

Teaching Microcontroller Systems with a Neuromorphic Application

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Abstract

This paper describes a series of experiments designed to teach microprocessor system principles to students at Baylor University. This three credit class is a required course taken by third year electrical and computer engineering students. The students in this course use the Atmel AVR 8-bit microcontroller. Through a series of individual lab experiences the students will learn serial communication, MATLAB-AVR interface, SPI communication, Digital to Analog Converter (DAC) use and basic theory, Analog to Digital Converter (ADC) use and basic theory, and an introduction to Neuromorphic engineering. “Neuromorphic” is the name given to an interdisciplinary field which combines concepts from neuroscience, engineering, computer science, and biology. A Neuromorphic investigator’s goal is to design systems based on biological nervous systems. The students in this class will apply their newly learned microcontroller skills to control and read from a brain inspired analog neuron circuit.

Keywords

Microcontroller, Education, Neuromorphic, Laboratory

Introduction

This paper describes laboratory experiments which accompany the lecture portion of a course at Baylor University. The course, Microprocessor Systems, is a required junior level class in the Electrical and Computer Engineering program. This course does not have an explicit laboratory section assigned to it so these experiments face two constraints: First, they take place during the lecture time, and second, they typically take place in a lecture room which does not have test and measurement equipment. The solution to this is to require each student to purchase a low cost microcontroller board that they can use with their personal laptops which they bring to class. Many of the experiments do not need test equipment, but when this is needed lab space must be reserved or the students must complete the projects on their own time.

In the following sections, the microcontroller hardware and software will first be described. This is followed by a brief description of ten experiments and their learning goals. Experiments one through eight have already been used in at least one class. Experiments nine and ten’s hardware and software are working and are scheduled to be integrated into the Spring 2017 Microprocessor Systems course at Baylor University. Lab ten is the connection to brain inspired, i.e. Neuromorphic, engineering concepts. The labs have been followed by a final project. This final project allows the students to apply what they have learned in the labs to a problem which they get to propose. Results in the form of student feedback is presented. Finally, future work is proposed.

Experiment Hardware

The Atmel Xplained Mini Evaluation board¹ is used for this class, Fig 1. This Printed Circuit Board (PCB) contains an AVR ATmega328p microcontroller and also an IC used to program it. Its low cost of about \$10 USD makes it easy for most students to purchase. There are protoboard areas on each side of the PCB which allows students to solder on headers or other components. There is one push button on the board and an LED which can be accessed.

