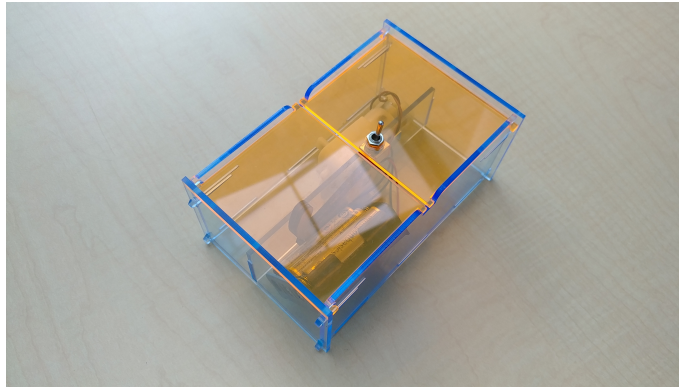# ENGR 40M Project 2a: Useless box
Prelab due 24 hours before your section, July 10–13, 2017
Lab due before your section, July 18–21, 2017

1 Objectives

In this lab, you'll assemble a "useless box" like the one featured in Make Magazine[1] and all over YouTube[2].

When the switch on the top of the box is flipped "on", a finger comes out of the box, turns the switch "off", and then retracts into the box. It is a silly gadget that's fun to play with and show your friends.

Logistics and parts. This week, we'll put the basics in place. Next week, we'll add the Arduino to make it even more fun. Since you're working in groups of two, between the two of you, you have parts to build two boxes. You can elect how to allocate these parts:

(a) You can, between the two of you, build the simple box this week, and build a new box next week for the Arduino version. This saves you having to reorganize your box next week, but you'll need to build the box a second time (which tends to be faster than the first time).

(b) You can, between the two of you, build the simple box this week, and use the same box next week to add the Arduino. This saves you building another box, but you'll need to rearrange your existing box to fit the Arduino, which will require careful planning this week and may require some desoldering next week.

(c) You can *each* do option (b) individually, so that both of you can keep an Arduino version of the box. We still encourage you to work as a pair to complete the parts of the lab other than building the box.

2 Parts

Batteries. We'll use three AA batteries in a plastic battery holder. The holder connects the batteries in series. You could also run this circuit off of your solar battery charger, but giving it its own batteries allows it to be a standalone toy.

Motor. We'll use a DC motor to drive the useless box's finger. The motor has two (electric) terminals. The polarity of the voltage (and hence current) applied to these terminals determines which way the motor

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[1] http://makezine.com/projects/the-most-useless-machine/
[2] http://www.youtube.com/watch?v=aqAUmgE3WyM

turns (clockwise or counter-clockwise). The circuit you build will need to apply one polarity to extend the finger, and the other to retract it.

The free speed of the motor (how fast it spins without any load) is determined by the voltage that is applied to it, and the torque (rotational force) is proportional to the current through the motor. This should make sense: to perform mechanical work (torque $\times$ speed), the motor must get the needed energy from somewhere. That energy comes from the electrical power being delivered to the motor. As the required torque increases, more electrical power (voltage $\times$ current) is required.[3]

Switches. The useless box uses two types of switches. The first is a *momentary single-pole-double-throw (SPDT) micro* switch, used to detect when the finger is fully retracted. The second is a *double-pole-double-throw (DPDT) toggle* switch.

A *pole* is the number of electrically independent but mechanically connected switches; a *throw* is the number of "options" each pole has. Thus, a DPDT switch has two electrically distinct switches that are mechanically joined, so that flicking the switch flips both switches together.
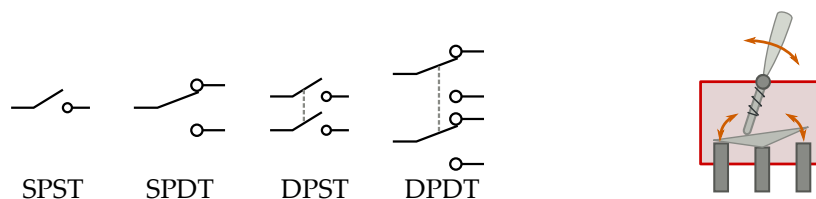
As an aside, the inside of the toggle switch looks something like the diagram to the right. Pushing the switch back and forth flips the rocker between one pair of contacts and the other.

