THE RESEARCH AND IMPLEMENTATION OF DIGITAL SIGNAL PROCESSING ALGORITHMS ON PULSE LIDAR

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Abstract

In order to increase SNR of the echo signal and improve the target detect ability of a pulse ranging LIDAR, researches on digital signal processing technology about the echo signal have been done. Based on digital filtering, pulse accumulation and correlation detection techniques, a signal processing circuit of the laser ranging radar has been designed, using DSP chip. Experimental results showed that digital signal processing technology of the LIDAR, significantly increase the echo SNR, and increase accordingly the maximum ranging distance.

1 Introduction

LIDAR is particularly suited to remote location and target tracking, therefore widely used in tracking and monitoring for rockets, satellites and other spacecrafts.[2]

A pulse ranging LIDAR launches one or a string of very narrow pulses (the pulse width less than 50ns) to the target .Counting time from the launch of laser pulses to reach the target then by the target to return to the receiver, thus the distance to the target is calculated. A traditional pulse LIDAR uses the counter counting clock-frequency pulses of the time interval to measure the distance. Reference[1] gives a pulse LIDAR block diagram. A traditional LIDAR signal processor detects targets only by a single pulse of the echo signal, and the signal processor can only work in the condition of large SNR.[9] MA gave a new methods used a new optical pre-amplifier of the LIDAR system receiver to enhance the performance and its range.[4] Currently, more and more digital signal processing technology were used in LIDAR signal processing.[6,8] By the application of digital signal processing technology, it can improve the performance for target detection and the ranging capability of the LIDAR. Algorithm is generally implemented by the DSP chip.[3]

2 Pulses accumulation technology

The long-range LIDAR's PRF is low, generally about 10Hz. For the moving target, the echo signals of the target are usually in different ranging intervals, that makes the LIDAR can not be like high-frequency microwave radar or high-frequency LIDAR to adopt a simple pulse-echo accumulation technology to improve the SNR.

To adopt multiple-pulse accumulation technology, three-pulse LIDAR system is designed, will launch three sequence pulses in accordance with 500μs time interval and the repetition rate of 10Hz. The target of flight speed of two and a half times the speed of sound can move 0.425m within 500μs. For the sampling rate of 200MHz with a resolution of the distance of 0.75m, the target moves about 0.56 the sampling interval. Assuming the number of the sequence echo pulses is m, in ideal situation, by the accumulator m radar signal pulses will be accumulated, and the signal power increase to m^2 times. Because of the randomness of noise, the noise power only increase to m times, the noise variance σ increase $\sqrt{m}$ times.[7] By the power SNR equation of a single pulse detection, $SNR_P = P_S / P_N$,the power SNR after the accumulation will be got by equation:

$$SNR_P' = \left(\frac{P_N}{P_S}\right)_m = \frac{m^2 P_N}{mP_S} = mSNR_P \qquad (1)$$

Thus the power SNR will increase to m times, the amplitude SNR will increase to $\sqrt{m}$ times after the accumulation. Adopting three-pulse accumulation technology, the ranging LIDAR's SNR will increase 1.732 times.

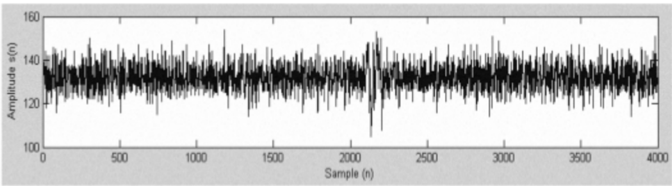

Fig. 1: A single pulse echo signal (SNR=2.698)

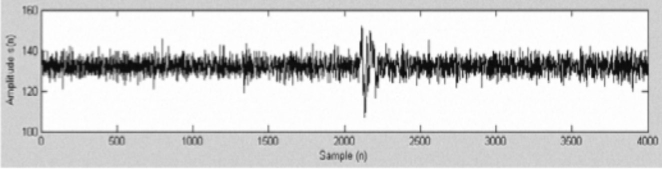

Fig. 2: The 3 pulses accumulation signal (SNR=5.296)

Fig. 1 is the echo video signal of a single pulse of a target. Fig. 2 is the result of three pulses accumulation. It can be seen that it is difficult to separate out the target with the global threshold in a single pulse echo, but easy to detect the target by adopting the 3 pulses signal cumulative technology to improve the SNR.

