An FPGA Implementation of SAR Polar Format Algorithm

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Abstract. In order to improve the imaging processing efficiency of two-dimensional interpolated synthetic aperture radar (SAR) polar format algorithm (PFA), the SINC interpolation based on block RAM group approach was proposed in this paper. Sampling floating point coordinates were converted to the fixed point, with the integer part of the coordinate being the address. And the echo data and the remaining fractional part were written into the block RAM group. And then we completed the addressing of the echo data and interpolation kernel coefficient in a clock. Echo data were weighted and the interpolation result was obtained. The parallel structure was easy to implement and pipeline output the result to be interpolated. Interpolation points can be down compatible, and it doesn’t increase resource utilization. Based on the SINC interpolation polar format algorithm, the measured data are processed by FPGA, and experimental SAR data of 8 KB × 16 KB points can be processed with 1.78 s when the system operating frequency is 200 MHz, which verifies the validity of the scheme.

1. Introduction

Synthetic Aperture Radar [1-4] in Topographic Mapping, Resource Detection and Catastrophe Damage monitoring and other military and civilian fields are widely used, so high precision the real-time imaging of SAR has become a hot topic in research. Gathering. In SAR imaging [5-7] mode, interpolation can implement polar coordinate format algorithm Two-dimensional data coordinate format in PFA (Polar Format Algorithm) Change. Literature[5] Different interpolation for SAR imaging PFA Method resolution from distance and azimuth, maximum side valve level, and Detailed analysis of calculations and other aspects was carried out, and a limited truncation was finally introduced. SINC interpolation of points is superior to other interpolation methods, and 8 points SINC interpolation the value is better than the 4 point SINC interpolation conclusion. This paper uses SINC interpolation real Two-dimensional data in the current PFA is sampled, so SINC interpolation is an effect An Important Cause for Calculating Speed and Accuracy of Polar-coordinate Format SAR Imaging Algorithm Su. In recent years, programmable portal array FPGA (Field Program) has been used Gate Array) has achieved rapid real-time processing of SAR data Development [8-11]. FPGA adopts hardware parallel architecture, low power consumption, abundant resources Rich data throughput is large, DSP's serial processing architecture determines it itself The limitations of using FPGA for signal processing are complex and numbered Processing according to a large amount of SAR real-time imaging is the best choice. Writing The FPGA proposed to implement SINC interpolation method is to sample the point Data cached into the entire RAM. The method is selected after 8 cycles8 sampling point data and weighted sum according to 8 points SINC interpolation principle The interpolation results are obtained. Although this method is implemented on the FPGA SINC interpolation, but does not implement pipeline
output data, speed Unhappy, did not play the advantages of FPGA parallel structure. Document[9] in Design of 7 points on FPGA platform using crosscutting FIR-filter structure SINC interpolation module, this scheme also can not achieve the flow of interpolation results Waterline output. In view of the shortcomings of the above methods, this paper proposes a new method based on part itioning the parallel structure SINC interpolation method of the RAM group, applied to two-dimensional interpolation FPGA implementation of polar coordinate format imaging algorithm. Sit the sample first. The mark is addressed by the integer part of the result through floating point operation The RAM group stores echo data and decimal points. Block RAM Group It consists of 8 sub-blocks RAM, which can perform addressing operations at the same time. Find all the 8 point SINC interpolation conditions in a cycle Sample data, and does not increase the amount of FPGA resources occupied. Finally, yes. The found sampling point data is weighted, and the pipeline output is interpolated. The results show that the efficiency of the scheme is 8 times that of the serial implementation. In addition, the image processing of polar coordinate format based on SINC interpolation is also presented. The system resource occupancy, processing speed and calculation precision are carried out Analysis. System clock frequency 200 MHz, produced at Xilinx Measurement of 8 KB × 8 KB Airborne SAR on VCT699T Development Board It is used about 1.78 S. Validation of the measured data and the operation of the scheme The calculation speed can reach the requirements of SAR real-time imaging and is practical.

2. Polar coordinate format algorithm
The geometric model of the cluster SAR mode of operation is shown in Figure 1, where Angle angle is \( \theta \), the track is parallel to the x-axis in the case of positive side view, assuming The radar makes a uniform linear motion at a speed of \( V \), \( \Theta \) and \( \phi \) are radar days, respectively. Instantaneous azimuth of the linear phase center APC (Antenna Phase Center) And pitch angles, 0 and \( \phi \), respectively, at the center of the synthetic aperture. Radar antenna The instantaneous coordinate of the phase center is (xaYZ. A), at the center of the hole is (0, YCZ. C). the distribution point target P in the scene, its position vector is RT = (XT) YT, 0). Ra and RT The phase center of the antenna to the center of the scene and the instantaneous distance vector of the target, the instantaneous distance value is Ra and Rt.

