

بسم الله الرحمن الرحيم

Sudan University of Science and Technology
College of Graduate Studies

Implementation of Digital Filters Using Microcontrollers

*A thesis Submitted for partial fulfillment of the M.Sc. degree
in Computer Engineering*

Presented by:

Ahmed Abdalla Mohamed Ali

Supervised by:

Prof. Saad Daoud Sulaiman

April 2007

ABSTRACT

Applications involving processing of data from external analog sources (sensors) often require some kind of digital filtering of the data prior to using the data to respond to some external event. In these cases 8- and 16-bit Microcontrollers (MCU) comes into the picture: They are inexpensive, efficient and have all the required I/O features and communication modules needed.

The Atmel AVR microcontrollers are excellent for signal processing applications due to their powerful architecture, strong instruction set and built-in multi-channel 10-bit Analog to Digital Converter (ADC). The megaAVR[®] series further have a hardware multiplier, which is important in signal processing applications.

This thesis describes the process of designing a digital filter and the implementation of an FIR filter using an Atmega16 microcontroller, which is one of Atmega Atmel AVR series family of microcontrollers.

The thesis in the first chapters explains the digital filters theory in brief, their main classifications according to the method of the digital implementation, their general equation formula for both FIR and IIR filters and describes the designing stages with the aid of a software package (MATLAB7).

In the last three chapters the thesis establishes in details the information needed for the implementation of digital filters in general on AVR microcontrollers firstly, and then focuses on the process of implementing a specific FIR filter on Atmega16 from scratch. A program has been written and a circuitry has been built, then results of the implementation are analyzed to support the theory.

تجريدة

التطبيقات المشتمة على معالجة للبيانات من مصادر تماثلية خارجية (حاسات) غالبا ما تتطلب بعض انواع الترشيح الرقمي لتلك البيانات قبل توظيفها في الاستجابة لحدث خارجي. في مثل تلك الحالات فإن المتحكمات ذات الخانات الثمانية وذات الستة عشرة خانة تدخل في الصورة.

المتحكمات Atmega AVR متحكمات ممتازة نسبة لبنيتها الفعالة، حزمة تعليماتها القوية، والمحول التماثلي-الرقمي المضمن ذو القنوات المتعددة وذو الخانات الثنائية العشرة. سلسلة mega AVR فوق ذلك، لديها ضارب مادي، وهو مهم جدا لتطبيقات معالجة الاشارة.

البحث في ابوابه الاولى يشرح نظرية المرشحات الرقمية باختصار، الشكل الاساسي للمعادلة العامة لـ "مرشحات الاستجابة النبضية المنتهية" و "مرشحات الاستجابة النبضية غير المنتهية"، ويشرح مراحل التصميم بمساعدة حزمة برمجيات MATLAB7، وفي ابوابه الأخيرة يؤسس بالتفاصيل المعلومات المطلوبة لتطبيق المرشحات الرقمية بشكل عام على متحكمات الـ AVR أولا، ثم يتمحور حول تطبيق "مرشح استجابة نبضية منتهية" محدد على المتحكم Atmega16 من البداية.

تمت كتابة البرنامج ثم بنيت الدائرة العملية وحللت نتائج التطبيق لتدعم النظرية.

TABLE OF CONTENTS

Abstract	II
التجريدة.....	
III	
Table of Contents	IV
List of Figures	VII
List of Tables	VIII
Chapter 1 INTRODUCTION	1
1.1 Background	2
1.2 Objectives.....	2
1.3 Chapters Outlines	3
Chapter 2 PRINCIPLES OF DIGITAL FILTERS	5
2.1 Introduction.....	6
2.2 Parameters of Filter Performance.....	6
2.2.1 Time Domain Parameters.....	6
2.2.2 Frequency Domain Parameters.....	10
2.3 General Digital Filters.....	10
2.4 FIR Filters.....	12
2.5 IIR Filters	14
Chapter 3 DIGITAL FILTERS DESIGN STAGES	17

3.1	Introduction.....	18
3.2	Filter Design Steps.....	18
3.2.1	Filter Specification.....	18
3.2.2	Calculations of Filter Coefficients.....	21
3.2.3	Realization Structures.....	21
3.2.4	Filter Implementation.....	22
3.3	Filter Design Using MATLAB7.....	22
Chapter 4 DIGITAL FILTERS ON AVR		26
4.1	Introduction.....	27
4.2	The AVR Hardware Multiplier.....	27
4.3	The AVR Virtual Accumulator.....	28
4.4	Overflow of Fixed Point Values.....	28
4.5	Coefficients Scaling.....	30
4.6	Coefficients Down Scaling.....	32
4.7	Analog-to-Digital Conversion on AVR	34
Chapter 5 THE IMPLEMENTATION		36
5.1	Introduction.....	37
5.2	The Filtering Algorithm.....	37
5.2.1	Filter Nodes Initialization.....	37
5.2.2	Loading Filter Coefficients.....	39
5.2.3	Getting Samples.....	39
5.2.4	Filtering a Sample.....	40
5.2.5	Scaling Down the Result.....	42
5.2.6	Output the Result.....	42
5.3	An Eight-Order FIR Filter Implementation.....	42
5.3.1	Features of the Implementation.....	42
5.3.2	Test Simulation Program.....	44
5.3.4	The Built-in Analog-to-Digital Converter Settings.....	46
5.3.5	The Hardware Circuitry.....	46

5.3.6 Filter Algorithm Performance..... 47

Chapter 6 CONCLUSIONS:..... 49
REFERENCES:..... 52
APPENDIX A: The Test Simulation Program 53
APPENDIX B: The Implementation Program 59
APPENDIX C: ATmega16 Datasheet Summary 64
APPENDIX C: DAC08 Datasheets 76

LIST OF FIGURES

Figure No.	Figure Title	Page
Figure 2.1	Impulse Response, Step Response, and Frequency Response	7
Figure 2.2	Passband, Transition band, and Stopband for a 0.4 Cutoff LPF	8
Figure 2.3	Frequency Domain Performance Parameters	9
Figure 2.4	System	11
Figure 2.5	FIR FILTER Direct form I Structure	13
Figure 2.6	Magnitude Response for FIR filter, $b_k = \{0.25, 0.25, 0.25, 0.25\}$	13
Figure 2.7	IIR Filter as Direct Form I Structure	15
Figure 2.8	IIR Filter Frequency Boosting	16
Figure 3.1	The Frequency Response of a Comb Filter	19
Figure 3.2	Frequency response parameters	20
Figure 4.1	Un-scaling the Accumulator Value to Give Desired Filter Output	33
Figure 5.1	Data flow in FIR Filter Algorithm	38
Figure 5.2	Filter Nodes Initializing Data Flow	39
Figure 5.3	Loading Filter Coefficients Data Flow	40
Figure 5.4	Getting Samples from the ADC Data Flow	41
Figure 5.5	Filtering Algorithm Data Flow	43
Figure 5.6	Magnitude Response of Eight Order FIR Filter with a Cutoff Frequency	44
Figure 5.7	Test program filter Results against Matlab Filter Results	46
Figure 5.8	Circuit Block Diagram	47

LIST OF TABLES

Table No.	Table Title	Page
Table 3.1	Frequency response parameters description	20
Table 3.2	Common Methods for calculating filter Coefficients	21
Table 3.3	Common Filter Design Structures	22
Table 5.1	FIR Filter Parameters	44
Table 5.2	Test Program Results	45
Table 5.3	Performance of Eight-Order FIR Filter	47
Table 5.4	Program Register Usage	48