Reduction of Interference in Automotive Radars using Multiscale Wavelet Transform

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Abstract: A technique is presented to minimise false decisions in automotive radars operating in close proximity. The technique also reduces the requirement on the power of the radar as signals can be detected with very low signal to noise ratios. The signal processing is achieved in real time using a field programmable array.

1. INTRODUCTION

Automotive radars are some of the most important civilian radar applications. The system creates new problems for radar designers as there will be occasions when a number of radars operate in close proximity and transmit the same frequency. The presented technique has the advantage that it minimizes the probability of false reading and reduces the required power transmitted and thus reducing the possibility of interference. The improvement is achieved by designing appropriate signal processing circuitry that will detect the required radar pulse in the presence of noise and interference from neighbouring radars. Correct detection with a signal to noise ratio of –12 dB can be achieved.

Automotive radars are allocated one band of operation and consequently discrimination between signals transmitted by different radars cannot be achieved using conventional filtering techniques. The presented techniques depends on radars transmit with different pulse widths and different pulse repetition frequencies [6,7]. The algorithm uses wavelet analysis [2,3] to detect the pulse in the presence of noise and other jamming signals and then extracts the pulses that match the transmitter's own pulse width. The signal processing is implemented on a field programmable gate array and works in real time [4,5]. The algorithm also reduces the transmitter power requirement considerably. This is achieved because correct detection can be made at much lower signal to noise ratios.

2. THE ALGORITHM

This algorithm is applied to decrease the effect of the jamming signal on the received target pulse. The algorithm is divided in two stages to decrease the computation complexity and hence increase the speed. The first stage is used in the case of high SNR signal and a low density false jamming signals. The second stage is applied when the first stage fails to detect the target pulse edges in the case of low SNR and a high density of jamming signals. The steps of the first stage of the algorithm are as follows:

1. Compute the multiscale wavelet coefficients of the received signal with the dyadic scale $a = 2^j, 1 \le j \le 4$.
2. Compute the local maxima (LM) of the wavelet coefficients at each scale.
3. Check the consistency of the position of the local maxima and correct it if required.
4. Recognize the local maxima coefficients satisfying the pulse width and remove all others.
5. Integrate the wavelet local maxima of all scale levels. The pulse edges will be added and become stronger compared to the noise coefficients in the integration step.
6. Divide the integration coefficients into two portions, positive and negative coefficients.
7. Each portion is divided into smaller segments and the maximum of each segment is computed. Then the average value of the all segments is computed (threshold level). The result is obtained at 20 % of the threshold level.
8. Target identification is determined by measuring the width between a coefficient which is lower than the negative threshold followed by a coefficient which is higher than the positive threshold. If the measured width matches the known pulse is considered to be true.

When the first stage fails to detect the pulse edges, the second stage of the algorithm is applied. The steps of the second stage are as follows:

9. As the scale increases, keep only the increasing local maxima coefficients.
10. Repeat steps 3, 4 and 5 in the first stage.
11. At the integration step, keep only the coefficients, which satisfy the known pulse width.
12. Repeat the step 6 to 8 in the first stage and identify the true target.

3. SIMULATION RESULTS

The detection of the received target pulse is simulated in the presence of noise and false jamming signals. The effect of signal parameter changes on the algorithm has been investigated. These parameters include SNR, false target density and Pulse repetition period (PRP) of the signal.

Consider the case of receiving a true and false radar pulse in the presence of white gaussian noise with $\sigma = 0.5$ as shown in figure 1(a). Next, we apply the first step of the algorithm to get the wavelet coefficients of the signal. Figure 1(b) gives the output after step 4 of the algorithm. We notice that the location of the local maxima edges has been corrected, the local maxima that do not match the pulse width have been removed. At this step, the edges can be clearly identified and give the final output of this stage as shown in figure 1(c). Figure 2(a) gives an example of a signal, which the first stage of the algorithm cannot detect. By using the second stage of the algorithm, a large number of false coefficients will be removed. Figure 2(b) illustrates the output after step 12 in the algorithm in which the integrated coefficients that correspond to the true target pulse edges are detected.

