The Card-Board DIY Microcontroller for Use with Paper Mechatronics (Resource Exchange)

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Colin Dixon holds a Ph.D. in Learning & Mind Sciences from the University of California, Davis. He researches the development of STEM practices and agency among young people creating things to use and share with the world. He writes about equity and identity in making and engineering, the role of community in science learning, and how youth leverage interests and experiences within STEM education.

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Introduction

In engineering education and STEM education more generally, the use of microcontrollers is increasingly common across a wide range of design projects found in robotics, programming, makerspaces, e-textiles, and more. Exemplified by the Arduino Uno, microcontrollers make tangible computing possible by connecting digital and physical worlds, and help teach a wide range of computational concepts, like inputs, outputs, loops, sensors, and pulse width. Recent commercially available microcontroller kits tailor designs for educational settings and help lower costs considerably. However, for many learners and educators microcontrollers are still costly, making it difficult for students to bring work home and to take risks with circuits and objects they are building.

In the Paper Mechatronics (Paper Mech) project (papermech.net), we have developed open-source designs that enable learners and educators to build their own papercraft projects powered and controlled by microcontrollers. The DIY microcontroller is one component of teaching creative engineering with Paper Mech to make and control paper-based machines using accessible computationally-enabled papercrafts. This design approach emphasizes the use of familiar materials, transparency, low-cost, and relatively light ecological footprint to support creativity and problem-solving. Students engaged in Paper Mech projects experience a cycle of design from planning, sketching, prototyping, testing, troubleshooting, and communicating projects with others.

To be able to control the paper machines, microcontrollers are used with servomotors, sensors and switches. The paper-based microcontroller can be assembled using a very low-cost chip (ATtiny85) that can be programmed with the Arduino IDE and powered using a 5-volt phone charger or USB cord. The board is congruous with the look and feel of playful papercrafts and prototyping. A board can be produced for under $8, making it possible to bring design activities to resource-constrained classrooms, and for learners to share their effort, stories and expertise across settings. Board design is robust enough for novices to achieve early success, yet open enough to scaffold learning about computational concepts and physical computing hardware through continued prototyping, programming, and troubleshooting. In these ways, the design helps expand both the range of creative possibilities and depth of engineering education.

We share different ways in which the DIY cardboard microcontroller was designed and used for different purposes with students. The description here focuses on basics of building the microcontroller for control and actuation of Paper Mech projects. We do not see this as stand-alone curriculum, but as a piece that can fit into a larger paper mechatronics unit, or any unit in which students make use of microcontrollers.

Lesson Objectives

- ❖ Students learn the part names and purposes of electronic components
- ❖ Students learn how to program a microcontroller to take sensor inputs and control a motor (optional)

❖ Students gain hands-on experience wiring electronic components

❖ Students are introduced to the basics of digital control using a microcontroller

Lesson Overview

The microcontroller can be used across different grade levels school shops and makerspaces, or in out-of-school settings like camps, workshops, or afterschool programs. Middle school students construct a cardboard microcontroller, using pre-programmed microchips, while high school students construct a board and also learn how to modify programs using Arduino and load them onto the microchip. Instructors or teachers will need to gather and organize supplies, and prep cardboard bases using a laser cutter or standard printer. If using a printer, paper templates are glued to thin cardboard (like a cereal box). With younger students who cannot solder, teachers can build the boards for students to use as they build and test interactive projects.

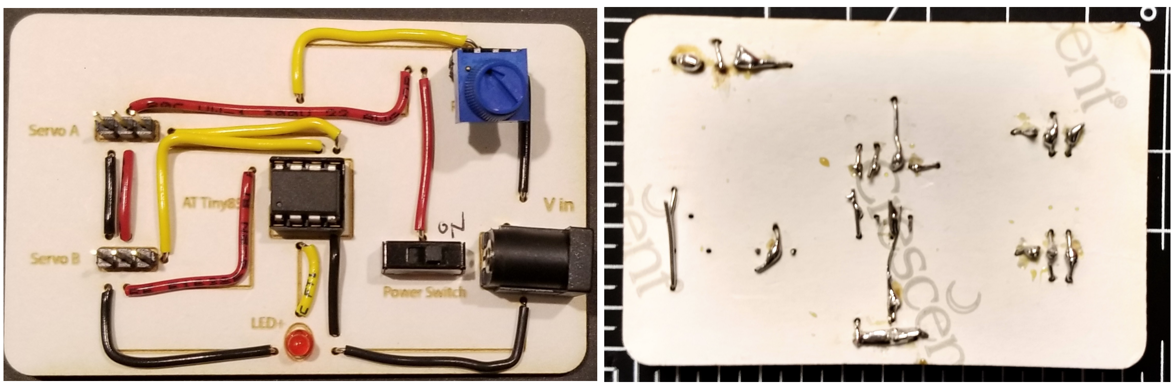

Figure 1: Assembled *Card-board* microcontroller, front (left) and back (right). Actual size 2x3 in.

