Facility implementation of adaptive clutter suppression to an existing wind profiler radar: First result

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Abstract: Adaptive clutter suppression (ACS) is a technique that mitigates signals from undesired objects by using subarrays. However, because many of existing wind profiler radars (WPRs) have a single-channel receiver, ACS cannot be applied to them. Aiming at implementing ACS capability to existing WPRs, a pilot system composed of auxiliary subarrays, Universal Software Radio Peripheral (USRP), and a workstation, was developed. The use of USRP enabled multi-channel reception and easy development of the software for real-time data processing by using C++. An example, in which ACS was applied to signals collected by the pilot system, is presented.

Keywords: radar, clutter, adaptive array, software-defined radio

Classification: Sensing

References
[1] S. Fukao, “Recent advances in atmospheric radar study,” J. Meteorol. Soc. Jpn., vol. 85B, pp. 215–239, Oct. 2007. DOI:10.2151/jmsj.85B.215
[2] M. Ishihara, Y. Kato, T. Abo, K. Kobayashi, and Y. Izumikawa, “Characteristics and performance of the operational wind profiler network of the Japan Meteorological Agency,” J. Meteorol. Soc. Jpn., vol. 84, no. 6, pp. 1085–1096, Jan. 2007. DOI:10.2151/jmsj.84.1085
[3] Met Office, “Network of wind profilers,” http://www.metoffice.gov.uk/science/specialist/cwind/profiler/, accessed 24 Apr. 2017.
[4] B. L. Cheong, M. W. Hoffman, R. D. Palmer, S. J. Frasier, and F. J. López-Dekker, “Phased-array design for biological clutter rejection: Simulation and experimental validation,” J. Atmos. Ocean. Technol., vol. 23, no. 4, pp. 585–598, Apr. 2006. DOI:10.1175/JTECH1867.1
[5] T. Hashimoto, K. Nishimura, and T. Sato, “Adaptive sidelobe cancellation technique for atmospheric radars containing arrays with nonuniform gain,” IEICE Trans. Commun., vol. E99.B, no. 12, pp. 2583–2591, Dec. 2016. DOI:10.1587/transcom.2016EBP3047
1 Introduction

Wind profiler radar (WPR) receives signals scattered by radio refractive index irregularities (clear-air echo), and measures height profiles of vertical and horizontal wind in the clear air. Owing to the capability of measuring wind in the clear air, WPRs are utilized for studying dynamical processes in the atmosphere [1]. WPRs are also used for monitoring wind variations routinely. In Japan, a nationwide WPR network, 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 [2]. A wind profiler network is also operated in Europe [3].

Received signal from an undesired object (i.e., clutter) contaminates a frequency spectrum of received signal (i.e., Doppler spectrum). The contaminated Doppler spectrum cannot be used frequently because the clutter contamination inhibits accurate measurement of wind velocity. Therefore clutter signals need to be mitigated. Clutter signals received by a sidelobe of a radar beam are able to be mitigated by using an adaptive array technique referred to as adaptive clutter suppression (ACS). By using atmospheric radars with a multi-channel receiver, ACS has been studied (e.g., [4, 5, 6, 7]). However, because many of existing WPRs have a single-channel receiver, ACS cannot be applied to them. In this study, it is demonstrated that ACS facility can be implemented to an existing WPR by additionally installing a simple system.

2 Facility for adaptive clutter suppression (ACS)

In order to implement ACS capability to an existing WPR referred to as LQ-13 [8], a pilot system (hereafter ACS system) was developed. LQ-13 has the center
frequency of 1357.5 MHz and the peak transmission power of 5.2 kW. The radar beam of LQ-13 is able to point to vertical and four oblique directions (i.e., toward north, east, south, and west with a zenith angle of 14°). Fig. 1 shows a block diagram of the ACS system. The ACS system is composed of three auxiliary subarrays (SAs), analog unit, three signal samplers referred to as Universal Software Radio Peripheral (USRP) X310 [9], and a workstation (WS). Because objects at the surface (buildings, trees, cars, and so on) are major sources of clutters, the ACS system mainly aims at mitigating clutters existing on the ground. The beam pattern of the SAs has the sensitivity maximum at the 0° elevation angle, has the sensitivity minimum at the zenith direction, and is omni-directional in the horizontal plane. In order to mitigate a clutter signal from an arbitrary horizontal direction, three SAs are used in the ACS system. The SAs are installed outside the clutter fence of LQ-13. The analog unit amplifies signals from the SAs and converts their frequency from the radio frequency (RF) of 1357.5 MHz to the intermediate frequency (IF) of 130 MHz. The USRP X310s digitize signals from the main antenna of LQ-13 (hereafter the main antenna) and those from the SAs. Then the USRP X310s perform digital quadrature detection. They also collect a trigger signal produced by the timing controller of LQ-13. The trigger signal and the complex time series are transferred to the WS with a transfer rate of 10 mega-samples per second through the 10 Gigabit Ethernet. The 10 Gigabit Ethernet is used for attaining the data transfer rate necessary for the multi-channel signal collection [10]. In order to synchronize frequencies of the USRP X310s with those of the transmitter and receiver of LQ-13, 10-MHz reference signals and 1 pulse per second (PPS) signals are supplied from the GPS receiver installed in LQ-13.
The WS carries out the real-time data processing after the quadrature detection. The operating system of the WS is Ubuntu 14.04 LTS. The software used for the real-time data processing is written in C++, and was developed by updating the software for the digital receiver which uses USRP as a signal sampler [11]. By the update, the facility of processing multi-channel signals was implemented. Because C++ is a general-purpose programming language, the use of C++ facilitated the update of the software. The software executes two kinds of threads; the data taking thread (DT) and the signal processing threads (SPs). In order to avoid memory conflict and to carry out continuous data collection without an interruption by data transfer between the threads, DT and SPs are interfaced with the shared memory. Using the trigger signal, DT carries out ranging. Ranging is carried out on the WS because USRP X310 transfers data only sequentially (i.e., both during transmission and reception) [8]. SPs carries out real-time data processing necessary for reducing the data amount. In order to process signals from the main antenna and those from the three SAs simultaneously, four SPs are executed in parallel.

