Medical & Electromechanical Design Lab
Vanderbilt University
2301 Vanderbilt Place
Nashville, TN 37235-1592

The Vanderbilt Haptic Paddle

Assembly Guide and Parts List

Introduction

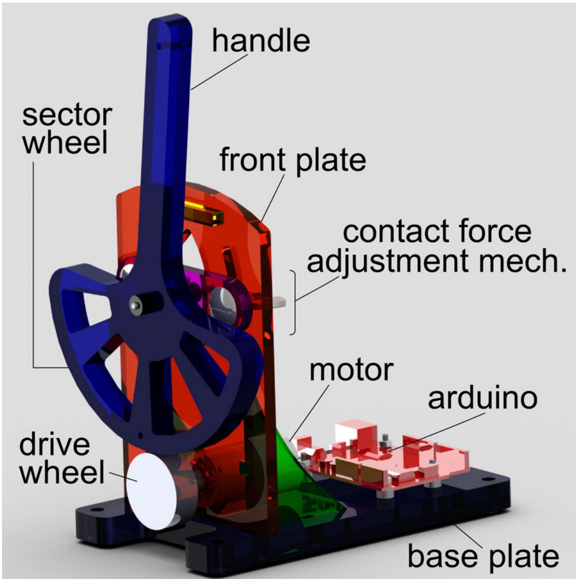

Figure 1: The Vanderbilt Haptic Paddle, a low-cost, easy to manufacture, force-feedback joystick.

The Vanderbilt Haptic Paddle (VHP) is a single-axis force-feedback joystick, developed for classroom instruction of systems dynamics, haptics, and robotics concepts. The VHP is inspired by the Haptic Paddle of Okamura et al. [1], as well as other haptic feedback devices [2, 3, 4] developed for education. The VHP uses a friction drive with adjustable contact force, avoiding the need to tension or re-attach a capstan drive cable.

This guide accompanies the complete CAD files, Simulink files, lab manuals, and Arduino code provided on the VHP website. Sources and prices for all the materials described in this guide are provided in the Bill of Materials Section at the end of the document. Manufacturing the VHP requires a laser cutter, lathe, and drill press.

1 Construct Acrylic Frame

Using the files provided on the VHP website, laser cut the parts for the VHP frame from $\frac{1}{2}$ inch and $\frac{1}{4}$ inch acrylic sheets. Loosely assemble the parts as shown in Figure 2, and then bond the parts together using a solvent acrylic cement, applied with a syringe or dropper according to the cement manufacturer's directions. After the cement cures, the frame will be quite rigid.

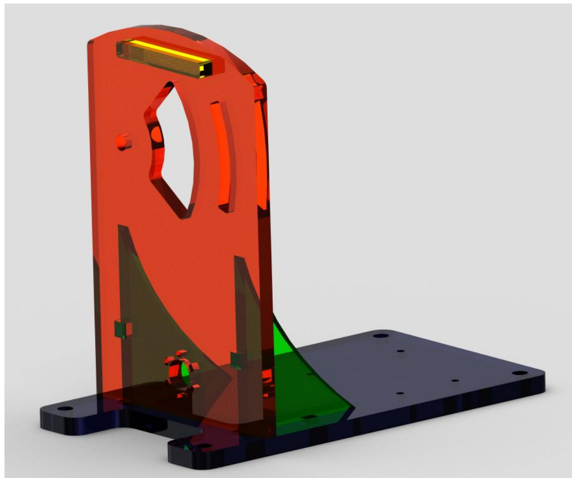

Figure 2: Laser-cut acrylic parts are bonded with acrylic cement to form a sturdy frame.

2 Press PTFE Bushings into Paddle

To obtain a low-friction contact between the rotating paddle and metal shaft, two PTFE bushings, visible in Figure 4, are pressed into the body of the handle. Laser cutters typically lack the accuracy to cut a press fit hole. The laser cutter files provided on the VHP website will create a narrow pilot hole. Using a plastic-cutting drill bit, enlarge the pilot hole to $\frac{1}{4}$ inch and finish the hole using a reamer before pressing the bushings in.