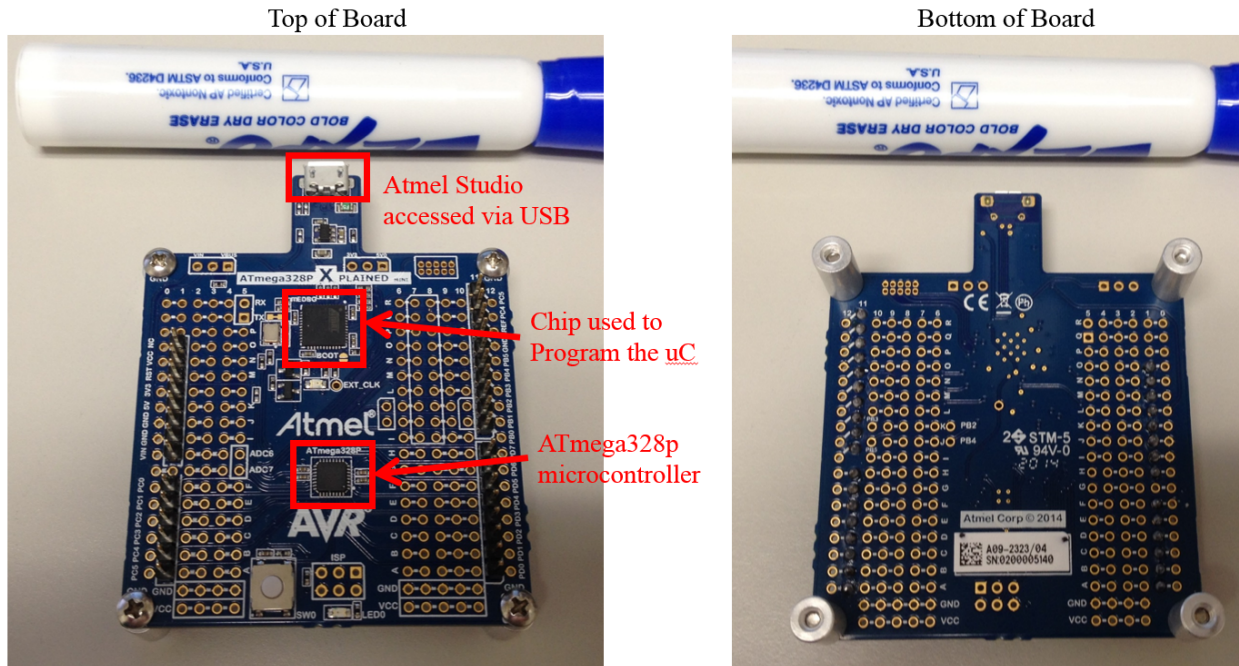


Figure 1: Atmel Xplained Mini Microcontroller board¹

Experiment Software

Atmel Studio: This software is Atmel’s integrated development environment which is used to program the hardware, Fig. 2.

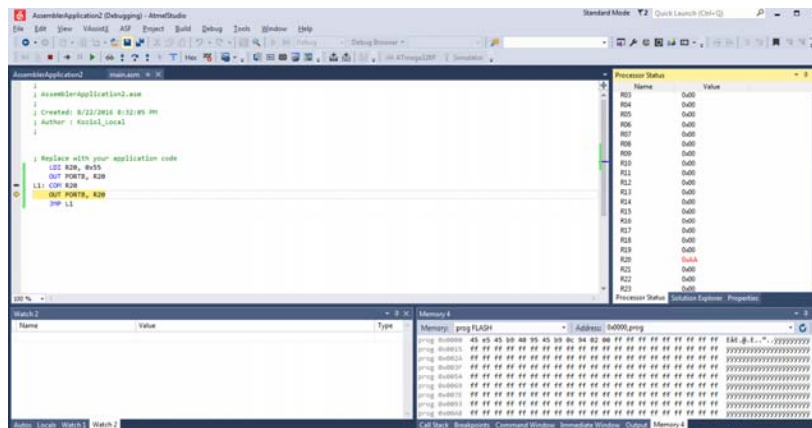


Figure 2: Atmel Studio software development environment²

It has an emulator so that one can run code without hardware, and it also has a debugger so that one can step through code on the hardware.

MATLAB: This math software is initially used to demonstrate serial communication, but students can also integrate it into their final projects. The software consists of the base MATLAB software and an add-on “toolbox” software. The serial communication labs use the Instrument Control Toolbox.

Experiments

Experiment 1- Introduction to Atmel Studio: In this assignment students install and become acquainted with the basic features of Atmel Studio software.

Learning Goals:

1. Learn how to install and get the software working on their personal laptop.
2. Learn how to create a project, write a simple assembly program, and step through it.

Experiment 2- Introduction to the Atmel Xplained Mini: In this assignment students are introduced to using their Xplained Mini hardware. There is a demo program preprogrammed into the microcontroller by Atmel which is a Morse Code program called “ReMorse”. The preloaded demo program has two functions: 1) They can type a letter on their computer and an LED on the Xplained Mini will blink the appropriate Morse code signal. 2) They can type Morse code using the button on the Xplained Mini and a terminal emulator will print the appropriate letter on their computer in a terminal window.

Learning Goals:

1. Make sure their board is working.
2. Learn how to use terminal emulation software to communicate with the board.

Experiment 3- Compiling, Programming and Debugging using the Atmel Xplained Mini: This lab is the equivalent of “Hello World” in typical programming classes. At the end of this lab students will have completed an entire tool flow from code development to running it on their microcontroller. After this lab they will be able to develop their own programs and run them on the microcontroller.