3 Digital signal filtering

Signal pre-processing includes mainly the signal difference filtering and smooth filtering to improve the SNR. In view of the strong undershoot characteristic of a target echo signal, every other point difference filtering is used. The interval between the undershoot point and the biggest point of the target echo of the signal is basically fixed. Every *m* points difference filtering is used, the filtering formula is

$$y(n) = x(n) - x(n+m) \qquad (2)$$

Using the smooth filtering to further improving the SNR:

$$y(n) = (1/N)\sum_{i=0}^{N-1} x(n+i) \qquad (3)$$

In the equations (1) and (2) $x\ (n)$ is input signal of the filter and $y\ (n)$ is output signal.
By difference filtering and smooth filtering, the SNR is obviously improved. Fig. 3 and Fig. 4 below, the original SNR was 4.35. After difference filtering and smooth filtering the SNR was 7.9 , increasing about 1.8 times.

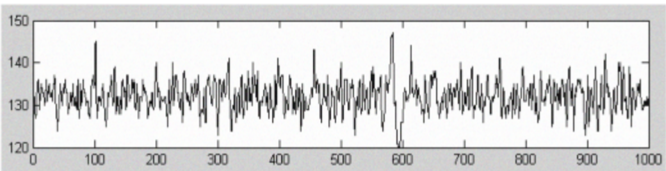

Fig. 3: The pre-filtering signal
(The signal amplitude 15, noise variance 3.51, SNR 4.27)

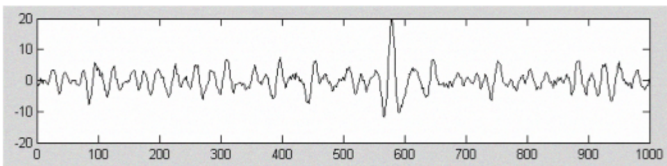

Fig. 4: The after filtering signal
(The signal amplitude 20, noise variance 2.55, SNR 7.9)

4 Target Detection

4.1 CFAR detection

After filtering on the signal, it is necessary to carry out the target CFAR detection. As the intensity of background noise changes with the external environment, in order to make the signal processor to maintain a steady CFAR, it must put the signal detection threshold level under the automatic adjustment according to level of noise.[5] In the paper the real-time threshold is set according to mean and variance of the noise. A section of continuous data is acquired from a frame data to statistical calculate noise variance σ, then set the threshold Δ, as the equation (4) shown.

$$\Delta = k\sigma \qquad (4)$$

By the difference filtering the DC level is basically 0, so only the variance statistics is needed. Taking into account the capacity problem of the software, in order not to make the target chain saturated, the threshold factor is changeable. When number of the potential targets in the chain grows, the coefficient increases, and the threshold is higher. On the contrary, the coefficient reduced, and the threshold is lower.

4.2 Correlation detection

Multiple-pulse correlation detection is used to target match according to correlativity of the targets, such as the speed of the target, the echo strength, the distance between the targets. The real target, according to the correlativity of each of them could be detected every time. But false targets generated by the noise, is not the case. Therefore, by adopting of multi-frame correlation detection, many times sequential observation on the target, false targets can be removed, and the true retained.

4.3 Targets matching

The targets matching is a process, in which comparing characteristic of pre-selection target in the current frame's new target chain with that of the potential targets of storage of the old chain , as detected in last frame . It is mainly the match of the position.
Set $P_{k-1}$is a potential target of the target chain, its position in the frame k-1 is X_{k-1}, X_k is the position of a potential target P_k in the current frame (the first frame k), if

$$X_K \in \{X_{K-1} + V - N, X_{K-1} + V + N\} \qquad (5)$$

think P_{k-1} and P_k are matching . N is the relevancy. V for the displacement between the frame targets, dealt with by the filter. When no the old target chain, no speed information, V takes zero. N takes more, as the maximum speed of the target, it is the largest displacement between the frame targets.
Digital signal processing procedure execution is completed by TMS6203. The program flow chart is shown in Fig. 5.
After the new target chain was formed in software implementation, the target information of the current frame correlate to that of last frame (historic records) information on the strength, location and speed characteristics. Correlating is mainly according to the position and the speed in the detection stage, at the same time the flashing characteristics and strength information of the signal is taken into account. When there is a strong signal, the confidence level is set to 2, or confidence level is 1. When new target matches the old one successfully, the target confidence level increases 1 or 2 in accordance with the current target confidence level. When the confidence level of the target reaches a certain value, this target is credible, can be identified as a true one. In this algorithm, for the strong target, the number of correlation times is small, it will be very soon captured, but for the weak target, it will be slowly captured because of more times of correlation.