Acrylic sheets. The box itself is made out of Plexiglas, a brand of acrylic sheets. We used a laser cutter to cut the pieces to shape, and the pieces are design with notches, slots and posts so that they fit together. You'll get the plastic for the boxes when you get to lab. We have a range of colors available.

One word of warning: Plexiglas is very brittle. Unlike the Lexan you used for the solar charger, Plexiglas does not bend. **If you try to bend it too much, it will shatter.** If things aren't working, please get your Master Maker to make sure you aren't doing something wrong.

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[3]It's actually slightly more complicated than this, since a stalled motor isn't doing any work (speed is zero!), but is drawing lots of current. Ask a TA if you're curious, or Google "motor curve".
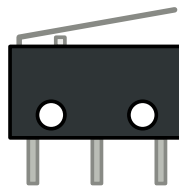
3 Prelab

Reminder: Prelabs are due on Gradescope 24 hours before your lab, or at the time your TA designates.

3.1 Characterizing the parts

P1: Probe the toggle switch with your meter to figure out which pins connect to which in each of the switch positions. Based on what you find, label the image below with the pin numbers from the schematic drawing.
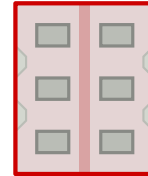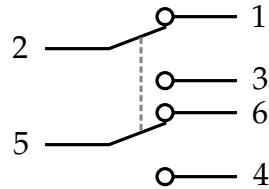
P2: The limit switch is a momentary SPDT switch. Probe the pins with your meter to figure out which pin is the *common* (C) pin (*i.e.* the pole), and which pins are the throws that are respectively *normally open* (NO) and *normally closed* (NC), and mark them on the drawing below.

P3: In the useless box we'll only need two of them—indicate which two on the same diagram above. *Hint: when the limit switch is not pressed, i.e. in its "normal" state, do we want the motor to be moving or stopped?*

The prelab continues on the next page.

3.2   Testing the motor

Use your alligator clips to connect to the motor. The motor tabs are very weak, so please be careful when you do this experiment and not tug on the motor leads.

P4:   Measure the battery voltage out of your 4.5 AA battery pack. Then connect the motor directly to the battery and measure the voltage across the motor. How do these two voltages compare?

P5:   Now measure and record the current through the motor. What happens to the current when you lightly grab the output shaft with your fingers?

P6:   Figure out how to control the direction of the motor. Label the pins of the motor and the direction that the motor turns in a way you can remember, since this will be critical when you assemble your box!

3.3 Circuit design

P7: Now that you have figured out how the switches are connected, and which polarity causes the motor to turn clockwise, you should be ready to draw a schematic diagram (a diagram that shows how you will connect all your devices) to show how you will connect the batteries, motor, and switches to make the useless box perform its function. The toggle switch is DPDT; the limit switch is an SPDT.

4 Assembling the circuit

Next week we'll be rearranging the useless box circuit, so **if you are going to reuse your box, it's best that you don't solder everything together just yet.** Just solder wires onto your switches and motor, and use a small breadboard to make the connections. If you know you want to keep the simple box, you can just solder all the wires to where they go. Since it is important that these wires be flexible, you should use multi-stranded wire, and not solid core wire. Your Master Maker should explain the difference. If they don't, ask them.