First they will create a project, then they will compile it into executable code. They will then send the compiled program to their Xplained Mini microcontroller using Atmel Studio. Finally they will use Atmel Studio to step through an assembly program.

Learning Goals:

1. Learn how to compile an assembly program into a Hex file (the type of file that is downloaded onto the microcontroller)
2. Learn to program the Hex file onto the microcontroller using Atmel Studio
3. Learn how to use the Atmel Studio debugger connected to the Xplained Mini board.
4. Demonstrate that they can use assembly code techniques presented in class lecture.

Experiment 4- Writing Macros using the Atmel Xplained Mini: This lab builds on the student's previous lab where they created delays to display their initials in Morse Code. In this lab they convert one of their functions into a Macro and use it to again display their initials in Morse Code.

Learning Goal:

1. Demonstrate that they can write and use a Macro.

Experiment 5- Introduction to C and the AVR: In this lab students program the AVR to control the Input/Output (I/O) ports using C, and they also create a time delay.

Learning Goals:

1. Become comfortable with using a microcontroller's datasheet and PCB's schematic
2. Learn to write C code to control an I/O port
3. Learn to write C code to implement a time delay
4. Learn how to compile a C program and download it to the AVR

Experiment 6- Introduction to AVR Timer/Counter Programming: In this lab students program the AVR to control the I/O ports using the timer/counter registers of the AVR to either create a time delay or count an external input.

Learning Goal:

1. Learn how to use the AVR's timer/counter registers

Experiment 7-USART Communication with AVR and MATLAB: In this lab students learn how to program the AVR to receive and send data using C. Students interact with the AVR using MATLAB and its add-on Instrument Control Toolbox.

Learning Goal:

1. Demonstrate that they can use MATLAB's serial communication capability to send data to the AVR, modify it in the AVR and then receive the modified data from the AVR.

Experiment 8-Analog to Digital Conversion and Interrupts: In this lab students will learn how to program the AVR's Analog to Digital Converter (ADC) using C. They will learn to use it using an interrupt service routine. This lab builds upon Experiment 7 because they will send their digital data to MATLAB over USART so that they can plot the results.

Learning Goals:

1. Learn how to use the AVR's ADC
2. Learn how to use an interrupt service routine (ISR).
3. Get experience soldering and interfacing a function generator with their Xplained mini board.
4. Experience important aspects of sampling theory (Aliasing) in actual hardware.

Experiment 9- Using the SPI on the ATMEGA328P to Control the AD5380-5 DAC³: In this lab students will learn how the SPI on the DAC IC expects to receive data. They then configure the SPI pins on the AVR. They will learn how to send data to the DAC. This can be measured with an oscilloscope or multi-meter.

Learning Goals:

1. Learn how to use SPI with the AVR
2. Learn how to use a DAC

Experiment 10- Using the AVR to control an Electronic Neuron circuit: In this lab students will be given a PCB with a neuron circuit⁴. This neuron circuit has five analog voltage parameters that need to be adjusted to create the spiking pattern like in Fig. 3. The students will apply their knowledge of DAC control to set these voltages and then measure the results on the oscilloscope.

Learning Goals:

1. Learn how to apply their microcontroller knowledge to a research problem and use test and measurement equipment to debug as needed.
2. Learn an introduction to Neuromorphic engineering.