Fig. 5: Program flow chart

5 Circuit design and test

Based on digital signal processing technology, the signal processor of laser ranging system was designed. Laser ranging system is the sub-system of certain model of aircraft's integrated information system, which requires measuring the distance of the flight target detected by the system, then send the ranging data to the host system for processing and display. Ranging LIDAR signal processor circuit diagram shown in Fig. 6.

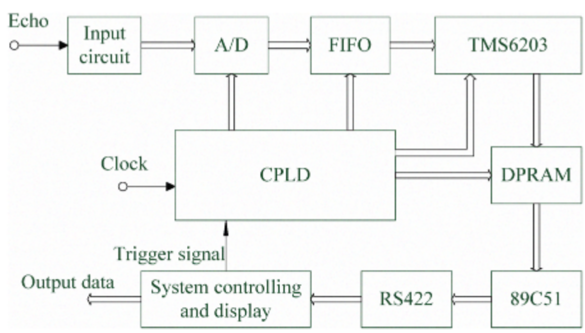

Fig. 6: Digital signal processor circuit diagram

When the host system finds the target, the laser is launched, at the same time using the laser backscatter the host system generates a trigger signal to the signal processor. After receiving the trigger signal, the processor begins to detect and compute. The core device of the signal processing board is TI's DSP chip TMS6203, which completes digital signal processing and ranging calculation. Through the laser signal input circuit, the echo signal is converted to digital signals by the ADC. The A/D sampling frequency is 200MHz, to meet the narrow laser pulse signal bandwidth. The digital signal from A/D sampling output is sent to the FIFO, after frequency division and deceleration then acquired by the TMS6203. By digital signal processing algorithms TMS6203 completes data processing and calculating. The output data through dual-port DPRAM is sent to the single-chip 89C51. 89C51 mainly completes data transmission, then the ranging data in the DPRAM through the RS422 interface is sent to the host system for processing and display. In the diagram, a CPLD device completes some of the interface functions and control timing, and by ping-pong operation the FIFO chip implements the deceleration and frequency division.

A section data statistical chart and the aeroplane position data in air-ground ranging test shown in Fig. 7 and Fig. 8.

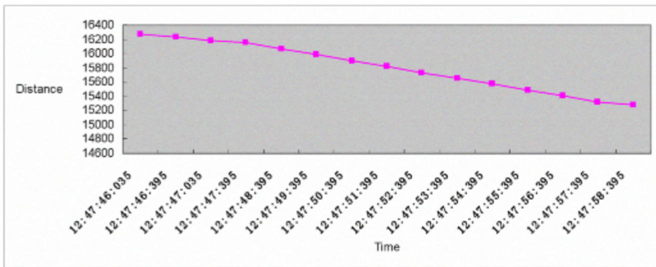

Fig. 7: A section data statistical chart

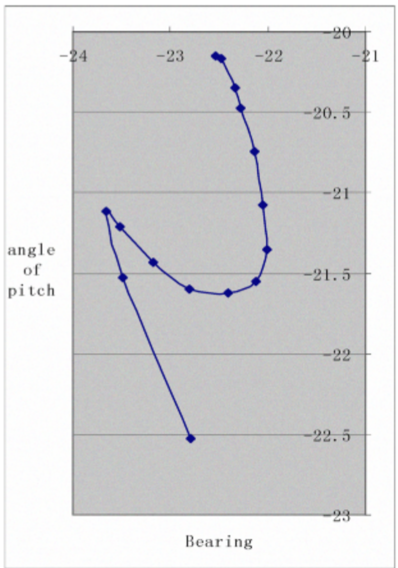

Fig. 8: The angle of pitch and bearing

6 Conclusion

The laser ranging signal processor, which was designed based on digital signal processing technology, has been through high-temperature experiments and vibration experiments, when connecting to the signal sources and the display, and then out in the experimental field of system, some experiments were carried out, its performance stable. The signal processing board was delivered to Party A, was well received. Adopting digital signal processing technology, the smallest detectable SNR of the LIDAR reach to 1.5, and the head-on intercepting and capturing distance can be improved to 2~3 times.

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