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\[
SB (T, F \tau u) = \text{Rect} TT () \cdot \text{Rect} F <\tau > k T () R:: \text{Rect} j 4 \pi (F C + F \tau u)(R a-R t[ ]) (1)
\]

In the formula: \( \tau u \) is a fast time variable, TrFor pulse width, K is the signal linear FM slope, FC For transmitting signal frequency, signal bandwidth \( B = k T r \), it Medium C is the radio wave propagation speed, \( T \) is the azimuth slow time, TaIt's azimuth aperture. Time. Based on planar wave front assumptions, Ra-Rt You can use the following formula:

\[
\text{Ra-Rt <UNK>}= \text{RaRa}= x t c o s \phi s i n \theta + y t c o s \phi c o s \theta (2)
\]

The distance migration curve that can get the point target can be expressed as:

\[
R C M B (T) = (x t c o s \theta s + y t s i n 2 \phi 0 s i n \theta s) Cos \phi 0 \Omega T +12 (-x t s i n 2 \theta s-2 y t s i n 2 \theta s) Cos 3 \phi 0 \Omega 2 T 2 +12 (3 x t c o s 2 \phi 0 s i n 2 \theta s-y t) +y t c o s \phi 0 + o ( T 3) (4)
\]

In the formula: \( \Omega = V Y c A n d \ldots \) From formula (4), it can be seen that the non-scene center point cable Sexual distance walking and second and higher high distance bending. From the point of view of signal coupling, the polar coordinate format algorithm is the general After interpolation to remove coupling, by interpolation make the distance and square in equation(3) The distance migration part of the position becomes the distance frequency \( F <\tau > \)And azimuth time T'sLinear function. In order to eliminate the upward coupling of distances, do the following scale for equation (3)

Transform: \( F \tau u = F C (\Delta R-1) + \Delta R F \theta \)
In the formula: \( \Delta R = \cos \phi_0 \cos \theta_0 \), \( F' \) for the transformed distance frequency variable, with the simplified formula, it is still written as \( F' \) below. After distance interpolation and Fourier transform, the distance migration curve of the target can be obtained as: \( RCM. (T) = y \cos \phi_0 + x \cos \phi_0 \tan \theta_0 \) (6)

In which: \( \tan \theta = \frac{aX}{aY} = \frac{v c \sin (\theta)}{v c \cos (\theta)} \) (7) Substituting formula (7) into formula (6) yields:

\[
RCM. (T) = y \cos \phi_0 + x \cos \phi_0 \cos \theta \sin (2\theta) \Omega T^{-1} + o(T^3)
\]

After the distance vector correction is completed, the distance vector variable \( YT \) the solution coupling is over. The rest of the migration related only to the orientation needs to be eliminated. Continue to replace equation (3) with the following variable:

\[
T' = (FC + F \tau) \tan \theta \Omega \cos \theta
\]

After distance and azimuth interpolation, the target distance migrates at this time the dynamic curve is: \( RCMKT (T) = y \cos \phi_0 \) (10)

It can be seen that after azimuth interpolation, the distance from the migration curve the distance migration associated with the azimuth variable is fully corrected. So high the effective and high-precision interpolation can be quickly and accurately completed. At present, the commonly used interpolation algorithms are linear interpolation, polynomial interpolation, and III. Sub spline interpolation and SINC interpolation. Linear interpolation is simple and convenient. However, the accuracy of the treatment is not high. Polarization interpolation and spline interpolation structures involve division Method and cyclic iteration, implement complex structure, implement time program using FPGA the structure of SINC interpolation itself is based on convolution architecture, and the core is multiplication and accumulation. Suitable for FPGA implementation. Considering resources, precision, and algorithm complexity, the system uses SINC interpolation for PFA imaging. According to 8 points SINC Interpolating principle, where the sampling point coordinates are in the\([W-4, W+4)\) range There is an echo data multiplied by the corresponding SINC coefficient and summed to obtain the interpolation result of the point to be inserted. Among them, the calculation of the SINC coefficient is the formula is:

\[
SINC (Wi-Fi) = \frac{\sin (\pi (Wi-Fi))}{\pi (Wi-Fi)} \]

In the formula: \( W \) is the coordinates to be inserted, \( Wi-Fi \) the coordinates of the sampling point. 8 points SINC The interpolation time domain reconstruction equation is:

\[
F(X) = \sum IFd (I) \cdot \text{Sinc}(x-i)
\]

In formula: \( FD (I) \) is the sample value of \( F(X) \) at \( X = I \), which is actually the interpolation results are obtained by weighted summation of echo data with SINC coefficient.

3. The FPGA Design Scheme of Two-dimensional Interpolating SAR Imaging

3.1. Overall structure of the system

The plate structure of the SAR imaging processing system under this scheme is shown in Figure 2. As shown. Analyzing the above principles, it can be seen that the opposite orientation and distance direction data enter efficient and high-precision interpolation can ensure that the distance migration is accurate. Calibration [12]. The system handles the echo data of radar sampling. The data format processed in the FPGA is a single-precision floating-point complex number.

