

# ECE4703 B Term 2009 Laboratory Assignment 6

Project Code and Report Due by 3:00pm 17-Dec-2009

The goals of this laboratory assignment are:

- to familiarize you with adaptive filtering and two applications of adaptive filtering on the TMS320C6713 and
- to familiarize you with the Least Mean Squares (LMS) algorithm and its implementation on a floating point DSP.

## 1 Problem Statement

In this assignment, you will write a C program for the TMS320C6713 DSK that realizes an *adaptive* FIR filter via the Least Mean Squares (LMS) algorithm. The LMS algorithm was developed in the 1960's and has been called the “workhorse of adaptive filtering”. LMS-adapted FIR filters are simple to implement and have been used in a wide variety of applications. In this assignment, you will use an LMS-adapted FIR filter for two useful applications: system identification and noise cancellation.

For all code written in this project, the AIC23 sampling rate should be set to 44.1kHz. All computations should be done in **single-precision floating point** math. It is highly recommended that you convert all inputs directly to floats immediately after reading them. All multiplies and adds should be done in floating point and the outputs should only be cast to shorts (and put in the appropriate 32-bit containers) prior to sending them to the AIC23. Using floating point math should considerably simplify your code and allow for easier troubleshooting.

Your filter update algorithm should be LMS as discussed in lecture. Specifically, your FIR filter coefficients should be updated as

$$b[k, n + 1] = b[k, n] + \mu e[n] x[n - k] \quad \forall m \in \{0, 1, \dots, M - 1\}$$

where  $\mu$  is a fixed filter update step size that you select,  $e[n]$  is the error signal at time  $n$ , and  $b[k, n]$  denotes the  $k^{\text{th}}$  filter coefficient at time  $n$ . Recall that selecting  $\mu$  too large will cause your filter to “blow up”.

The following parts of the assignment will use your adaptive filtering code to do two useful signal processing tasks.

### 1.1 Part I: System Identification

In this part of the assignment, you will use your LMS-adapted FIR filter to estimate the impulse response of an unknown system. See Figure 8-4 in your textbook for a block diagram of this system.

Here,  $x$  is the input to the unknown system and  $d$  is the output of this system. You are provided with these signals but not the impulse response of the unknown system. The goal is to determine the impulse response of the unknown system. Luckily, LMS will do this automatically for us since it will adapt the filter to minimize the mean squared error between its output  $y$  and the output  $d$  of the unknown filter. This can only occur if the LMS-adapted filter's impulse response becomes very similar to the unknown impulse response. After your filter has adapted, its impulse response should be very similar to the unknown system and the mean squared output error should be very small. A block diagram showing the AIC23 channels for the system identification system is shown in Figure 2.

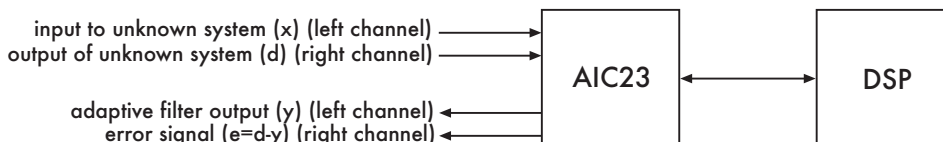


Figure 1: Inputs and outputs of adaptive filtering system for system identification.

To test your adaptive filter, try making up your own test signals (in Matlab) with a known system (you could, for example, use the bandpass filter from Lab assignment 2 as your “unknown” filter). Generate a white noise input and use the Matlab `conv` or `filter` function to produce the output of the “unknown” test system. You should stop the execution of your code before the test files finish to halt the adaptation and view the results. Plot the impulse response of your adaptive filter. Does it make sense? Can you verify that your filter converged correctly? Experiment with various filter lengths  $K$  and step sizes  $\mu$  to see which combinations are able to most effectively identify the unknown system. Is your error signal (right channel output) going to zero? Also check the frequency response of your adaptive filter. Does it make sense?

Once you are confident that your adaptive filter is working correctly, download the files in `lab6part1.zip` from the course web page and test your adaptive filter on a truly unknown system.

