Noncooperative Radar Illuminator Based Bistatic Receiving System

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Abstract

Target detection and tracking systems using illuminators of opportunity have received significant interest in the past few years. The passive bistatic radar system under investigation in this paper exploits non-cooperative navigation radar. In order to provide useful surveillance or cueing information, certain data must be collected from the direct-path signal of the illuminator. Detection of aircraft is an important step to demonstrate its potential in remotely surveillance. The PBR illustrates the detection of civil passenger aircrafts in the airspace by receiving a bistatic return when they are illuminated from non-cooperative emitters. The results show that target detections have been achieved from real data. “Air-truth” data obtained by a Mode S ADS-B receiver is used to verify the results of this bistatic system.

1. Introduction

Generally speaking, bistatic radar is defined as one that uses antennas at different locations for transmission and reception. PBR is one kinds of bistatic radar where there is no cooperative emitter, but instead exploits existing, non-cooperative, radio-navigation transmissions known as illuminators opportunity[1]-[5].

A scenario with non-cooperative radar illuminator considered in this paper is illustrated in Fig.1. It is necessary for the PBR to have two receive channels: one for the reception from an area of interest (surveillance channel), the other to receive a signal directly from the transmitter of opportunity (reference channel) which provides a reference for correlation based matched filtering. Assume that the transmitter is mechanically scanned in azimuth, and the receiver is stationary while the target is moving. Both the transmitter and receiver are focusing on the moving target. The receiving system intercepts the direct-path waveform transmission through a reference antenna when it tunes to the transmitting frequency, and target reflection echoes are intercepted by the target antenna. Time and phase synchronization need to be completed via direct-path signal. Then, optimum detection and parameters estimation are commonly involved in passive coherent processing. Surveillance and early-warning may be achieved in the area of interest.

In this paper, we will present the design and trial system of a PBR framework. The performance of the PBR receiver is analyzed using measurements of field data. The data presented has been processed coherently. Experimental results of this bistatic hitchhiking radar are shown for the purpose of aircraft detection. Detection plots of real aircraft targets are presented and compared with ‘air-truth’ data obtained from a Mode S/ADS-B receiver.

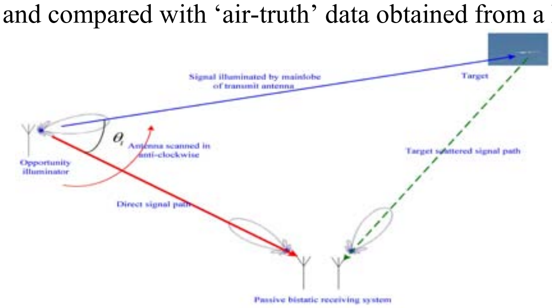

Fig.1 Schematic of passive bistatic pulsed radar system

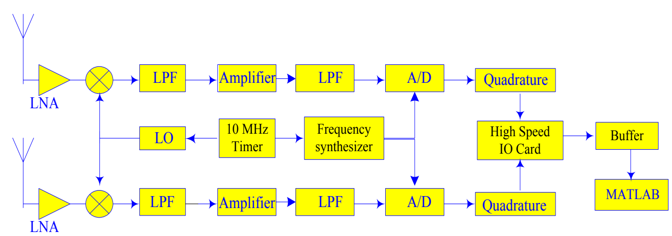

Fig.2 Block illustration of the passive receiving system

2. Framework of the Bistatic Receiving System

The PBR includes two receive channels: one is for the reception from an area of interest (surveillance channel), the other is used to receive a signal directly from the transmitter of opportunity (reference channel) which provides a reference for correlation based matched filtering. A block diagram of the system hardware is shown in Fig.2.

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3. Experimental Scheme, Hardware Setup and Results

The system described in this paper was built on a low budget and is one of the simplest architectures that can be used to explore this technology.

