Research on Surface Movement Radar Based on Adaptive Target Detection Technology

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Abstract: Aiming at the situation of heavy traffic in civil airport, complicated scene in airport and complex weather (foggy weather), and this paper introduces an airport surface movement radar based on adaptive target detection technology. The signal processing design mainly adopts adaptive STC (Sensitivity Time Control) and adaptive clutter detection technology to improve the target detection probability (>97%), reducing the false alarm probability ($<3\times10^{-7}$) and improving the system's anti-interference and environmental adaptability. That can improve the airport operating efficiency while ensuring the flight safety of the aircraft, meeting the requirements of civil aviation CNS equipment.

1INTRODUCTION

With the development of economic activities, the rapid development of air transport industry and the growing fleet size of airlines have resulted in the rapid increase of aircraft take-off and landing frequency in the airport. The frequency of aircraft and motor vehicle movements has also become increasingly frequent simultaneously. In the area of airport surface, the probability of collisions between take-off, landing and taxiing has greatly increased as a result of the obstruction of the air traffic controllers and other irresistible factors such as the weather (rain, snow and fog). Therefore, it is becoming increasingly prominent to effectively solve the problem of traffic congestion and conflicts in the airport, and the management of aircraft and mobile vehicles at airports is becoming increasingly important.

As an important equipment of civil air traffic control field, Surface Movement Radar (SMR) not only can detect and locate the target in real time, but also can accurately obtain the information such as the movement trajectory of the aircraft and vehicle in the conflicts of aerodrome surface. However it also appeared many problems in the course of operation. In some airports, the effective reflection area of buildings is large, and small targets (vehicles, etc.) near tall buildings are easily lost. Airports with damaged clearances have a serious impact on the increase of false targets due to complex electromagnetic environment, crosstalk and multipath system performance. Some airports have poor weather conditions, radar systems can easily detect false targets and lose real targets, greatly reducing SMR’s performance.

At present, they mainly use TERMA from Denmark and INDRA from Spain in the domestic airports. In recent years, as the state vigorously promote the civil aviation CNS equipment localization process requirements, the domestic SICHUANG company of CETC-38th and other companies have successfully developed a surface movement radar system and has achieved "Civil Aviation Air Traffic and Communications Navigation Surveillance Equipment Provisional License". These devices in the licensing process of certification, the system requires to be strictly validated and system tested to ensure that their systems performance and reliability meet the relevant technical requirements.

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2 SURFACE MOVEMENT RADAR SOLUTION

2.1 Solution

The current airports face many problems, and it lead that the existing equipment cannot meet the needs of the airport operation. It is a better solution to select the appropriate airport surface movement radar, which should have the following aspects:

- Powerful target processing ability;
- Higher of the detection probability, lower of the false alarm probability;
- Stronger of anti-interference and environmental adaptability.

It is the basic requirement to have the above capability that SMR can enter the Chinese civil aviation market for sales and usage. The specific targets should meet the requirements of civil aviation industry standard MH / T4043-2015 "Technical Requirements for Civil Aviation X-band Surveillance Movement Radar".

Based on adaptive target detection technology, the surface movement radar mainly uses adaptive STC gain control to improve the dynamic range of the system greatly. The gain control voltage changes proportionally with the intensity of the input clutter so as to ensure that both the strong and the weak targets can be detection. According to meteorological conditions and geographical conditions, the clutter real-time updates using adaptive clutter detection technology. The adaptive threshold detection can greatly improve the target detection capability and anti-interference ability under different scenarios and weather.

2.2 Surface Movement Radar Signal Processing Design

The signal processing flow of surface movement radar is shown in Fig.1. It mainly complete target detection, reporting the original trace and the background clutter to the back-end recorder.