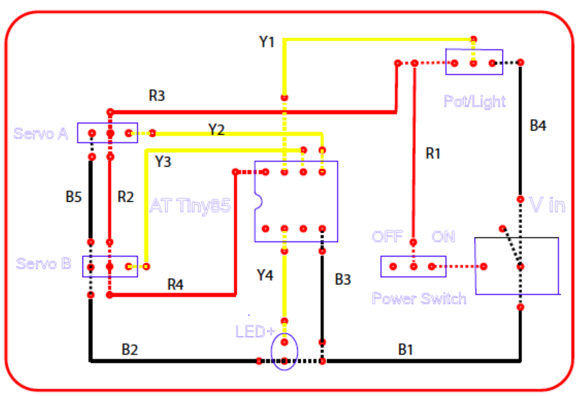

Figure 2: Circuit schematic (actual size) for printing on laser cutter or standard printer

Grade Level	Task	Estimated Time
Middle school	• Assemble, solder, and test microcontrollers using potentiometers	3 hours or 3 class periods • Cut and strip wires and assemble circuit boards (2 hours) • Solder (1 hour, depending on prior experience)
High school	• Fabricate, assemble, solder, and program a microcontroller with a light (or other) sensing and/or automated actuation	4 hours • Cut and strip wires and assemble circuit boards (1 - 2 hours) • Solder (1 hour, depending on prior experience) • Load programs & test (1)
Teacher prep	• Make cardboard bases for microcontroller • Order and organize circuit components • Load programs onto ATtiny85 microchips (if students will not do this)	1-2 hours depending on how many are cut • Download file template • If laser cutting, scale red line widths to ".001" • Laser cut illustration board pieces

Microcontroller Materials

- Board schematic (see below)
- Hook up wire of different lengths (Red, Black, and White/Yellow) (see lengths below)
- Illustration board for breadboard (for example, Crescent 14 ply, Cold Press), or paper + cereal box cardboard if using standard printer.
- ATtiny85 chip
- 8 pin socket
- 2 Stackable Header - 3 Pin (Female, 0.1")
- 3-Pin SPDT Slide Switch
- Red or green LED
- Breadboard trim potentiometer - 10K [optional]
- Photocell (CdS photoresistor) [optional]
- DC Barrel Jack/Connector Jack 2.1mm
- 5V 2A Switching Power Supply or Battery Pack with 3 or 4 AA batteries

Materials for use with Paper Mechatronics or other interactive project

- Continuous Rotation Micro Servo - FS90R (360 Servo)
- Micro servo (SG92R) (180 Servo)
- Craft materials – cardboard, skewers or lollipop sticks, colored feathers, cardstock, origami paper, colored pencils, glue, tape, etc.

Tools

- ATtiny AVR USB Programmer
- Lasercutter or standard desktop printer

- Wire cutters
- 1/16” Holepunch or pushpin (if not using laser cutter)
- Soldering Iron with solder and stand
- Wire stripper
- Scissors

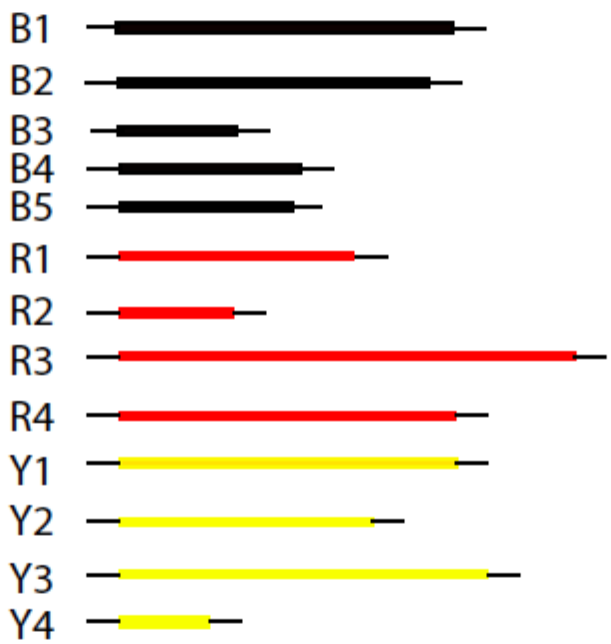

Figure 3: Wire lengths needed for DIY microcontroller

Hazard/warning-Safety

When soldering, put proper safety rules and procedures in place. Lead-based solder that gives off fewer fumes than lead-free solder. Make sure the room is well ventilated. If using lead-based solder, have students wash hands after activity and do not allow eating in the lab.