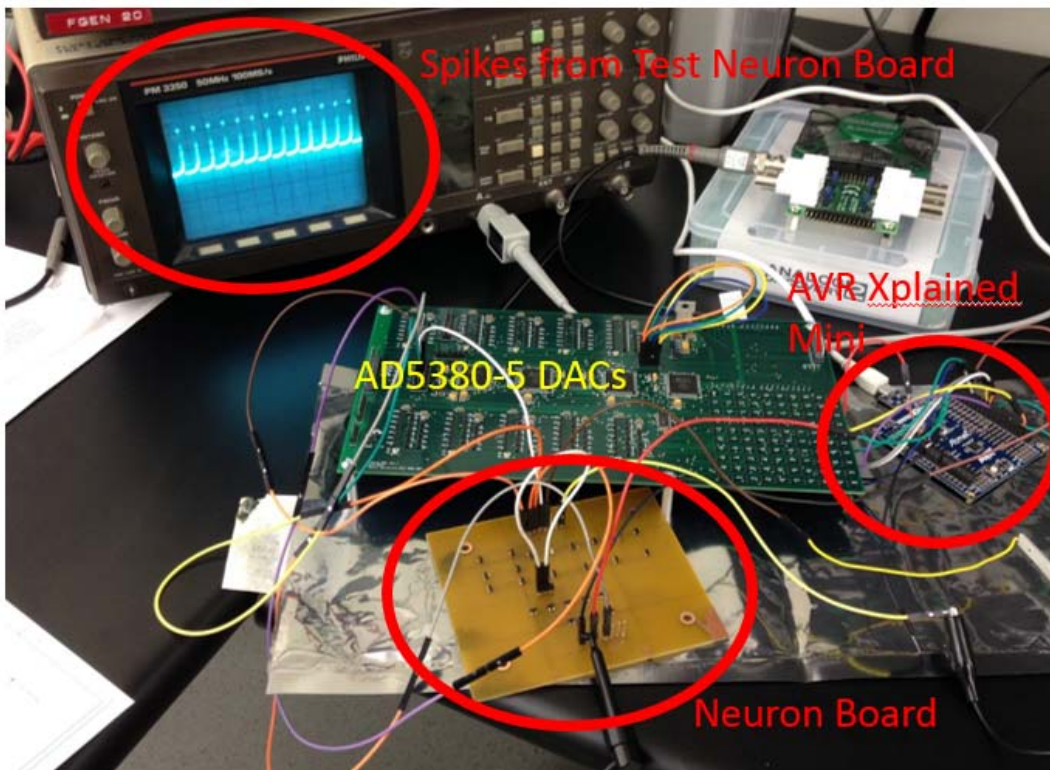


Figure 3: AD5380 DAC board (Experiment 9) controlling the electronic neuron board (Experiment 10).

