Hardware Specialization Technique for Vibration Control

063724 Yasuaki Tezuka Graduate Adviser : Shuichi Ichikawa

1 Introduction

The demands for high-performance control systems are ever increasing. As an alternative to a software-based system, hardwired implementation of a control system is anticipated.

Logic circuit can be reduced, if any input is given as a constant. The derived circuit usually operates at a higher frequency, as the logic depth and layout area are reduced. Such technique is called as **Hardware specialization**, since the circuit is specialized to a specific input data. The specialized circuit has to be generated for each set of input values, and it is thus natural to use reconfigurable devices to reprogram the internal logic according to the input data. To date, hardware specialization has been applied to some applications [1].

The purpose of this study is to evaluate the hardware specialization techniques for control applications: e.g., IIR digital filters and vibration control systems. Vibration control is a method which reduces or eliminates vibration. Specialization to specific input data and specific parameters are both examined.

2 Evaluation Method and Environment

In the research and development of control systems, computer-aided Model-Based Design is widely used to design time-varying systems. Target systems are designed, simulated, and analyzed on Mathworks MATLAB/Simulink in this study. Hardware Description Language (HDL) is generated by Simulink HDL Coder (Add-in software).

First, the target model is constructed and verified as a continuous system. Then the model is redesigned to the corresponding discrete model with an adequate fixed-point data type. The sampling frequency is set to 512 Hz in all examples of this study. HDL coder converts this discrete model into VHDL codes, which are synthesized, placed, and routed with Altera Quartus II software with the optimization option Balanced. Target device is an Altera Cyclone III FPGA EP3C120F780.

For verification purposes, some of the designs were actually downloaded into an Altera Cyclone II Starter Kit (EP3C25F324), which was driven by 25 MHz system clock. The output signals are written in on-board SRAM for verification.

3 Evaluation of Digital Filter

There are two categories of digital filter: infinite impulse response (IIR) and finite impulse response (FIR). In this study, IIR filters are specifically examined. The target is the third order Butterworth Low-pass filer with cutoff frequency 3 Hz. There are some forms of IIR digital filter implementation, in which four forms listed below are evaluated.

DF1 Direct Form I
DF2 Direct Form II
Cascade Biquad Cascade Form
Parallel Biquad Parallel Form

For each form, the following two Simulink models are constructed and converted into VHDL codes. The first one is Generic, which is the model whose filter parameters are given externally from input ports. The other is Specialized, which is the model whose filter parameters are given internally as constant values. In Specialized design, filter coefficients are given as constants in the Simulink model, which is converted into the VHDL codes that include constant values. Figure 1 summarizes the evaluation results

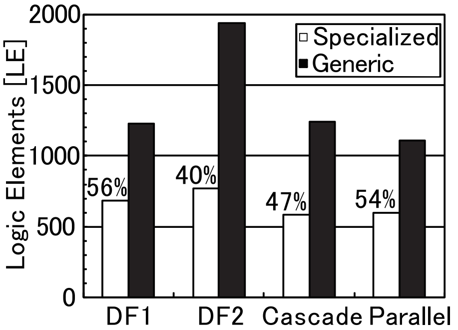

Figure 1: The effect of Gain-Parameter Specialization for IIR Digital Filter

of four forms. Logic scale is expressed in logic elements (LEs) of Cyclone III FPGA.

In each form, the logic scale of Specialized was reduced to approximately 50% of that of Generic. In any case, the reduction of logic scale was mainly induced by reducing combinational logic gates. No reduction was observed in register elements. Operational frequencies were also improved by specialization in all forms; the improvement was between 23% (DF1) and 39% (Parallel).

4 Evaluation of Vibration Control

Two vibration control systems are evaluated. One is Hybrid Shape Approach (HSA) [2] which is based on Notch Filter. Another is Preshaping [3] with Low-pass Filer (LPF) which adds reverse-phased input against natural vibration. Each control systems are specialized in four cases listed below.

Unfixed Not specialized.
Fixed Parameter Specialized to parameters.
Fixed Input Specialized to input pattern.
All Fixed Specialized to both parameters and input pattern.

The parameters of HSA are filter coefficients. The parameters for Preshaping with LPF are filter coefficients and Preshaping parameters. The input pattern is a square wave (period 10 sec., amplitude 1, 50% duty). All Fixed is an experimental case, because it might be possible to output the precomputed values stored in a table. Filter part is implemented as an IIR digital filter of Cascade form.

Table 1 summarizes the results of four designs of HSA. The numbers in parenthesis are the resource utilization of an EP3C120F780 device. As readily seen, Fixed Parameter is 50% smaller and 40% faster than Unfixed. Meanwhile, Fixed Input is larger than Unfixed; no reduction was observed in Fixed Input.

Table 2 lists the evaluation results of Preshaping with LPF. The respective logic scales of Fixed Parameter and Fixed Inputs are 10.6% and 9.6% of Unfixed. Most of the reductions were derived from Preshaping, which is a dominant part of Unfixed. By examining other input patterns, the logic scale was shown to be linearly dependent on the bit width that is necessary to represent the waveform of input pattern.

Table 1: Evaluation result of HSA

	Unfixed	Fixed Parameter	Fixed Input	All Fixed
Total LEs	1232	587	1277	617
Combinational Logics	1232	587	1277	617
Registers	32	32	65	65
Frequency [MHz](85℃)	26.0	37.3	26.1	37.2

Table 2: Evaluation result of Preshaping with LPF

	Unfixed	Fixed Parameter	Fixed Input	All Fixed
Total LEs	86271	9114	8305	1071
Combinational Logics	49707	922	7282	815
Registers	65568	8256	2144	353
Frequency [MHz](85℃)	17.42	26.44	19.27	29.55

5 Conclusion

In this study, the effects of hardware specialization for vibration control were quantitatively evaluated. By using hardware specialization, the implementation cost of control circuit can be significantly reduced. For practical applications, more complex and practical control systems should be examined in the following studies.

References

[1] K. Compton and S. Hauck, "Reconfigurable computing: a survey of systems and software," ACM Computing Surveys, vol.34, no.2, pp.171–210, Section 4.5 and 5.2, 2002.

[2] K. Yano, T. Toda, and K. Terashima, "Sloshing suppression control of automatic pouring robot by hybrid shape approach," Proc. IEEE Conf. Decision and Control 2001, vol.2, pp.1328-1333, 2001.

[3] N.C. Singer and W.P. Seering, "Preshaping command inputs to reduce system vibration," ASME Journal of Dynamic Systems, Measurement, and Control, vol.112, pp.76–82, 1990.