3 Assemble Friction Drive Components

Torque from the VHP's motor is transmitted to the handle by a friction drive mechanism, consisting of an aluminum drive wheel fastened to the motor shaft rolling in contact with a strip of neoprene rubber adhered to the sector wheel. The drive wheel can be manufactured on a metal lathe from 1.5 inch diameter 6061 aluminum bar stock.

Cut the 0.5 inch wide strip of neoprene friction strip from a sheet of adhesive-backed neoprene. Mount the strip symmetrically on the sector wheel as shown in Figure 3. Rolling the sector wheel on table while help eliminate air bubbles in the adhesive.

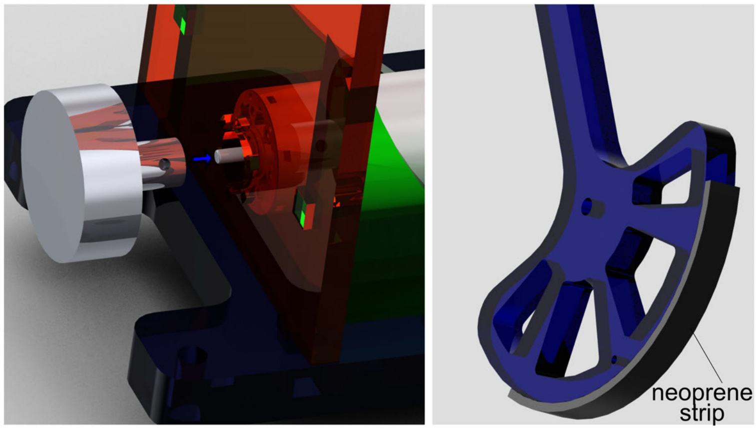

Figure 3: Left: After bolting the motor to the front plate, the drive wheel is secured to the shaft with a set screw (not shown). Right: a neoprene strip provides a reliable frictional contact with the drive wheel.

4 Assemble Contact Force Adjustment Mechanism

The paddle of the VHP revolves about a $\frac{1}{8}$ inch shaft mounted on a small acrylic bar that may be rotated and locked into position by tightening a wingnut as shown in Figure 4. Swinging the bar downwards increases the force between the paddle and drive wheel. A very light downward force is required to avoid slippage - excessive force will introduce significant friction and load the motor shaft.