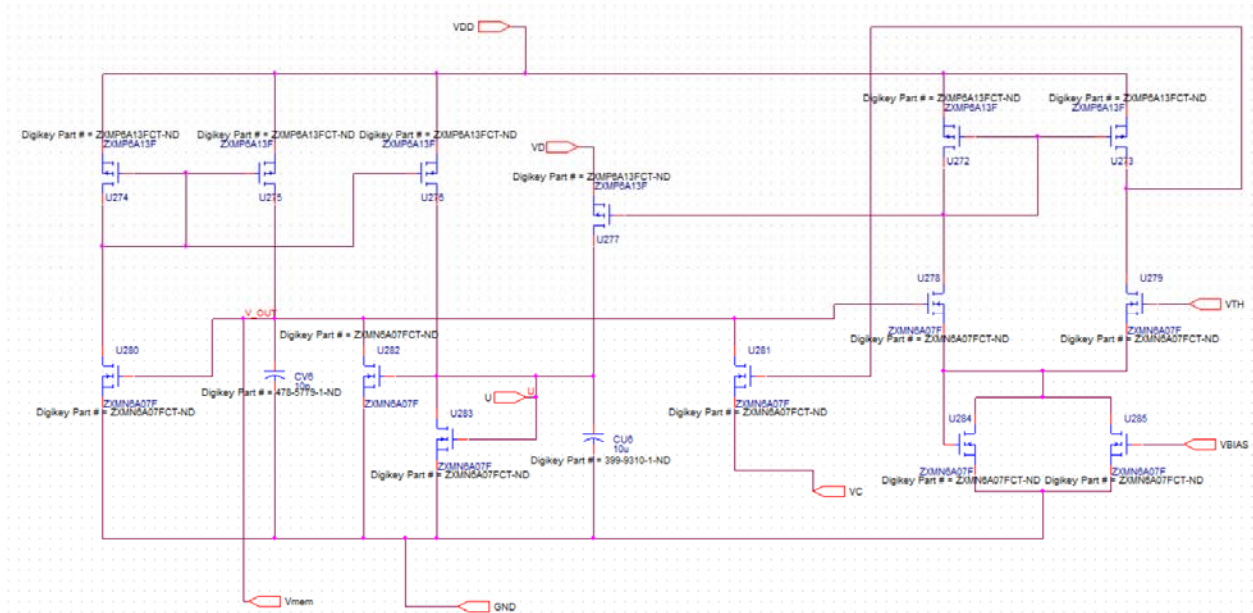


Figure 4: Neuron Circuit⁴ for Experiment 10

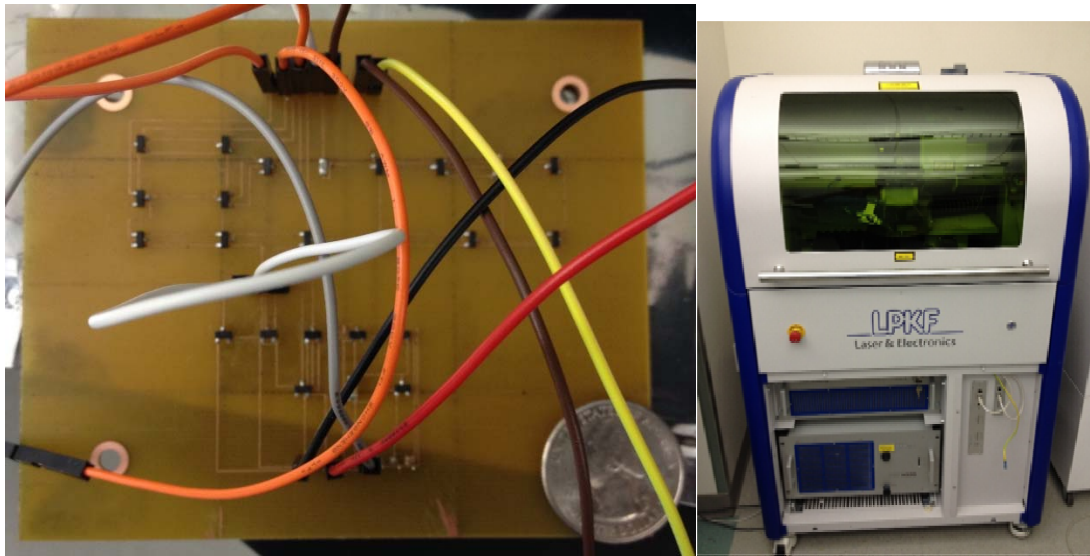


Figure 5: Neuron Circuit from Fig 4 made into a PCB at Baylor University using LPKF Laser etcher.

Results

Anonymous feedback was collected in the form of a survey during the Spring 2017 course's Lab 5. This provided a mid-term evaluation and allows us to make course corrections to future labs if needed. The students were asked four questions with multiple choice answers. They were also given an opportunity to make written comments. All nineteen students completed the survey. The results are shown in Fig 6. In the written portion of the survey, some students suggested

adding “Challenge” problems to the lab assignments. The authors plan to incorporate this suggestion into future labs to challenge the students who may already have microcontroller experience and/or find the labs too easy.