Fig.3 Photo of noncooperative trial system

Fig.4 Photo of double-channel receiving antennas

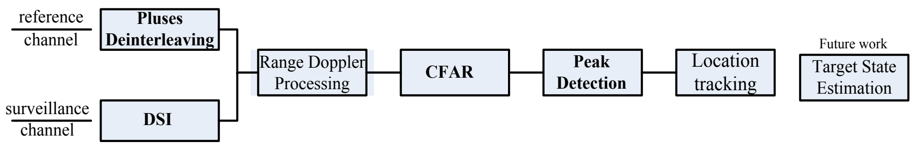

Fig.5 Signal processing block diagram

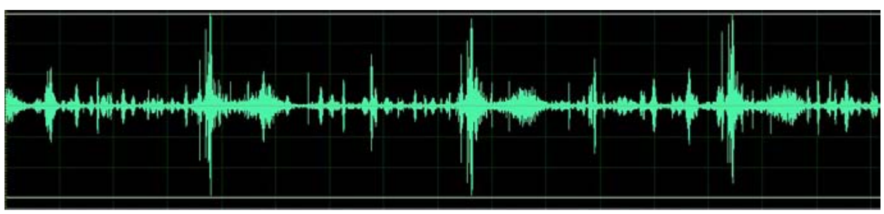

Fig.6 Waveforms of the raw data

This receiving system hardware was set up at a room on the top of a building, as shown in Figure 3. The AIS subsystem is explored to induct the tracking of ship-borne navigation radar, while the ADS-B subsystem is used to record the "air truth" data of the aircraft of interest, which will be used to demonstrate the remotely surveillance feasibility of the PBR. The picture below in Figure 4 shows the trials system situated on the roof of a building near the Yellow Sea. A block diagram of the processing algorithm is shown in Fig. 5.

3.1 Deinterleaving of Direct Path Signals

This Section details pre-processing of the raw data obtained from field test. Initial data gathered can be seen by the following graph in Figure 6 showing power level against the rotation angle of the Radar. At this time, the direct path reference signal is intercepted from different lobe radiation of the transmit antenna. It is found that the propagation factor between the direct path channel and the target channel is different during the coherent dwell time. At the same time, as shown in Figure 6, signals from other illuminators in the same channel are intercepted, inevitably. Therefore, it is desired to consider the deinterleaving of radar pulses for further processing.Maintaining the Integrity of the Specifications.

An improved dynamic correlation deinterleaving algorithm based on ref.[6] is explored to sort the raw data. The result in Fig.7 is the waveform of interest which will be used for detection.

Zooming in to the area around the main beam shows the following variation of power with respect to the radar transmitter direction, as shown in Figure 8. By zooming in further to a region approximately the main beam illumination, which corresponding to the approximate point where aircraft are illuminated. A series of power levels against time can be obtained for the groups of pulses, as shown in Figure 9.