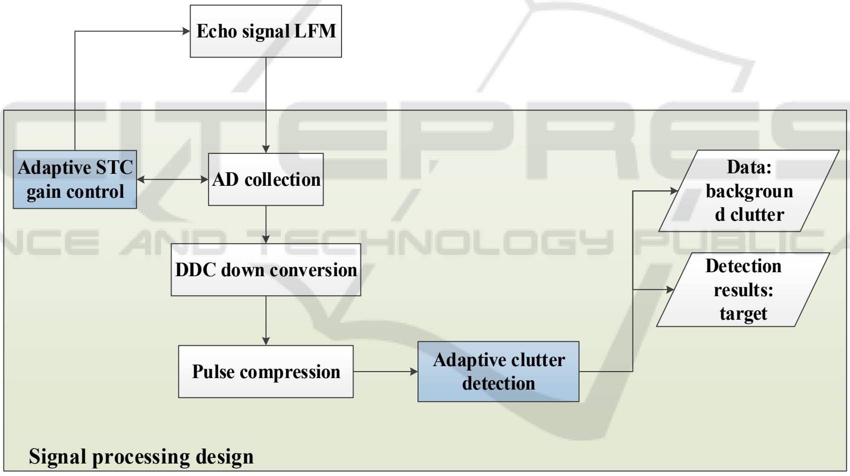


Fig.1 Surface movement radar signal processing

As shown in FIG.1, the echo signal is collected by the AD. Adaptive STC gain control is performed according to the collected data to ensure that the signal has no saturation distortion. Subsequently, the signal is down-converted, pulse-compressed by DDC (Direct Digital Control). Finally, it outputs background clutter and target information after the adaptive clutter detection.

Signal processing design mainly uses adaptive STC gain control and adaptive clutter detection techniques. The following will be described in detail.

3 THE MAIN TECHNICAL REALIZATION OF SURFACE MOVEMENT RADAR

3.1 Adaptive STC gain control technology

3.1.1 Algorithm Design and Implementation

At present, STC to control the sensitivity of receiver mainly depends on the rule of the strength of short-range clutter with distance (time) change, and setting the value of the STC attenuation responded. However, these have some disadvantages, such as the inability to manually calibrate the STC curve for a particular area and the inability to detect small targets in the context of a strong clutter. This paper designs and implements a relationship curve between STC gain and time. The curve is adaptively generated according to the specific environment scenario. The specific implementation flow is shown in Fig.2. This method not only keeps the input signal level at a reasonable magnitude, but to complete the target detection without loss of echo signal power.

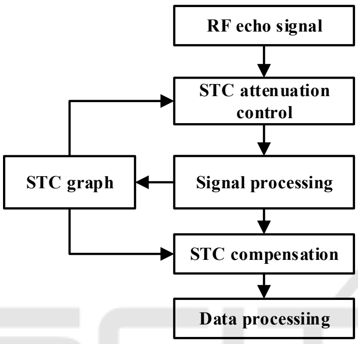


Fig.2 The workflow of adaptive STC

a) According to the actual scene, STC two-dimensional (angle-distance dimension) graph is established, and the size of STC sub-module is determined according to the actual needs, including the angle interval and distance interval;

b) The radar system enters the "adaptive STC curve establishment" mode, and the signal processing board establishes an adaptive STC curve according to the data intensities in different distances collected from different angles so as to automatically change the STC attenuation, so that the input signal strength is maintained within the receiver's dynamic range.

c) After the STC curve is established, the system works normally. After STC attenuation and controlled, the intensity of echo signal in the channel keeps within the dynamic range of the receiver. It can generate the STC waveform to use a digitization method. Each amount of attenuation is calibrated manually after the adaptive STC is generated to determine the error between the actual gain and the commanded gain.

d) In order not to lose the signal power, STC compensation is performed on the received echo signal in the signal processing board to restore the real signal;

e) Carry on the subsequent processing to the compensated signal, it finishes the target's STC control and realized.

3.1.2 Simulation test results

Fig.3-1 shows the background of the original clutter with no STC control at the airport. It shows that the terminal and office building are obviously saturated and there is a piece of strong background clutter (104 square meters magnitude of RCS (Radar Cross Section)), which inundated many small targets, leaving observers unable to observe the area. Fig.3-2 shows the clutter background after adaptive STC processed. It can be seen that both the terminal and the office building undergo STC attenuation, and the entire clutter background remains within a stable range, avoiding saturation and blocking of signals. Like these, it not only solves the problem of strong clutter submerging small targets and improves the detection probability, but also reduces the false alarm and missed alarm caused by system saturation.