- Solder wires to your switches. You may not need connections for all of the switch's pins; consult your schematic to decide which pins to attach wires to.
- Test your work for bad connections by gently wiggling the wires and making sure that they don't move and by using your multimeter to check the resistance of the connections. A good connection should have resistance less than a couple of ohms.
- Also check that you don't have any short circuits—places where exposed wires touch or where blobs of solder connect things that shouldn't be connected.
- Next solder wires to the motor. Since the tabs of the motor are weak, **wrap the ends of the wire through the plastic band that holds the motor to the gearbox to provide some strain relief.** This will prevent an accidental yank from breaking the motor tabs. Remember to use different color wire for the different motor terminals, so you can get the motor to run in the correct direction.
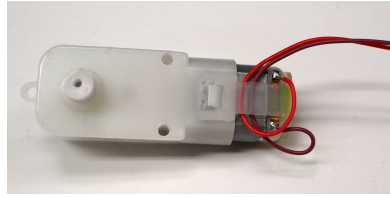
- Use your small breadboard to connect the switches, motor, and battery according to your schematic. You can plug the battery holder wires into the breadboard if you put a tiny bit of solder on the wire. You might be able to push the stranded wire into the board by twisting the wire strands together without solder. But if this doesn't work, you can put a little solder on these wires too (this process is called *tinning the wire*).

- Now test it! Does the limit switch turn off the motor when it's running in reverse? Does the DPDT switch drive the motor forward regardless of the limit switch?

5   Assembling the box

You should have the pieces below:
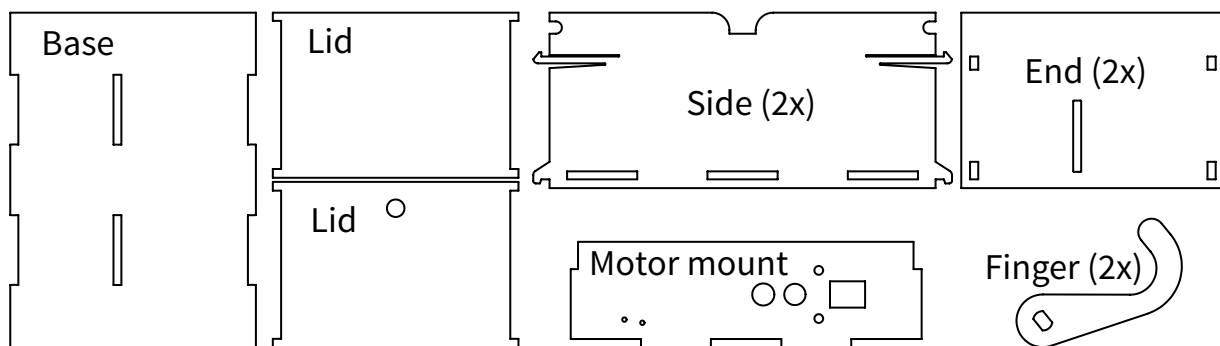
1. Glue two fingers together to make a wide finger. If you're using acrylic glue, a little, teeny, tiny bit is enough. It comes out like water, and can easily make a mess if you're not careful. **Also, it is extremely important that the fingers are aligned to each other before you glue them. We suggest you put them both on the motor mount (to make sure the pieces are aligned, and then put a tiny amount of glue on them).**

2. Attach the motor with #6 screws. The screws should go through the mount piece and tap into the plastic gearbox housing. The end of the shaft with two flats should poke through the mount piece.

3. Attach the limit switch with #2 (little itty-bitty) screws. The screws should go through the switch and tap into the mount piece.

4. Mount the toggle switch onto the lid.

5. Press the glued finger onto the motor shaft, and secure it using the tiny screw and washer included in your parts bag.