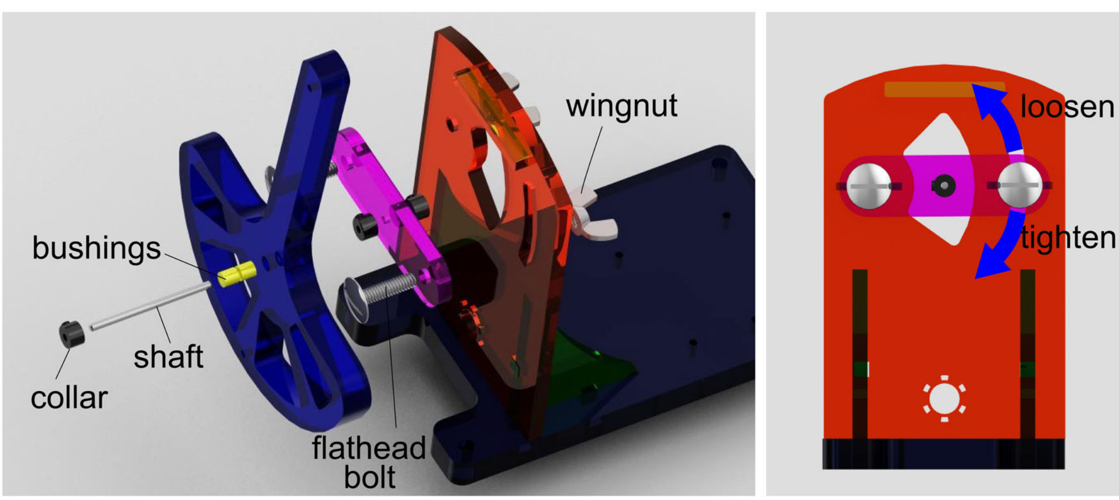

Figure 4: Left: The contact force adjustment mechanism is built with durable commercial hardware and can be easily disassembled. Right: the shaft can be raised or lowered to adjust the contact force on the friction drive wheels.

5 Connect Electronic Components

The VHP electronics include an Arduino Uno microcontroller, an Ardumoto Motor driver shield, and a KMA199E magnetic angle sensor system listed in Table 2. A small magnet is mounted on the drive wheel, and the KMA199E senses the angle of magnet. The KMA199E is connected to an Arduino analog input, and the Ardumoto shield is stacked on top of the Arduino as shown in Figure 7.

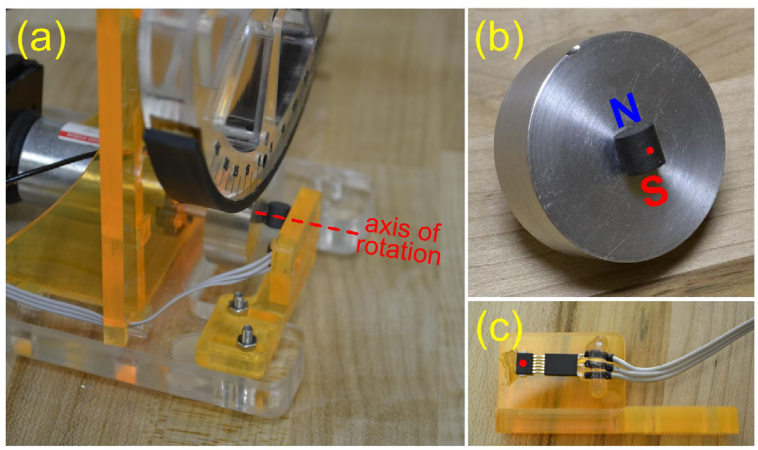

Figure 5: The position sensing components are shown assembled in (a), and include a magnet epoxied to the aluminum drive wheel (b) and a KMA199E magnetic angle sensor (c) glued to an acrylic arm which can be adjusted to properly position the sensor with respect to the magnet. The red dots in (b) and (c) should be aligned with the wheel's axis of rotation shown in (a).

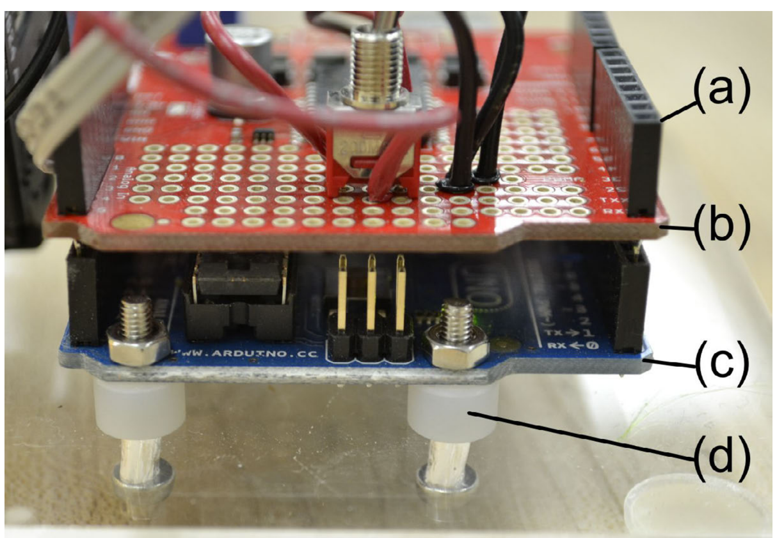

Figure 6: (a) A stackable header connects the Ardumoto board (b) to the Arduino (c). Nylon spacers (d) serve as standoffs to support the circuit on the acrylic base.