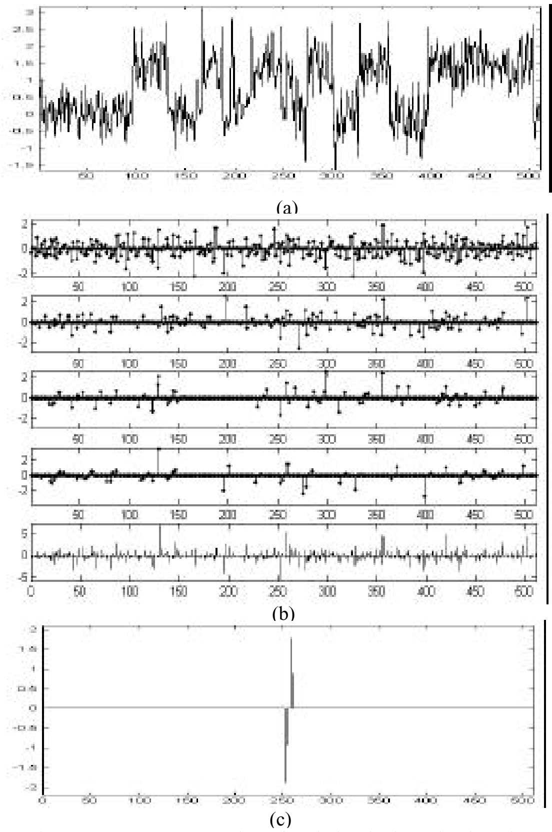

Figure 1 (a) Example of original signal. (b) The LM of the WT coefficients at the output from step 4 of the algorithm. (c) Output of the first stage of the algorithm.

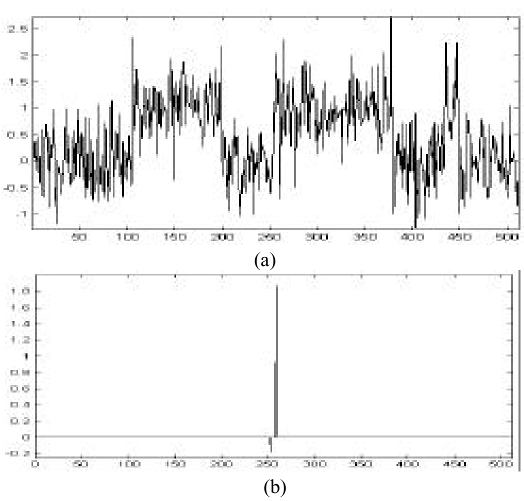

Figure 2 (a) The original signal, (b) The output of the second stage of the algorithm

Finally we will evaluate the reliability of the algorithm. The algorithm can either a) fail to detect any pulse edges, b) detect the true pulse edges. We define the probability of identification as the percentage of runs when the pulse width of transmitted pulse match the pulse width of the received pulse. Figure 3(a) shows the probability of identification as a function of SNR. Figure 3(b) shows the probability of identification as a pulse repetition period increased which decrease the SNR more.

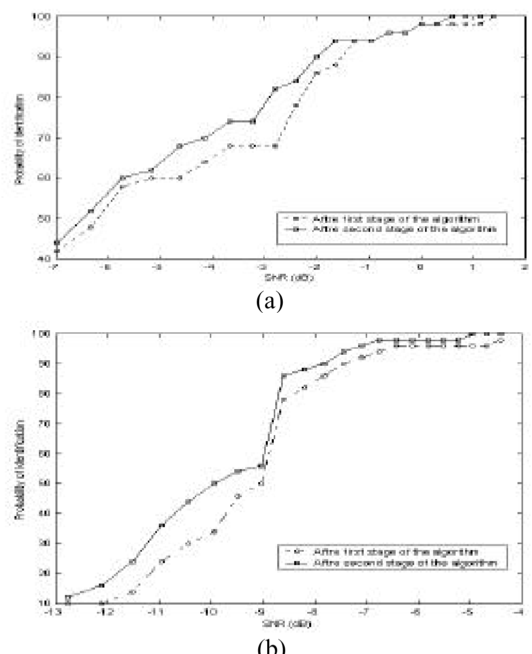

Figure 3 (a) For the probability of target identification, (b) The probability of identification as the SNR is decreased

4. REAL-TIME IMLEMENTATION

The developed radar target identification system in the presence of jamming conditions [8,9] is shown in figure 4. The ADC converts the signal to the 2's complement digital format then the digital signal enters the FPGA device to identify the target pulse edges coefficients from unwanted coefficients.

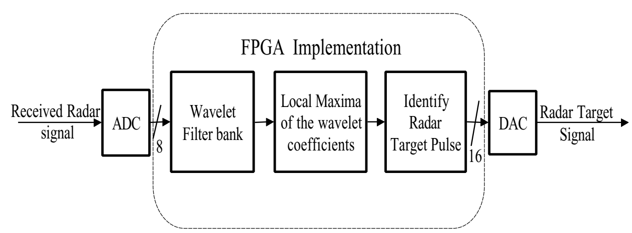

Figure 4. Architecture of radar target identification system

In the FPGA of figure 4, the design consists of three stages. First, the wavelet coefficients of the input signal using fast wavelet transforms (FWT) are calculated. Second, the local maxima of the wavelet coefficients are extracted. Third, the target pulse edges are identified from the unwanted false edges. The identified target pulse edges in digital signal format are the output from the FPGA device toDAC which converts the output to an analog signal.