6. The rest of the box just slides and snaps together.
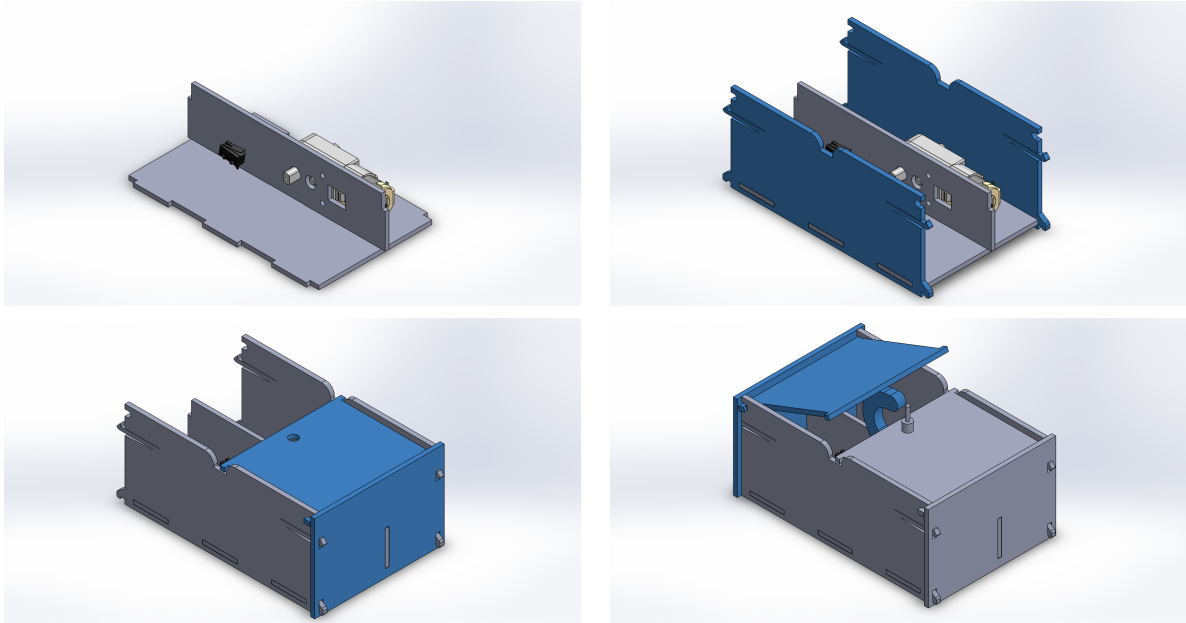
Fit the motor mount to the base. Note that the mount piece is offset so that the finger is centered in the box. Then fit the sides on. Put one lid on, and snap the corresponding end on. The end should first hook at the bottom and then snap into place.

Be careful and don't use too much force, since the acrylic tends to break rather than flex. There are files and sandpaper in the lab if the fit is too tight. Also, be careful with your box, because a hard fall on the concrete floor will cause it to shatter.

6 Analysis

A1: If you look carefully at your box, you will see that sometimes when the finger retracts into the box it hits the limit switch and then seems to bounce up, and then retracts a little before stopping.

Explain what causes it to come back up, and explain what pulls it back down again.

7 Reflection

Individually, answer the questions below. Two to four sentences for each question is sufficient. Answers that demonstrate little thought or effort will not receive credit!

R1:   What was the most valuable thing you learned, and why?

R2:   What skills or concepts are you still struggling with? What will you do to learn or practice these concepts?

R3:   If this lab took longer than the regular 3-hour allotment: what part of the lab took you the most time? What could you do in the future to improve this?

8   Build Quality rubric

Breadboard-to-breadboard wires (sometimes called "jumpers") should use solid core wire for ease of insertion into the breadboard. Wires that run around the box should use stranded wire, which is more flexible and less likely to break when flexed repeatedly.

Plus

- All solder joints are clean
- Wires are color coded and use the correct type of wire core (stranded/solid)
- Wires are about the right length and routed sensibly to keep required length to reasonable level
- Box is cleanly put together, and shuts without additional force (or glue) and is clean to look at inside
- Breadboards are laid out in an efficient or clearly followable manner
- The toggle switch doesn't extrude significantly above the lid
- The finger nicely rises and falls hitting both switches almost exactly

Check

- Everything fits in the box, but one side of the lid has to be slightly held down
- Wire routing may show some evidence of a lack of planning
- Wires mostly use the correct type of wire core
- All solder joints are reliable
- Wires are color coded
- Breadboard is followable with effort

Minus

- The box does not consistently work
- Everything fits in the box, but one side of the lid has to be held down
- Excessive wire lengths demonstrate lack of planning
- Marginal/weak solder joints that may cause wires to break off at any moment
- Wires inside the box are prone to short-circuiting
- Wires are not color coded