have the detector output data expressed as $outIQ(n)$ ($n = 1, 2, \ldots, N$).

3. Wind Velocity Calculation Method

Using the output data $outIQ(n)$, wind velocity, i.e., raindrop velocity is calculated by using pulse-pair method [1] . Any rain drops in motion affect the frequency of the returned radar beam according to the Doppler effect. Since the targets move slightly between a pulse and the following pulse, the returned wave has a noticeable phase difference or phase shift from pulse to pulse. Doppler weather radars are using this phase difference (pulse pair difference) to calculate the wind velocity which is given by

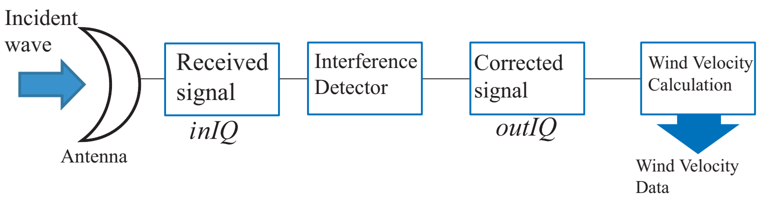

Figure 1: Block diagram of weather radar

$$v = -(\lambda/4\pi T_s)\arg\{R\} \tag{1}$$

$$R = \frac{1}{N}\sum_{n=1}^{N} outIQ(n)^{*} outIQ(n+1) \tag{2}$$

where λ, T_s, arg and * are wavelength, pulse-repetition period, argument of a complex number and complex conjugate, respectively.

4. Interference Detection and Correction Method

4.1 Conventional method

We outline the conventional interference detection and correction method. The amplitude ratio between nth input and the $(n-1)$th output is defined as follows:

$$r(n) = \frac{max(inamp(n), outamp(n-1))}{min(inamp(n), outamp(n-1))} \tag{3}$$

where $inamp(n)$ and $outamp(n-1)$ stand for the amplitudes of $inIQ(n)$ and $outIQ(n-1)$, respectively. If $r(n-1) \leqq thr1$ and $r(n) > thr2$ ($thr1$ and $thr2$ are thresholds for interference decision), then nth input is regarded as interference-included data because of substantial change of the input. In this case, the nth output is replaced with the $(n-1)$th output as shown below.

$$outIQ(n) = outIQ(n-1) \tag{4}$$

For $n = 1, 2$,the output is the same as the input in this method, which means no correction .

4.2 Proposed method

We explain the proposed method for interference detection and correction. At the nth input, we define four ratios as

$$p(n) = \frac{inamp(n)}{inamp(n-1)}, q(n) = \frac{inamp(n)}{inamp(n-2)}, s(n) = \frac{inamp(n)}{outamp(n-1)}, t(n) = \frac{inamp(n)}{outamp(n-2)} \tag{5}$$

If $p(n) > thr2$ and $q(n) > thr1$, then the nth input is regarded as interference-included data from the reason that the amplitude suddenly gets large. Otherwise, if $s(n) > thr4$ and $t(n) > thr3$ ($thr3$ and $thr4$ are also thresholds for interference decision), and the $(n-1)$th input was determined as interference-included data, then the nth input is also regarded as interference-included data from the reason that interference is incident continuously . In this case, the nth output is corrected as follows:

$$outIQ(n) = A(n) \times \exp(j\theta_n) \tag{6}$$

where, $A(n)$ and θ_n are estimated amplitude and phase, respectively, and they are estimated in the following manner:

$$A(n) = \alpha A(n-1) + (1-\alpha) \times outamp(n-1) \tag{7}$$

$$\theta_n = \theta_{n-1} + \psi(n-1) \tag{8}$$

Here,

$$\psi(n) = \beta\psi(n-1) + (1-\beta)(\theta_n - \theta_{n-1}) \tag{9}$$

where, α and β are forgetting factors ($0 \leqq \alpha, \beta \leqq 1$). The larger they are,the more estimated value is dependent past value.

5. Computer Simulation

Under conditions described in Table 1, the computer simulation is carried out to clarify the performance of interference detection and correction methods in the Doppler weather radar. Figures 2 and 3 show the interference detection percentage versus SIR (Signal-to-Interference Ratio) in the conventional and proposed methods, respectively. Also, wind velocity errors are shown in Fig.4 and Fig.5 corresponding to Fig.2 and Fig.3, respectively. Furthermore, the corresponding frequency distributions of the wind velocity (Doppler velocity) are drawn in Fig.6 and Fig.7, respectively. As a reference, the frequency distribution in no interference environment is shown in both figures. In Fig.2 and Fig.3, detection percentage means the ratio of the number of hits of correct interference detection to the number of total hits. On the other hand, false detection percentage [0=>1] means the percentage of hits in which it is judged that interference is included though there is no interference. Similarly, false detection percentage [1=>0] means the percentage of hits in which it is judged that there is no interference though interference actually exists. Here, if SIR> 20, then input data are considered to include no interference in this simulation. From Fig.2 and Fig.3, it is found that detection percentage of proposed method is improved compared with that of the conventional one. Figures 4 and 5 shows that wind velocity error of proposed method is smaller in low SIR (strong interference). Also, from Fig.6 and Fig.7, we can confirm that frequency distribution of calculated wind velocity approaches more that in no interference case. When the amplitude of input suddenly becomes small, the proposed method considers that it is due to Rayleigh fading of the desired wave and that there is no interference. Also, the proposed method takes account of the case where successive hits include interference. In addition, the proposed method predicts the present output from the past output data in the case where it is judged that there is interference, instead of simple replacement with the previous output. These points are considered as a reason why the performance of the proposed method leads to such significant improvement.