The flow of data inside the FPGA device is processed in parallel as much as possible and the logic design stages are pipelined to obtain the speed required in the real time operation. The high-density FPGA device is obtained from theXilinx XLA family in order to implement the whole design in one device to conserve the board space, power and design cost and to obtain the speed required.

Now we shall discuss the implementation of each stage of the design on the FPGA device.

5. IMLEMENTATION of FWT

Our task here is to discuss the implementation of the FWT on FPGA to get the wavelet coefficients of the input radar signal. Multiscale wavelet coefficients [1,2] of the input signal can be obtained by using multiresolution signal analysis [8]. The four wavelet scale coefficients of the input signal needed in our design correspond to changes in the wavelet scale in the dyadic steps of $a = 2^1, 2^2, 2^3, 2^4$. To implement these coefficients, we construct a filter bank with four stages as shown in figure 5. The basic elements in the filter bank are FIR filters [10].

FWT implementation is based on using algorithm *a trous* [4,5]. The original filter coefficients, which are the filter coefficients of the first filter bank, represent aHaar wavelet. The rest of the filter bank coefficients are calculated using*a trous* algorithm. In this way we can construct filters with constant coefficients. It will help to use constant coefficient multiplier (KCM) in the FPGA design [11].

The implementation of the digital filters with sample rates above a few MHz require using parallel distributed arithmetic (PDA) FIR . We use the DSP logicore [12] to construct the PDA FIR filters with fixed-point coefficients and to target thefilters macro to the XC4085 XLA device [13]. The filter bank stages of figure 5 are constructed after pipelining, scaling the filter outputs and synchronizing the data in the wavelet scales by using a proper delay. The wavelet coefficients hp1del, hp2del, hp3del, and hp4 when the input is a unit pulse are shown in figure 6.

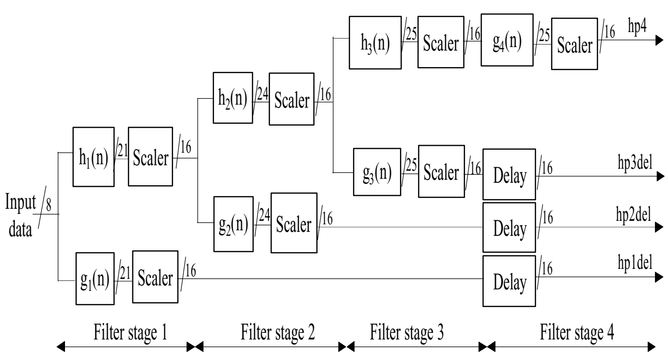

Figure 5. Wavelet filter bank

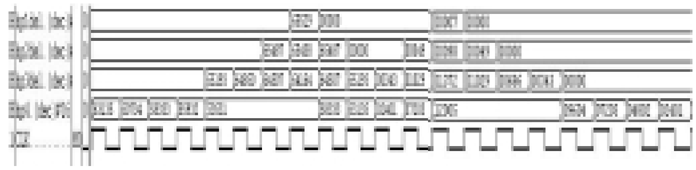

Figure 6. Wavelet coefficients output from filter bank whe the input is unit pulse.

6. IMLEMENTATION of THE LOCAL MAXIMA STAGE

This module is used to extract the extreme values of the input vector and output a copy of the input vector with non extreme values set to zero [8]. The module macro is placed at the output of each scale of filter bank as shown in figure 7. The flow of data in this module is shown in figure 8. The serial input data is converted to parallel using the delay elements. The comparison stage outputs only the coefficient B if and only if it is an extreme value.

This maxima stage was modeled with VHDL to build amacro which can be instantiated in the top-level schematic design.