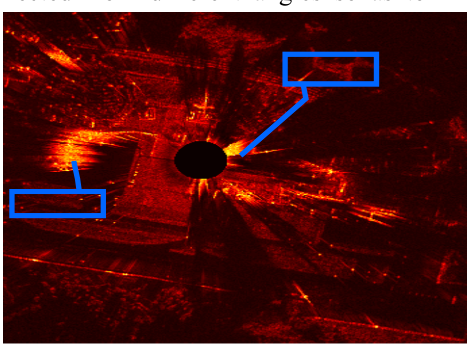
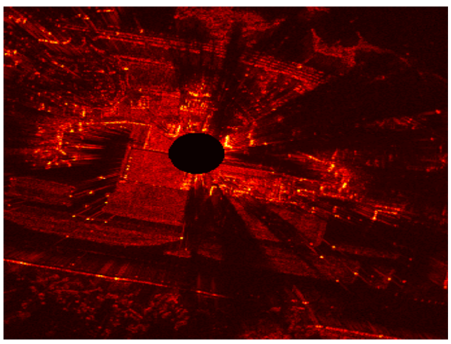


Fig.3-1 Original clutter background



Fi.3-2 Clutter background after adaptive STC processed

3.2 Detection technology of adaptive clutter map

3.2.1 Algorithm design and implementation of clutter map detection

Clutter detection recording clutter in real time is a time-domain adaptive threshold detection method. It can analyze the existence, strength and changes of clutter in order to change the characteristics of the processing system. In doing so, it can adapt to the changing clutter environment. After pre-processing, the signal processor sends the pulse pressure result to Doppler filter of zero speed for filtering. One data are recursively calculated to update the clutter data in real time and adjust the clutter detection threshold. Another data compared with the adaptive clutter threshold, when the data is greater than the threshold, then it is the target. The process shown in Fig.4:

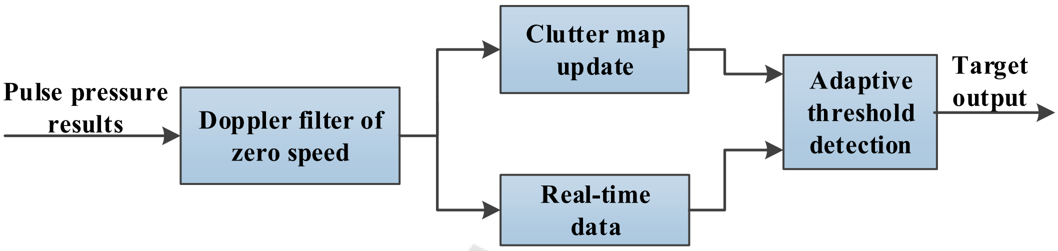


Fig.4 Flow chart of adaptive clutter detection

3.2.2 High-precision clutter map storage

The system realizes the surveillance of the entire airport surface. The structure of clutter map storage is divided by azimuth and distance units. The azimuth units are determined according to the system's angular accuracy and angular resolution. Based on the system's ranging precision and angular resolution, the distance units are determined. The specific schematic diagram shown in Fig.5:

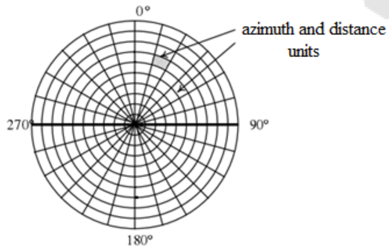


Fig.5 The division of clutter map storage space

3.2.3 Clutter map update

The clutter map update uses recursive computation and its data is stored by the system. When a new frame of data arrives, the system reads the clutter map data and recursively computes with the new data to update the clutter map data in real time. The recursive operation shown in Fig.6:

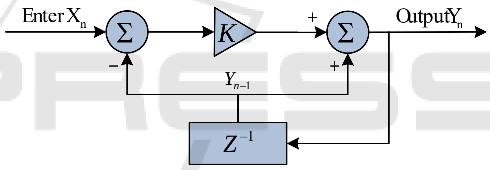


Fig.6 Block diagram of the clutter update

Its expression is

$$Y_n = (1 - K) \cdot Y_{n-1} + K \cdot X_n \qquad (1)$$

K in the formula (1) is a forgetting factor of less than 1. Z^{-1} represents the delay of the antenna scanning period (clutter map memory). After the antenna is scanned in multiple circles, the amplitude clutter map stores the average clutter value of the distance element in the corresponding azimuth.

