Development of a high-resolution 1.3 GHz wind profiler radar

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Abstract - **Range imaging (RIM), which uses multiple frequencies, enables wind profiler radars (WPRs) to measure wind and turbulence with enhanced range resolution. Adaptive clutter suppression, which controls sidelobes by using subarrays, is useful for mitigating clutter contamination. In order to apply RIM and adaptive clutter suppression not only to scientific researches but also to operational monitoring of wind and turbulence, a high-resolution 1.3 GHz WPR, referred to as LQ-13, has been developed. In order to implement the capability of oversampling and adaptive clutter suppression to LQ-13, a digital receiver composed of general-purpose software-defined radio receiver and a workstation is used. By using both RIM and oversampling, LQ-13 is able to measure wind and turbulence with high range resolution. Some measurement results showed that multi-channel signal collection by the digital receiver can be used for adaptive clutter suppression.**

Index Terms — **Radar, meteorology, wind, software-defined radio receiver, adaptive signal processing**

1. Introduction

Wind profiler radar (WPR) measures height profiles of vertical and horizontal winds in the troposphere. It receives signals scattered by radio refractive index irregularities (clear-air echo) and measures Doppler shift of the scattered signals [1]. Owing to its capability to measure wind velocities in the clear air with high height and time resolution (typically a hundred to several hundreds of meters and less than several minutes, respectively), 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, 3]. WPR is also utilized 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), is operated in order to provide upper-air wind data to the numerical weather prediction [4]. A wind profiler network is also operated in Europe [5].

Because the refractive index irregularities can be produced by temperature and humidity perturbations caused by atmospheric turbulence, WPRs can be used to measure turbulence parameters (e.g., dissipation rate and diffusivity) [6]. In order to resolve turbulence structure and retrieve turbulence parameters with reduced uncertainties, high resolution is indispensable. Range imaging (RIM) is a technique that enhances range resolution down to several tens of meters by using multiple frequencies and adaptive signal processing. Measurements using RIM have proved that RIM is an indispensable means for measuring fine structure of instability waves such as Kelvin-Helmholtz waves (see [7] and references therein). Adaptive clutter suppression is a technique that controls sidelobes of the radar beam by using subarrays and adaptive signal processing. Adaptive clutter suppression is useful for mitigating clutter contamination [8].

Currently RIM and adaptive clutter suppression are used only for scientific research. Our goal is to apply them not only to scientific researches but also to operational monitoring of wind and turbulence. In order to implement and evaluate performance of them, a high-resolution 1.3 GHz WPR has been developed.

2. Wind Profiler System

Table 1 lists specifications of the high-resolution 1.3 GHz WPR. The WPR is referred to as LQ-13. LQ-13 is developed based on a commercial WPR referred to as LQ-7 [9]. Center frequency of LQ-13 (1357.5 MHz) is the same as WINDAS WPRs. In order to perform RIM measurements, transmitted frequencies can be changed every transmission. The phased array antenna is composed of 13 Luneberg lenses, and is able to change its radar beams to vertical, north, east, south, and west directions. Solid-state transmitters are attached to each of the Luneberg lenses, and the 13 transmitters radiate pulses with a total peak power of 5200 W.

In order to implement the capability of oversampling and multi-channel signal collection with low purchase cost, LQ-13 uses a digital receiver composed of Universal Software Radio Peripheral (USRP) and a workstation. USRP is a general-purpose software radio receiver produced by Ettus research. By using USRP, oversampling and multi-channel signal collection can be implemented with low purchase cost. USRP digitizes received signals at the intermediate frequency (IF) of 130 MHz and then produces video in-phase and quadrature-phase (IQ) signals. The IQ signals produced by USRP is transferred to the workstation. By using USRP, the digital receiver is able to sample received signals with a sample rate as high as 10 mega samples per second (MS s^{-1}). The high sample rate is used for oversampling. A combination of RIM and oversampling is useful for unambiguous RIM measurement in range [10].

The workstation carries out the real-time signal processing such as ranging, low-pass filtering in range, decoding of the phase-modulated signals, and signal integration in time (i.e., coherent integration). The signal processing performed by the workstation is useful for reducing the data amount stored to the hard disk drive. The operating system of the workstation is Ubuntu 14.04 LTS. The program used for the real-time signal processing is written by C++. Because C++ is a general-purpose programming language, the use of C++ enables us to change, update, and reuse the software easily. It is noted that because USRP sends signals to the workstation sequentially (i.e., both during the transmission and the reception), the workstation carries out ranging by using trigger signals sampled by USRP.

TABLE I
Specifications of LQ-13.

Frequency	
Center frequency	1357.5 MHz
Maximum number	5
Switch timing	Every transmission
Antenna	
Phased array elements	13 Luneberg lenses
Beam directions	Vertical and four oblique directions (north, east, south, and west) with a zenith angle of 14°
Beam width	4°
Peak Power	5200 W
Digital receiver	
Signal processing hardware	USRP and workstation
Receive frequency	130 MHz
Sample rate	10 MS s^{-1} (typical)

For single-channel data collection, both USRP N210 [11] and USRP X310 [12] are available. For multi-channel data collection, USRP X310s are used because it has high data transfer rate. Through the 10 Gigabit Ethernet interface, USRP X310s transfer received signals to the workstation. Some measurement results showed that multi-channel signal collection by the digital receiver can be used for adaptive clutter suppression.

Coherent radar imaging (CRI) is a technique that enhances angular resolution by using adaptive signal processing and subarrays [7, 13]. CRI is also useful for resolving fine-scale turbulence structure and for mitigating clutter contamination. Currently, in order to implement CRI capability, a function to calibrate the phases of received signals among plural USRP X310s is developed.

3. Conclusion

High-resolution 1.3 GHz WPR, which is referred to as LQ-13, has the capability of RIM and oversampling. Some measurement results showed that multi-channel signal collection by the digital receiver can be used for adaptive clutter suppression. The capability of oversampling and adaptive clutter suppression are implemented by using the digital receiver composed of USRP and a workstation.

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