All grades

In Paper Mech workshops, students are first encouraged to tell a story about a character which they then bring to life with a cardboard mechanisms and cutouts or drawings on cardstock and other materials. Design and construction of these interactive objects can be approached in a number of ways. These can include identification of an audience and goals for what an object might communicate or evoke, can focus on bringing to life an event in history, literature or students’ lives, or might center around exploration and self-expression with a high degree of openness and autonomy. More in-depth description of paper mech workshop models and resources can be found on the website listed above. Card-board microcontrollers could also be used with robotics, computational music, or other topics.

Before moving on to build their microcontrollers, students should plan whether they imagine a motion that is “back and forth” (involving a 180 motor) or “around and around” in a circle (360 motor). Student may have to adjust the size and/or materials of their papercraft projects to match the strength of servos they are using. If using micro servos, limit the size to no more than 6" wide or tall. After the paper artifact is created, attached it to a small hobby servo horn using double-sided tape or hot melt glue.

To support understanding of the microcontroller and electronics more generally, educators can ask students how the paper machine gets its energy to move. Explain the role of a servo, then give students card-board controllers and demonstrate how to connect the motor to the microcontroller. Point out different components which make an electric circuit. Make conceptual connections to other devices or machines that change speed or volume with a dial, such as a fan, as well as to servo applications like robot arms or aircraft rudders. Let students explore how to change the speed of the motor using the potentiometer.

At the end of the workshop or class sessions, students gather their paper machines onto a group table display to showcase and share them with others. Alternatively, students can each give a short presentation and tell a story about their papercraft.

Middle School Students

Students are given the task to assemble, solder, and test different microcontroller programs. Explain that the microcontrollers will be used in a subsequent project, or if project have already been constructed using other microcontrollers, explain how they will replace those.

1. Students receive a bag of materials with pre-cut wire and parts to assemble a cardboard microcontroller.
2. Ask students to empty the bag onto a tray and examine the components. See if they can guess what is the purpose and name of each component.
3. Using an overhead projector, show a picture of a completed microcontroller then pass around a completed one and the assembly handout.
4. Students use wire strippers to remove ¼" off each end of wire using Figure 2 as a guide for relative lengths.
5. Using the circuit schematic as a guide, students begin to assemble their microcontroller by placing components into the cardboard PCB. (If no laser cutter is available, students can use the cardboard templates mounted onto cereal boxes or other stock cardboard with a glue-stick. Holes are punched with a pushpin.) Components are held in place with cellophane tape backing before they are soldered in place.
6. Show students the conventions of black wires are for ground (GND) and red wires are for power/voltage, while yellow or white wires are for carrying signal information.
7. Help students solder connections indicated by dotted lines in the circuit template. If students have not soldered before or this is not possible in their classroom, ask parents or mentors to help with soldering outside of the class or workshop time.
    a. One alternative to soldering is to use copper tape or folded aluminum foil with a glue stick to connect the circuit. However, it may be necessary to expand the size of the board, and copper tape may make control of the servo less precise.
8. Completed boards can be personalized and decorated with craft materials such colored pencils or origami paper.
9. Load programs onto ATtiny chips using USB Programmer and distribute to students to plug into

   their boards. Chips can be programmed to work with 180 or 360 degree servos and potentiometers.
10. Test boards with paper mech machines or other interactive objects.

High School Students

Students are given the same task as middle school students with the main difference that students are shown how to modify and load computer code written in Arduino onto a new ATtiny85 chip. Students use the USB port on their laptop to connect a ATtiny AVR USB Programmer. Sample Arduino scripts and instructions can be found on the papermech.net website. Scripts are used to control a 180 microservo motor or a 360 continuous servo motor. Programs can be written for use with a potentiometer or photocell light sensor, or can automate a desired action. Give students a choice as to which type of microcontroller they would like to make and how they would like to customize the motor speed or type of control and feedback. After students modify their code, download this to the ATtiny85 and transfer the chip to the cardboard microcontroller 8 pin socket. Additional instructions on writing and modifying code using Arduino IDE are beyond scope of this resource guide, but will be available on the Paper Mech website and on-hand during presentation at the Resource Exchange.

As circuits may not work on the first try, due to weak connections, short circuits, errors introduced to code, and fluctuation in power sources, remind students that testing and troubleshooting are part of the iterative design process of design, test, refine. A voltmeter can help diagnose problems with the circuit and can be used to demonstrate how the circuit uses electricity to sense and control. Control theory can be brought into the project by comparing a microcontroller that is controlled by the on/off switch compared to one which servo motor is controlled by the amount of light in the room using the photo sensor. Discuss inputs, outputs from the circuit, and how the sensor, motor and other components are controlled.

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