3.2.4 Simulation results

Fig.7 shows the single-frame data clutter detection diagram. Blue represents the raw data the system received, while the purple colour represents the noise floor. Green is the adaptive clutter detection threshold. When the original data is greater than the adaptive clutter detection threshold, it is the target.

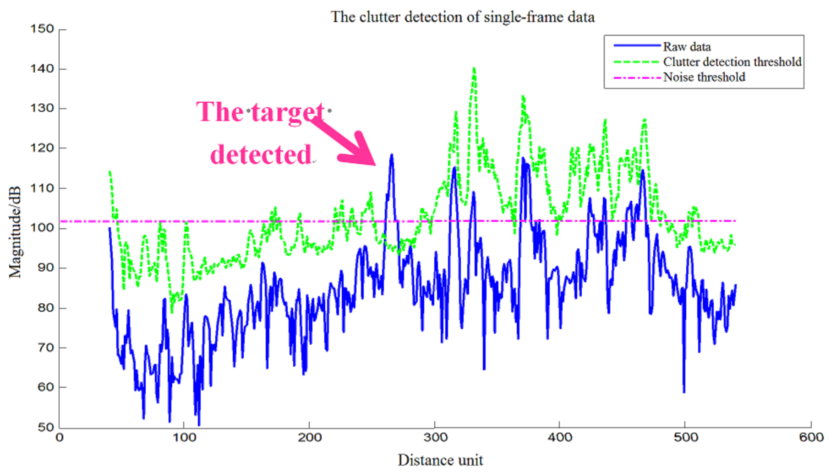


Fig.7 The clutter detection of single-frame data

Fig.8-1 and Fig.8-2 show the multi-frame raw data and adaptive clutter detection results respectively. From the original data, it can be seen that the terrain is complex and the clutter is more. After the adaptive clutter threshold detection, the detected target is very few with only two targets. Thus it greatly reduces the false alarm probability of the system and improves the detection performance of the system.