Table 1:Simulation condition

Number of pulse hits(number of total data) N	32
Velocity distribution	Gauss distribution
Wind velocity	4m/s
Wind velocity width	4m/s
SNR	10dB
SIR	-100dB ~ 100dB
Data number including interference	8~11,20~23
Interference decision threshold[$thr1$,$thr2$,$thr3$,$thr4$]	[10dB,10dB,10dB,10dB]
Forgetting factor [α, β]	[1-$\frac{1}{n-1}$,0]
Number of iterations	1000

6. Conclusion

Via computer simulation, we have shown that the proposed method can improve the accuracy of interference detection and correction, resulting in high calculation accuracy of wind velocity, in the Doppler weather radar suffering from interference. As the future work, we will evaluate the interference detection performance in more detail, and we will improve further the interference detection and correction method.

References

[1] Hideo Adachi , Yuko Sato,“Doppler Weather Radar ”, TOSHIBA REVIEW, Vol.55, No.5 , pp. 27-30, May 2000.

[2] Masaru Kawaguchi, Masashi Nagata, Yasuhiko Hara, Masanori Sudoh, and Shigeo Kawashima, “History of Radar Development and Radar Technical Tendency in JRC” , pp.7-8, 2005.

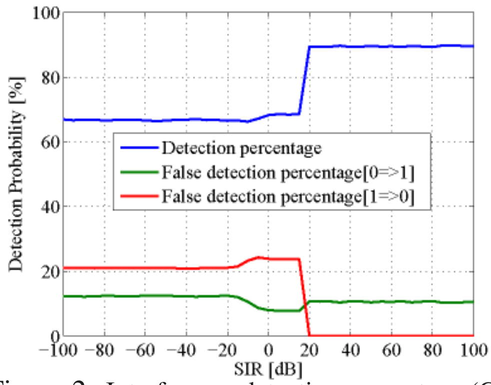

Figure 2: Interference detection percentage (Conventional method).

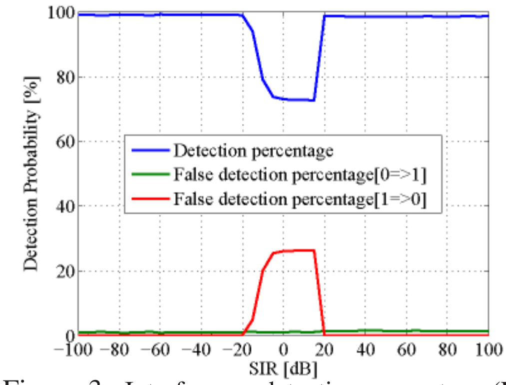

Figure 3: Interference detection percentage (Proposed method).

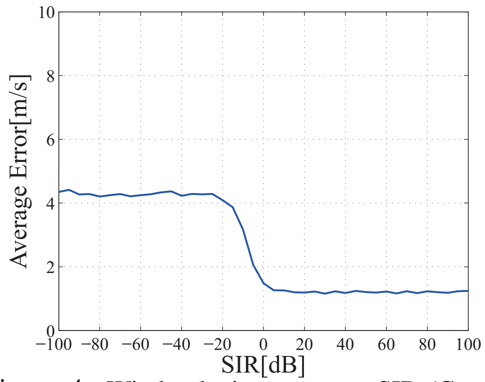

Figure 4: Wind velocity error vs. SIR (Conventional method).

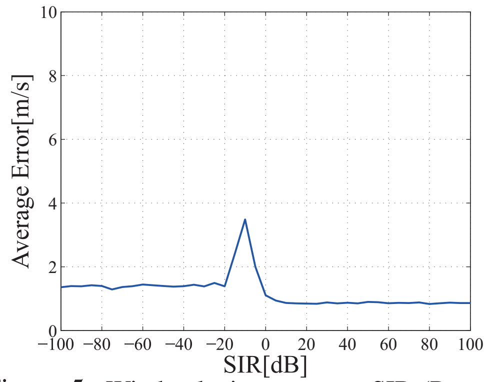

Figure 5: Wind velocity error vs. SIR (Proposed method).

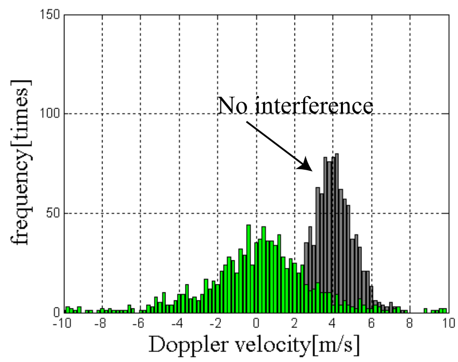

Figure 6: Calculated wind velocity frequency distribution vs. SIR(Conventional method).

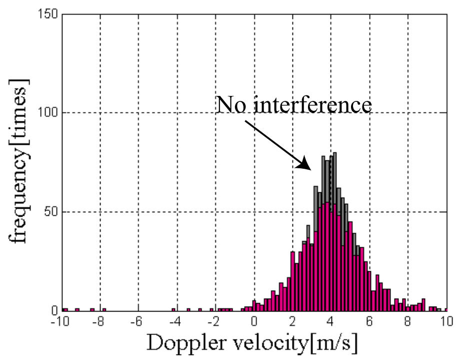

Figure 7: Calculated wind velocity frequency distribution vs. SIR(Proposed method).