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博　士　論　文　概　要

論　文　題　目

Hardware Implementation of Particle Swarm Optimization and its Application for Adaptive Signal Processing

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As one of the most well-known optimization algorithm, Particle Swarm Optimization (PSO) attracts more and more attention and presents its talented potential in recent years. Strongly nature-inspired by the swarm intelligence, PSO, proposed by Kennedy and Eberhart in 1995 for the first time, is conceived as a simulation of animal flocking, learning and sharing information when a group of insects or birds seek for food in a search space. Owing to the feature of group communicating and learning like animals, PSO is first used to machine learning field in the early stage. In pace with the algorithm improving and the superior performance springing up, PSO is popularly introduced to solve complex nonlinear problems, such as data mining, biometric, circuit synthesis, economic analysis, power system optimization and positioning system, starting after 2000. Recently, in an attempting to employ PSO in above system with real-time requirements, its hardware implementation with high calculating speed and high stability based on large scale integration (LSI) goes to a significant subject. Especially, as the PSO application on adaptive signal processing and mobile system becomes worldwide attention-focused, a general purpose hardware architecture which can deal with complex nonlinear issue is sincerely expected.

First, the processing speed is very important for real-time system. Furthermore, the stability is also a necessary performance. Existing PSO software is too time-consuming and cannot provide the real-time processing speed. To meet this challenge, an attractive subject is to implement PSO in hardware. Thus, a novel hardware implementation of PSO with high speed and stability is sincerely desired.

Second, the conventional 2-dimension PSO cannot satisfy real-time application for complex nonlinear control. Thus, a hardware implementation of multi-dimension PSO is urgently needed to control the multi-parameter of complex application. A general purpose hardware architecture of multi-dimension PSO is expected in this subject as a fundamental hardware platform. It can create a new solution for complex nonlinear control with real-time requirements.

Third, as a classic subject of complex nonlinear control, adaptive filter has flexibly changeable coefficients to be regulated. Conventional algorithms of adaptive filter are difficult to be realized in hardware with a high adaptive speed. Therefore, the proposed hardware of multi-dimension PSO are applied for adaptive filter as a particular application and pioneer design.

Chapter 1 [Introduction] This chapter briefly introduces the concept and the background of the PSO. The current research status and development of PSO are presented as an outstanding evolutionary algorithm. However, there still are some challenges for PSO development. Then, the objective and scope of this research are indicated in this chapter. Three subjects are proposed for facing the challenges.

Chapter 2 [A Hardware Architecture of Particle Swarm Optimization for Real-time Control] PSO with random time-varying inertia weight and acceleration coefficients (PSO-RTVIWAC) proposed in 2009 has better convergence and higher accuracy than the conventional PSO algorithms. In this chapter, as the first subject, a novel hardware implementation of PSO-RTVIWAC is developed to raise the processing speed for real-time positioning system. The proposed architecture incorporates two features to improve the processing speed and the calculation stability with an acceptable chip area cost. One feature is a pipeline approach to realize parallel computation. The other is a synchronous module control. By implementing the LSI of proposed pipeline architecture on a field programmable gate array (FPGA), the calculation speed for one particle (76.9ns) outperforms the serial hardware implementation proposed in previous work by 17 percent. The chip cost of the hardware is about 47,664 gates. The system error of previous hardware is completely eliminated. The proposed architecture achieved not only high processing speed but also high stability. This novel subject provides a high performance PSO hardware for real-time system.

Chapter 3 [A Hardware Implementation of Multi-dimension PSO for Complex Nonlinear Control] In order to meet the complex nonlinear application having multi-parameters to be controlled, this chapter further proposes a basic architecture design for establishing a general purpose hardware of multi-dimension PSO as a fundamental platform and implements the proposed hardware in FPGA. Based on the architecture proposed in Chapter 2, the PSO hardware for each dimension is paralleled to realize the multi-dimension calculation. One feature of this approach is to provide the coefficients for multi-dimension calculation by building memories and recycling the prestored values. The other feature of this multi-dimension PSO hardware is to employ the proposed pipeline technology in the selective module. The proposed hardware architecture achieves flexible scalability which can make it possible to realize the dimension extending. An 8-dimension PSO based on the proposed hardware design is implemented into Altera Cyclone II (FPGA) as an example. The chip cost includes 1,229 logic elements (Gate Count: 14,748) and 834,016 bits memory (Gate Count: 3,336,064), which is reasonable for 8 dimension extending. The calculation for one particle can be completed within 77.0ns. The proposed hardware can be employed to solve complex nonlinear problems with real-time requirements due to its high accuracy and processing speed. This hardware design is a general purposed hardware implementation of multi-dimension PSO and suitable for particular nonlinear applications with different dimension.

Chapter 4 [Implementation of the Multi-dimension PSO for Adaptive FIR Filter Development] The conventional adaptive filter approaches are too complex to be implemented in hardware and the calculation speed is not satisfactory. The control of filter coefficients is a classical multi-parameters issue and the PSO dimension number can be flexibly adjusted according to the order of filter. Thus, the general purposed hardware implementation of multi-dimension PSO presented in Chapter 3 is employed to design an adaptive FIR filter as an example of complex nonlinear application in this chapter, aiming to achieve a high updating speed of filter coefficient. The adaptive filter based on 8-dimension PSO as an example in Chapter 3 is implemented in FPGA. By slightly adding fitness calculation (1.8% of the entire system), the hardware architecture can provide a much faster update speed than software and conventional approach. The coefficient update rate of the proposed design reaches 92.5 KHz (11μs), which is about 4,625 times faster than least mean squares (LMS) algorithm implemented by software and 27.2 times faster than recursive least squares (RLS) algorithm implemented by dedicated hardware. The mean square deviation between hardware results and MATLAB software results is 5.4×10^{-5}. This adaptive filter presents superior performance for real-time requirement. The above results prove that the proposed research can provide a high coefficient updating speed to control the filter performance. This successful application verifies that the proposed multi-dimension PSO hardware can effectively work for adaptive signal processing as a complex nonlinear application.

Chapter 5 [Conclusion] In this chapter, the conclusion is described and the future work is drawn for the research.

This research concentrates on the PSO hardware implementation with high performance and its application for adaptive signal processing. The first subject presented a novel hardware implementation of PSO with high speed and stability for real-time control system by using pipeline technology and synchronous module control. In second subject, a general purpose hardware architecture of multi-dimension PSO with flexible scalability are proposed as a fundamental platform. In the third subject, an adaptive FIR filter design based on the proposed hardware platform is introduced as the particular application and pioneer design. These proposals are favorable contributions for LSI implementation of PSO and its application for adaptive signal processing area and mobile system.