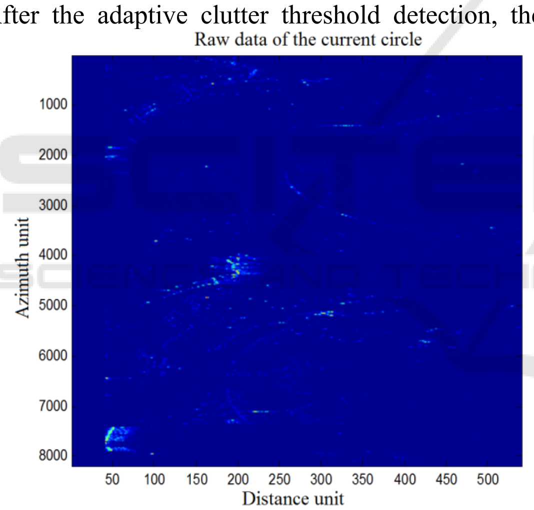


Fig.8-1 Raw data

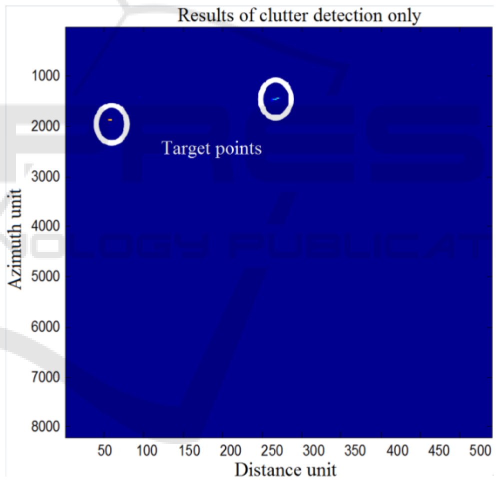


Fig.8-2 Test results of adaptive clutter map

4 SYSTEM PERFORMANCE AND EXAMPLES

4.1 Detection probability and false alarm probability

■ **Detection probability**

At a domestic airport, a reflector of 1 square meter is placed in a plurality of areas of the radar detection. After N scanning times, the number of scanning times undetected by this reflector is recorded. The detection probability P_d equals the number of scanning times undetected divided by N, then multiply by 100%. After the design of the surface movement radar scanning, the P_d measured more than 97%.

■ **False alarm probability**

After clearing the airport, the multiple areas of the airport (confirm that there is no target in the area) is observed. Step 1: Divide an area at the test site to determine there are no targets in the area. Statistics the number times N of false targets the system detected in T seconds, then the false alarm probability P_{fa} equals divided by N, afterward divide by area size, final multiply by 100%. After the design of the surface movement radar scanning, the P_{fa} measured less than 3×10^{-7}.

4.2 Field test results

Over a long period of time in a rainy day, Fig.9-1 shows the test results of conventional pulse radar processing in a domestic airport. The red base map shows the scene of the airport and the blue shows the target result of the system test. The observation shows that: 1) the contours of strong clutter (terminal, lamp post and barbed wire) are all detected as low-speed targets, resulting in more false alarms; 2) the RCS of targets is small, so they are undetected leading to leakage alarm on far away from the runway.

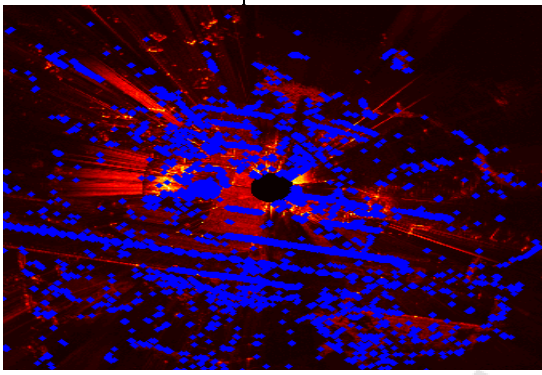


Fig.9-1 Test results of conventional pulse radar system.

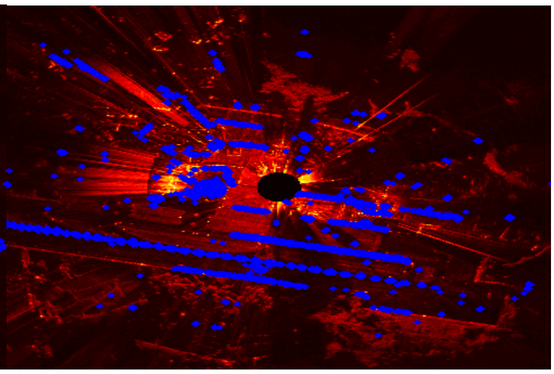


Fig.9-2 Test results of this system after treatment

Fig.9-2 shows the detection results of the radar system after adaptive STC gain control and adaptive clutter detection. The red bottom is the scene of the airport and the blue is the target of the system test. The results show that: 1) The contour of strong clutter (terminal, lamp post, barbed wire) is eliminated, reducing the false alarm probability; 2) On far away from the runway, the RCS of the targets (aircraft and vehicle) is small but both are detected, improving the detection probability of the target.

5 CONCLUSIONS

Adopting adaptive STC and adaptive clutter detection technology, it can well solve some problems that the conventional SMR equipment has more false alarms, lower detection probability and lost target under the background of strong clutter in complicated and variable weather environment. That greatly improves the detection probability of the target (>97%), reducing the false alarm probability ($<3\times10^{-7}$). Through improving the overall system performance and anti-interference, it ultimately improves operating efficiency of the airport. Therefore, during the process of certification and testing of CNS equipment, the technical solutions of manufacturers should be focused on the design review of SMR, and the relevant testing requirements should be formulated to ensure that the system can meet the requirements of civil CNS equipment.

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