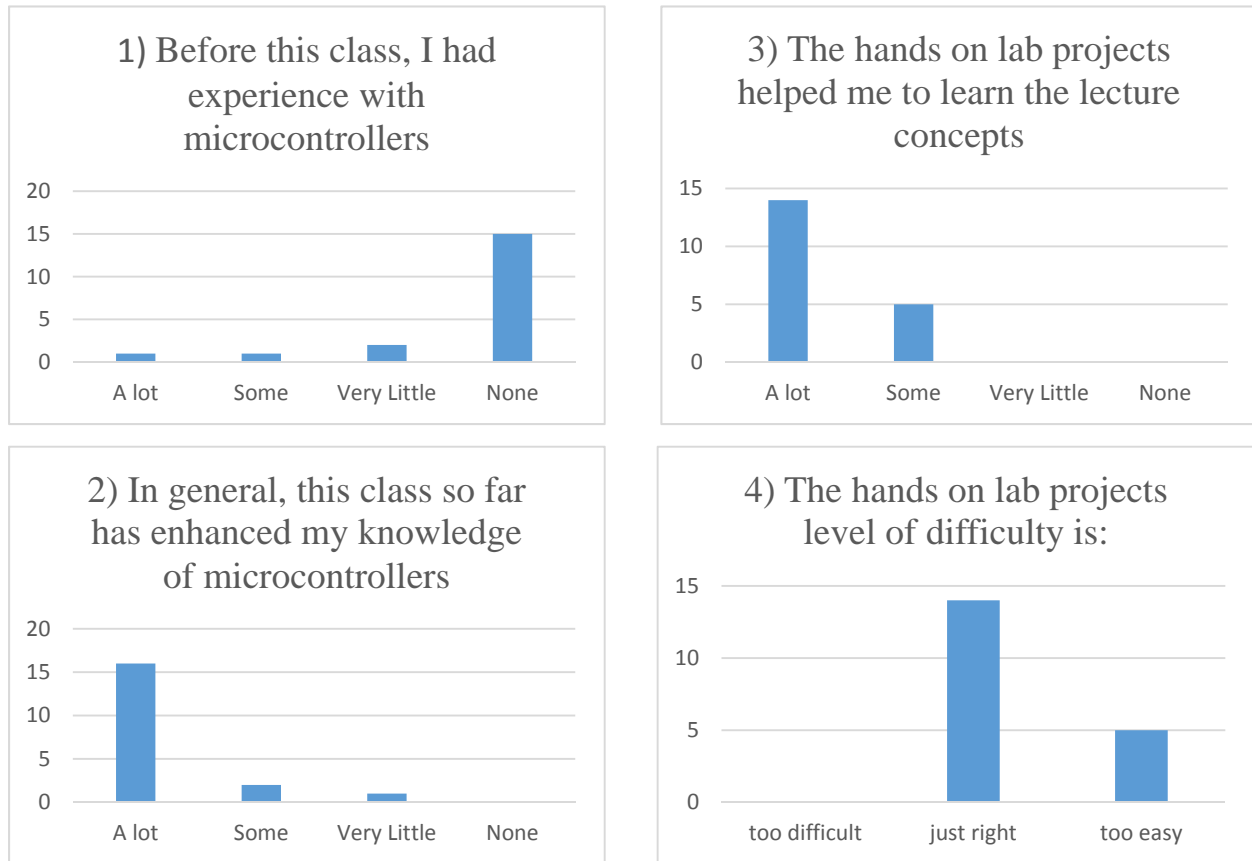


Figure 6: Anonymous mid-term survey data during the completion of Lab 5.

Future Work:

Our neuron board demonstrated that the complete PCB design and build cycle is capable at Baylor University. A future lab may teach the students part or all of this build cycle. Candidate design projects include: building a PCB for the AVR microprocessor to replace the Xplained Mini, building a DAC PCB to replace our expensive DAC board, building their own neuron circuit perhaps with a DAC on-board the PCB. We would also like to integrate a low-cost portable oscilloscope/logic analyzer into the laboratories. A candidate is the Analog Discovery 2 by Digilent⁵ (Shown in the upper right of Fig 3).

References

- 1 Atmel Xplained Mini board, <http://www.atmel.com/tools/mega328p-xmini.aspx?tab=documents>
- 2 Atmel Studio software, <http://www.atmel.com/Microsite/atmel-studio/>
- 3 AD5380 DAC, <http://www.analog.com/en/products/digital-to-analog-converters/da-converters/ad5380.html>
- 4 Wijekoon, Jayawan HB, and Piotr Dudek. "Compact silicon neuron circuit with spiking and bursting behaviour." *Neural Networks* 21.2 (2008): 524-534.

- 5 Diligent Analog Discovery: <http://store.digilentinc.com/analog-discovery-2-100msps-usb-oscilloscope-logic-analyzer-and-variable-power-supply/>

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