Data storage the unit is used by calling the MIG (Memory Interface Resolution) kernel Control the signal of the household interface to realize the echo data, intermediate processing Results are stored and transposed to read and write. Digital signal processing unit based on PFA The imaging algorithm coordinates the logical structure and timing of the FPGA. In order to achieve the distance and azimuth processing of the sample data to complete the high score Identification of SAR imaging [13]; In order to meet the needs of SAR real-time imaging, and Based on the features of FPGA parallel architecture, distance and azimuth data weight Sampling is implemented using SINC interpolation to minimize FPGA reality current signal processing time. The system operates at 200 MHz clock frequency At rate, the data is temporarily stored in DDR3 transferred from the PC to the board card. After PFA imaging
algorithm processing, the imaging results are transmitted by Ethernet at high speed Transfer interface and external SFP transceiver to PC host Line display imaging.

3.2. Ethernet data transfer module
During the SAR imaging process, the echo data and imaging office the result data is realized in the upper computer and FPGA board through the Ethernet module Transfer between cards [14]. This design uses LogiCO RE provided by Xilinx IP Ethernet 1000BASE-X PCS / PMA implements the physical layer; Xilinx The three state Ethernet medium access controller solution IP Tri-Mode Ethernet MAC completes physical address addressing, data assembly frames, Function of data link layer such as error check and retransmission; UDP/IP protocol stack separately Functions of the current network layer and transport layer.

3.3. Digital Signal Processing Unit
This scheme uses two dimensional SINC interpolation to realize digital signal processing single Resampling of the distance and azimuth data in the element, here the key medium The SINC interpolation calculation based on block RAM group is implemented on FPGA Law. This is called in both distance and azimuth processing. SINC interpolation module this scheme is greatly accelerated with the same resource occupancy rate the interpolation speed. The entire SINC interpolation process can be divided into four steps Carry on, take the interpolation length of 16,384 as an example, for each step Line detailed introduction.

Step 1: Cache sampling point data. Due to sampling points in the time series the coordinate can not be entered into the interpolation module synchronously. Sampling point data is temporarily cached to FIFO. Step 2: Sample point coordinates floating point transfer fixed point. The first design of this scheme the coordinates of floating-point sampling points are first converted into fixed-point coordinates, and the number of fixed-point types to ensure that there is no overflow according to the setting of the integer bit width, set to 16 in this article Bit. At the same time, in order to meet the requirements of the 16 equal SINC quantization coefficient table, the decimal width is set to be greater than or equal to 4 bits, set in this article as16 bits. Step 3: Use the integer of the point sampling point coordinates as address storage the decimal part of the sampling point data and the sampling point coordinates. One of the RAM. The address can only store one data if two or more sampling point coordinates the integer part is the same and the decimal part is different, the previous seat will appear the case where the targeted data is covered by data with the same integer part.

Step 4: Calculation of interpolation results. In step 3, follow the sample The integer of the point coordinate stores the echo data for the address, assuming that it is to be inserted The coordinate of the point is W(W is an integer), that is, Entire_update isW-4, W-3, W-2, W-1, W, W +1, W +2, W +3, calculated Sub block RAM's Sub _ address, addressed stored echo data and The decimal part takes out the sampling point that satisfies the conditions around the insertion point. And then, find the corresponding SINC in the SINC quantization coefficient table through the fractional part Coefficient. Among them, the method of quantifying the SINC series used in FPGA As shown in Table 1, it mainly divides each unit distance into 16 parts, from the quantification of SINC coefficient is realized. Finally, according to the SINC coefficient the final interpolation results are obtained by weighted summation of echo data.

Data Processing Results and Analysis of 3 SAR When analyzing the experimental results, this module is based on Xilinx Virtex 7 series xc7vx690t chip is the processing board for the processing core Verifying, when the system clock frequency is 200 MHz, imaging processing The system uses 1.78 S to complete the data processing of 8 KB × 16 KB points. Matlab's processing process is configured in hardware for Intel(R) Core (TM) i7-4890 CPU @ 3.60 GHz processor, single Threads complete the same processing time is 1,546.099 S, contrast can be seen FPGA The effect of data processing acceleration is quite.
4. Conclusion
In this paper, a scheme based on two-dimensional SINC interpolation polar coordinates is proposed. FPGA implementation method of SAR imaging algorithm. In implementing SINC interpolation, the focus is on how to quickly and efficiently find the conditions around the point to be inserted. The contribution point, using the FPGA parallel architecture pipeline output SINC plug Value result. Dividing the entire RAM stored echo data into 8 sub-blocks RAM implements the addressing of 8 sub-blocks RAM in the same cycle, Implementation of every other clock cycle output to insert the results of the calculation. With When, the method proposed in this paper, does not increase the resource consumption rate, can lose in parallel the interpolation results are given, and the imaging processing time is greatly shortened. The Implementation of Two-dimensional SINC Interpolate Polar-coordinate Format SAR Real-time Imaging It's a viable one.

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