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情報通信研究機構における1.3GHz帯ウィンドプロファイラの開発
Development of next-generation 1.3 GHz wind profiler radar by National Institute of Information and Communications Technology (NICT)

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1. Introduction

Wind profiler radar (WPR) measures height profiles of vertical and horizontal wind in the clear air. By producing perturbation of temperature and humidity of the air, turbulence generates irregularities of the radio refractive index. WPR receives the echo scattered by the irregularities of radio refractive index with a scale half of the radar wavelength (i.e., Bragg scale). The echo is referred to as the clear-air echo. Because the clear-air echo moves with the background wind, vertical and horizontal wind are able to be measured from the Doppler shift of the clear-air echo [1].

Owing to the capability of WPR to measure wind profiles in the clear air, WPRs have been used for atmospheric research such as radio wave scattering, gravity waves, turbulence, temperature and humidity profiling, precipitation system, and stratosphere-troposphere exchange processes [2]. WPR is also used for monitoring wind variations routinely. In Japan, a nationwide 1.3 GHz WPR network, which is referred to as Wind Profiler Network and Data Acquisition System (WINDAS), has been operated in order to provide measured upper-air wind profiles to the numerical weather prediction [3]. WPR networks are also operated in other countries [4].

2. Next-generation 1.3 GHz wind profiler radar (WPR)

Though WPR is a useful means for measuring wind profiles in the clear air, measurement resolution attained by WPR and quality of wind products obtained by WPR have room to be improved. Turbulence is the threat for aircrafts. However, time and height resolution of conventional WPR (typically up to ~1 min and 100 m, respectively) are not sufficient for resolving small-scale turbulence. Natural disasters caused by localized torrential rainfall (e.g., landslides and floods) are threats to the human society. Therefore fine-scale monitoring and prediction of weather condition are required in order to prevent and reduce such natural disasters. In order to meet the requirement, quality of wind products obtained by WPR needs to be improved. Undesired echo, which is referred to as clutter, degrades quality of wind products because it contaminates the signal received by WPR. Clutter has various sources (e.g., building, trees, vehicles, sea surface, birds, and aircrafts).

Aiming at enhancing measurement resolution and quality of wind and turbulence products, next-generation 1.3 GHz WPR has been developed by National Institute of Information and Communications Technology (NICT).

3. Techniques of next-generation 1.3 GHz WPR

Next-generation 1.3 GHz WPR utilizes new techniques for enhancing the measurement resolution and the quality of the products. Range imaging (RIM) is a technique that enhances range (height) resolution down to several tens of meters by using multiple frequencies and adaptive signal processing. In RIM, the transmitted frequency is changed every transmission. As the adaptive signal processing, direction-constrained minimization of power (DCMP) is generally used. DCMP is also referred to as the Capon method. By using the set of multiple received time series, each of which is collected with the same transmitted frequency, DCMP is applied with the constraint that the gain at the desired range is kept to be constant. The constraint leads to minimize the power of signals from undesired ranges. Previous studies have proved that RIM is an indispensable means for resolving small-scale turbulence [5].

Adaptive clutter suppression (ACS) is a technique that mitigates clutter received by the sidelobe of the receive antenna. ACS applies norm-constrained DCMP (NC-DCMP) to signals collected by multiple antennas (subarrays) [6]. NC-DCMP is applied with the constraint of constant gain at the direction of the peak of the main lobe. The maximum of the weight norm is also constrained in order to preserve the shape of the main lobe. By minimizing the output power with the above-mentioned constraints, NC-DCMP mitigates clutter received by the sidelobe.

4. Development of software-defined receiver

By implementing RIM and ACS capabilities in existing WPRs, the installation cost of next-generation 1.3 GHz WPR can be reduced. We therefore aim to implement RIM and ACS capabilities in existing WPRs. In order to develop the techniques of next-generation 1.3 GHz WPR by using an existing WPR, we have been developing a software-defined receiver (SDR).

The SDR is composed of USRP X310s and a workstation (WS). USRP X310 is a general-purpose signal sampler used as a platform of software-defined radio [7]. The USRP X310s execute analog-to-digital conversion of multi-channel received signals at the intermediate frequency, and then carry out quadrature phase detection. Signals processed by the USRP X310s are transferred to the WS through the 10 Gigabit Ethernet. The WS carries out real-time digital processing (e.g., frequency filtering, decoding of phase-modulated received signals, and integration in time) and then stores the processed signals to a hard disk drive. The software used for the real-time digital processing is written in C++, a general-purpose programming language. Therefore the functions in the real-time signal processing are easy to be changed, added, and reused.

The SDR has the capability of oversampling (OS) with a maximum rate of 10 Mega samples per second. An experiment using the SDR demonstrated that combined use of RIM and OS (RIM plus OS) significantly reduces deterioration in sensitivity caused by the shape of the transmitted pulse [8]. It was shown that the capability of ACS is able to be implemented to an existing WPR by additionally installing auxiliary antennas which receive clutter existing on or near the ground. The multi-channel reception capability of the SDR was used for collecting signals from the main antenna of the WPR and the auxiliary antennas [9].

5. Conclusions

We described the concepts and techniques of next-generation 1.3 GHz WPR. WPRs with the capability of RIM and ACS are currently installed at the NICT Headquarters in Koganei city, Japan and the Hasumiya ventilation site of the Hanshin Expressway Company in Kobe city, Japan. The WPRs are not used only for developing techniques of next-generation 1.3 GHz WPR. They are also used for elucidating processes in development of deep cumulus convection and for exploring new applications which employ next-generation 1.3 GHz WPR for preventing and reducing natural disasters. We expect that the development of next-generation 1.3 GHz WPR will contribute to prevent and reduce natural disasters.

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