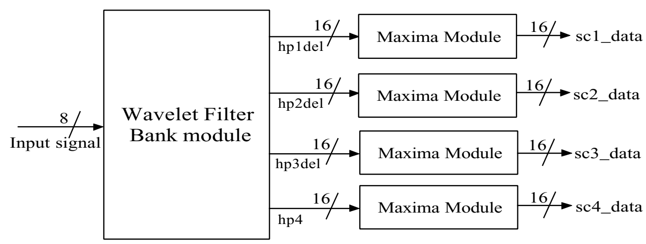

Figure 7. Maxima modules

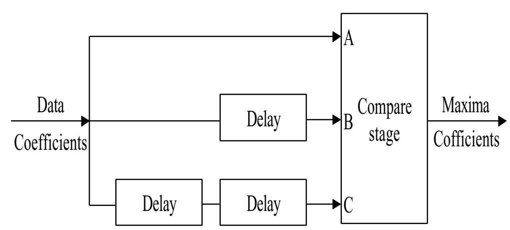

Figure 8. Maxima module architecture

7. TARGET PULSE IDENTIFICATION STAGE

In the previous stage, themaxima coefficients are extracted from the wavelet coefficients. These maxima coefficients not only represent the target pulse edges but also some of unwanted coefficients.

The unwanted coefficients are:

- Unwanted coefficients from noise, which represent more irregular coefficients.
- Unwanted coefficients from received false targets, which represent more unwanted edges inmaxima coefficients.

The objective of this stage is to extract the target pulse edges from the unwanted coefficients.

This module consists of four stages as shown in figure 9. The function of each stage is as follows:

- Stage 1: At each wavelet scale, recognize only the maxima coefficients satisfying the known transmitted pulse width (PW) and remove the others.
- Stage 2: Integrate the four wavelet scales, so that the level of target pulse edges will be stronger relative to the unwanted coefficients.
- Stage 3: At the integrated level, get the maximum and the minimum of the integrated maxima wavelet coefficients.
- Stage 4: Measure the time between the maximum and the minimum after integration. The target is identified if this time matches the PW.

All these stages are implemented with the VHDL to create a macro which can be instantiated in a top-level schematic design. The waveform signals at each stage of the module are shown in figure 10. It is clear when the coefficients do not satisfy the pulse width SC4_DATA, the output from the pulse width check stage is zero at SC4_MID.

8. CONCLUSION

The performance of automotive radars can be considerably improved by applying the wavelet transform to detect the reflected pulses and discriminate between the wanted and spurious pulses. The signal processing also reduces the power requirement which in turn reduces the interference between radars in close proximity and the cost of the transmitter front end.

8. REFERENCES

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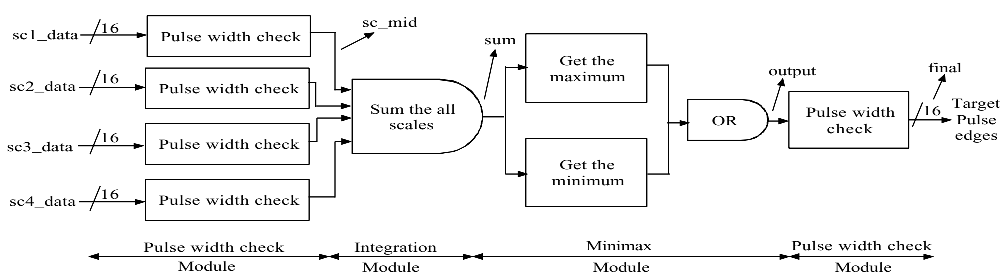

Figure 9. Architecture of the target pulse identification stage

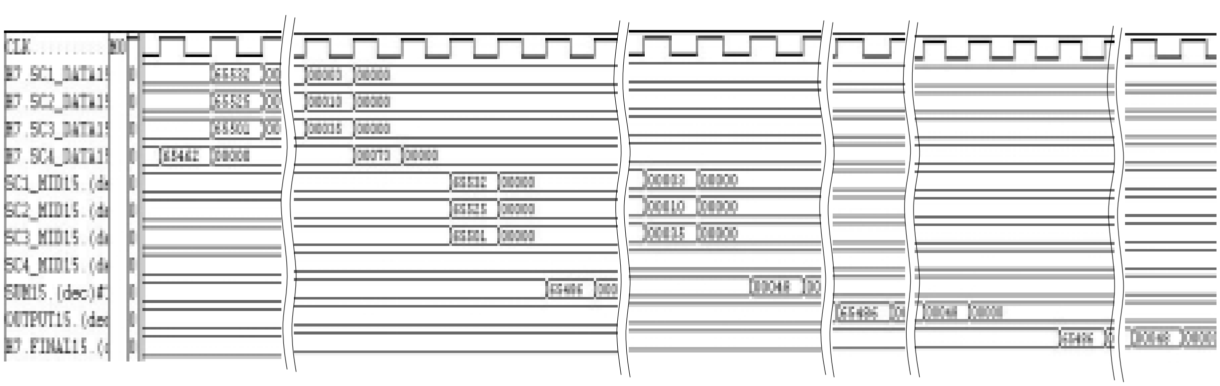

Figure 10. The input and output waveform signals of the target identification stage