The ACS system as developed is easy to be installed to existing WPRs. Requirement for its installation is only supply of the following signals from an WPR to the ACS system; 10-MHz reference signal, 1 PPS signal, trigger signal for transmission or reception, and received signal from the main antenna. C++ library referred to as Universal Hardware Driver (UHD) [12] is used to control the USRP X310s. By using UHD, all the controls of the USRP X310s, including the configuration of the measurement parameters (number of receive channels, receive frequency and data transfer rate), are executed by the software written in C++. Therefore it is not necessary to use Hardware Description Language and other tools for designing the logic on the Field Programmable Gate Array in the USRP X310s.

3 Measurement result

In this section, an example of a measurement result is presented. As an algorithm for adaptive signal processing, directionally constrained minimization of power with constrained norm (DCMP-CN) [5, 6, 7] was used. In the DCMP-CN used in this study, the value of the directional constraint was 1 for signals from the main antenna and 0 for signals from the SAs. The values were used because the SAs are not sensitive at the beam directions of the main antenna (i.e., at the zenith angle of 0° or 14°) [5]. Therefore, under the condition that the weight for signals from the main antenna is unchanged and that the norm maximum of weight vector is limited, the DCMP-CN minimizes the power of the synthesized signal. The norm constraint value of 1.5 was used. The amplitude of the time series from the main antenna and those from the SAs were normalized so that they have the same noise power. The direct current (DC) components of the time series were removed because the removal gave the better ACS performance for the antenna configuration described in Section 2 and for the location of LQ-13.

Fig. 2 shows an example of time series. The beam direction and the transmitted subpulse width were eastward and 1 µs, respectively. The signal from the main antenna is shown in Fig. 2a. The time series has two components; a clear-air echo from the main beam and a clutter signal from a sidelobe. The clutter signal changed...
slowly with time, and the slow change is clearly seen especially in the Q component. On the other hand, the clear-air echo varied more with time. The weighted sum of the signals collected by the three SAs is shown in Fig. 2b. Because the SAs are not sensitive at the beam direction of the main antenna, only the signal from the clutter was measured. The sum of the signals from the main antenna (Fig. 2a) and those from the SAs (Fig. 2b) is shown in Fig. 2c. It is the final result obtained by applying the DCMP-CN, and shows that the signals from the SAs were weighted so that they cancel the clutter signal from the main antenna.

Fig. 3 displays the Doppler spectrum of the time series shown in Figs. 2a and that of the times series shown in Fig. 2c. The Doppler spectrum point at 0 Doppler velocity is not plotted for the unsmoothed plots (i.e., blue and black curves)
because their values are small. When the DCMP-CN is not applied, the clutter signal is dominant at the ranges at which Doppler velocity is close to 0 (blue curve). Owing to the contamination of the clutter signal, the estimated Doppler velocity is as small as $-0.06 \text{ m s}^{-1}$. However, it becomes $-0.48 \text{ m s}^{-1}$ by applying the DCMP-CN (black and red curves). With an assumption that the clutter signal was completely removed by the DCMP-CN, the signal to clutter ratio is estimated to be $-10.4 \text{ dB}$.

It is noted that the phase differences of the SAs caused by the hardware need not be calibrated because the signals from the SAs do not contain the clear-air echo (see Fig. 2b). This advantage also contributed the easy installation of the ACS system.

4 Conclusion

In this study, we demonstrated that ACS facility can be implemented to an existing WPR by additionally installing a simple system comprised of auxiliary subarrays, USRP, and a workstation. Because increasing number of SAs gains adaptability of sidelobe control, experiments using more number of SAs are useful for evaluating performance of ACS. Such experiments are easy to be realized because the use of USRP and the software written in C++ facilitate changes of the ACS system. By taking advantage of the availability of the ACS system, further studies, which aim at implementing ACS capability to existing WPRs, are going to be carried out.

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