## 1.2 Part II: Noise Cancellation

In this part of the assignment, you will use your LMS-adapted FIR filter to cancel undesired noise from an audio signal. The structure for this adaptive filtering application was discussed in lecture. A block diagram of the AIC23 channels used in the noise cancellation system is shown in Figure 2. The left input channel signal contains  $d+n$ , the desired component corrupted by an undesired noisy component. The right input channel contains  $n'$ , a noisy signal that is correlated (similar to but not the same as) the noisy term  $n$  in the left input channel. Your goal is to cancel as much of the noise as possible while also minimizing distortion on the desired signal. Luckily, the LMS-adapted filter does just that by adapting its coefficients so that the mean squared error ( $e = d + n - y$ ) is minimized. This is accomplished by adapting the filter coefficients so that  $y$  (the filtered version of  $n'$ ) approximates  $n$  and the residual signal  $e$  contains only the desired component.

As in Part I, you should test your noise cancellation system with known signals first. Generate some noise  $n$  and filter it with an arbitrary filter to produce  $n'$  (the correlated noise signal). Also generate a desired signal  $d$ , add the noise signal  $n$  to it, and test your adaptive filter. The right output channel  $e$  should sound similar to the desired signal  $d$ . There may be some residual noise in the output. Experiment with various filter lengths  $K$  and step sizes  $\mu$  to see which combinations

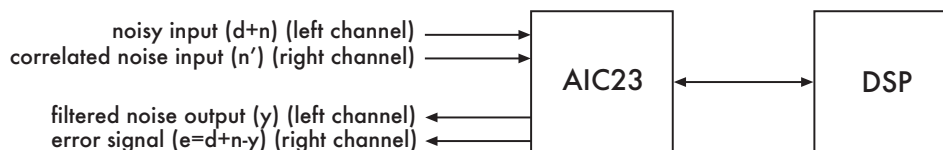


Figure 2: Inputs and outputs of adaptive filtering system for noise cancellation.

are able to most effectively mitigate the undesired noise.

Once you are confident your noise cancellation system is working well, download the files in `lab6part2.zip` from the course web page and test your adaptive noise cancellation system on unknown signals.

## 2 Suggested Procedure for Software Design

1. Begin by reading Lab 5 in your textbook if you haven't already done so. This is a good place to get started since it covers most of the details needed to implement the system identification adaptive filtering system. You are also encouraged to explore the Chassaing examples in the `myproject` directory.
2. A good first step would be to implement fixed FIR filtering on the left channel input. Leave your code modular to allow for any length FIR filter. Ensure that your fixed FIR filter is working correctly before proceeding. You are encouraged to use code developed in earlier lab assignments, if it works correctly.
3. Modify your code to allow for adaptive filtering. Here, you will need to implement the LMS filter coefficient update. It might be a good idea to set  $\mu = 0$  and ensure that nothing has changed from your non-adaptive case.
4. Select a good value for  $\mu$  and test your adaptive filter on the provided signals as well as any signals that you think might be interesting. You will need to play these stereo signals out of the headphone jack on the computer using Matlab or another audio player. Make sure whatever audio player you use is not adding any special effects to the signals<sup>1</sup>.
5. Also don't forget to initialize your filter coefficients to something reasonable (like all zeros) before you adapt them.

## 3 In Lab

You will work with the same lab partner as in the prior laboratory assignments. Please contact the instructor if your lab partner has dropped the course or if you have concerns about your lab partner's performance on the prior assignment.

---

<sup>1</sup>Media players (and sometimes the Windows soundcard driver itself) is notorious for adding unexpected effects to the playback/recording signals. Make sure all effects are off. You should be able to confirm that the frequency response of the playback/recording system is almost flat.

## 4 Code Submission and Specific Items to Discuss in Your Report

Since this assignment is due on the last day of classes, no late submissions can be accepted. Please make sure you submit your project code and report on time.

The emphasis of this assignment is on the implementation of the LMS algorithm and two applications of adaptive filtering. Your report should focus on any implementation issues that you encountered including any results and insight gained in terms of selecting  $K$  and  $\mu$  for the various signals. Your report should also focus on any insight gained from the two applications including presenting results that conclusively demonstrate that your filter is converging to the optimum solution. In the system identification application, you should generate your own  $x$  and  $d$  with a known system (using the Matlab `conv` command) and show that your filter converges correctly by plotting its impulse response over the known system's impulse response. In the noise cancellation application, you may want to record the entire signal during the convergence of your filter and plot selected parts of this signal to show the presence of the noise at the beginning of convergence and the cleaned-up signal later in the convergence process.