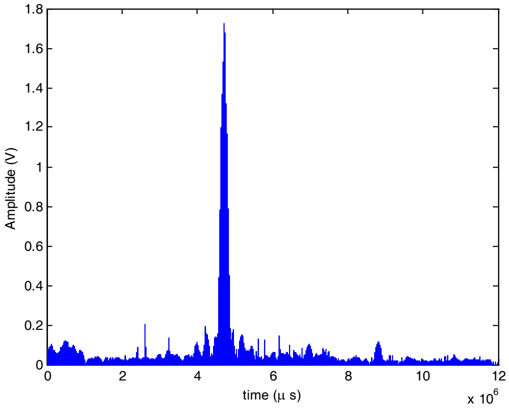

Fig.7 Deinterleaving pulses waveform

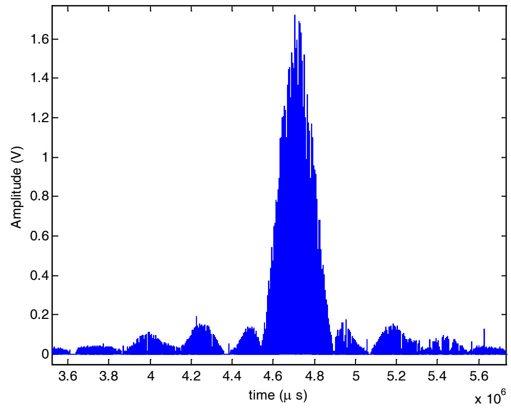

Fig.8 Radar mainlobe deinterleaving pulses waveform

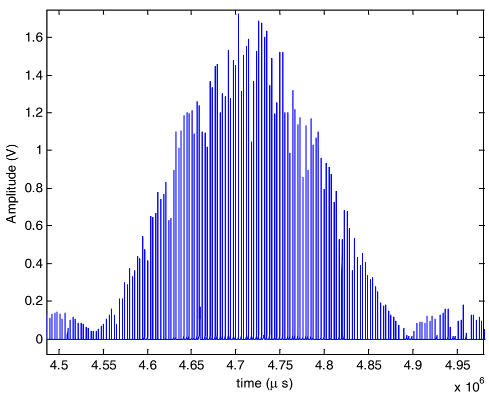

Fig.9 Main beam illumination deinterleaving pulses waveform

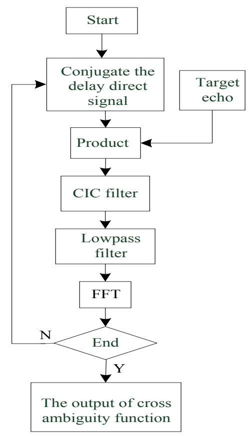

Fig.10 Flow diagram of proposed algorithm

3.2 Coherent Processing Results Based CIC Filter

We will examine the detection performance of PBR in the complex signal environment. The direct-path data examined were sampled from a marine radar which is an X band bridge-master incoherent pulse radar. Once the desired signal has been extracted and leaked to the adaptive filter for DSI and clutter suppression, the 2-D detection plots are constructed in accordance with the bistatic ambiguity function[7].The flow diagram for the main steps is illustrated in Fig.10.

The steps of this improved algorithm can be described as follows:

(1) Calculate the product of the conjugated, different time delayed direct-path signal and the target echo;

(2) Decimate the product sequence by CIC filter[8]-[9];

(3) Filter out the frequencies higher than maximum possible Doppler shift;

(4) Compute of the Doppler velocities for the interested range bin by FFT;

(5) Repeat step (1)-(4) until the algorithm stopped.

The above analysis concerning detection and parameters estimation was conducted with actual measured data, i.e. raw I, Q data samples for an entire transmit antenna rotation. Since then, such data become available, and we will examine it with respect to above analysis. Herein, the direct path interference is suppressed according to the algorithm in[10]. The Fourier transform receives inputs from each group of 16 pulses, which similarly located range bins in 16 pulse repetition intervals. The PRF is 550 Hz which can be estimated from the direct-path signal.

Supposed that the equivalent sample frequency after decimation is 1600 Hz , the pass band is 200 Hz , and then $R = 3750$, $f_c = 1/8$. According to table 1 and table 2 in reference [8], we can get the CIC filter parameter $N = 4$, $M = 1$, and the aliasing attenuation is 68.5 dB while the pass band attenuation is 0.90 dB. The frequency range need to analyze is shortened to be $[-800,800]$ Hz .The cutoff frequency for the 5th order low pass filter is 400 Hz .

The main difference between the basic algorithm and this modification is the presence of two additional steps involved by CIC filter decimation and low-pass FIR filter. Figure 11 shows the result of coherent processing described above. The detection plot is compared against 'air-truth' data from a Mode S/ADS-B receiver as shown in Figure 12.

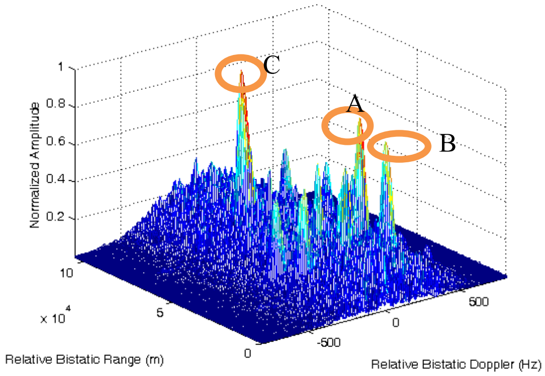

Fig.11 Amplitude-Range-Doppler of CAF

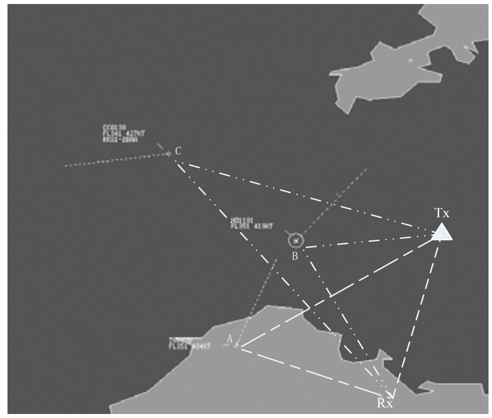

Fig. 12 Targets displayed on the corresponding air-truth positions.

Conclusions

In this paper, we have presented the design and framework of an experimental PBR. The PBR illustrates the detection of civil passenger aircrafts in the airspace by receiving a bistatic return when they are illuminated from non-cooperative emitters. The performance of the PBR receiver is examined using measurements of field data. The data presented has been processed coherently. The results show that target detections have been achieved from real data. Experimental results of this bistatic hitchhiking radar are shown for the purpose of aircraft detection. Detection plots of real aircraft targets are presented and corroborated by air-truth data from a Kinetic Mode S/ADS-B IFF receiver.

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