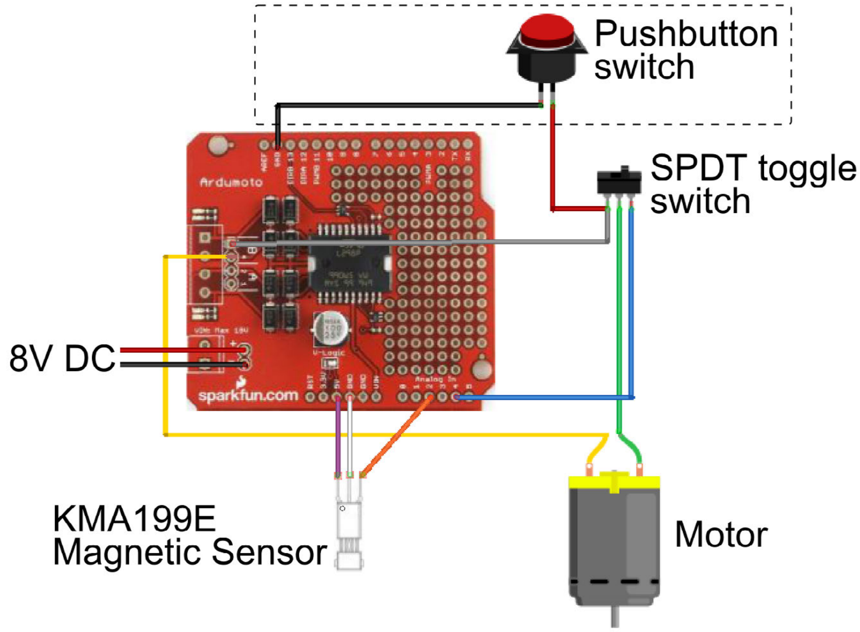

Figure 7: Wiring diagram. The wires attach to the Ardumoto using pin holes provided from the Stackable Header Kit 2. The pushbutton circuit (dotted line) needed only for the motor spin-down experiment in Lab 1 (see the lab handout on the VHP website).

The Arduino Uno Wiring language code performs two functions: First, the Arduino reads the wheel angle from the KMA199E (keeping track of multiple rotations - the wheel angle is not restricted to ±180°), and transmits the position to a host realtime Simulink model via USB. Second, it receives a motor command signal over USB and controls the voltage to the motor, which is amplified with the Ardumoto shield.

Bill of Materials

Tables 1 and 2 include all components required for manufacturing eight Vanderbilt Haptic Paddles. Note that the DC motor could be replaced with various low-cost alternatives.

Table 2: Electronic components for the Vanderbilt Haptic Paddle

Item	Part Description	Supplier	Part #	Unit Price	Quantity	Price
1	Arduino Uno	Sparkfun	DEV-09950	$29.95	8	$239.60
2	Ardumoto shield	Sparkfun	DEV-09815	$24.95	8	$199.60
3	Stackable header kit	Sparkfun	PRT-10007	$1.50	8	$12.00
4	KMA199E Magnetic angle sensor	Mouser	771-KMA199ET/R	$6.50	8	$52.00
5	Alnico magnets	McMaster	57295K73	$1.40	8	$11.20
6	SPDT Toggle switch	Mouser	612-200-A1121	$2.50	8	$20.00
7	Pushbutton switch:	Mouser	633-SB4011NOM-RO	$3.58	8	$28.64
8	DC motor	Maxon	353144	$111.00	8	$888.00
	Total					**$1,451.04**

Table 1: Mechanical Components for Eight Haptic Paddles

Item	Part Description	Supplier	Part #	Unit Price	Quantity	Price
1	0.5” × 24” × 24” acrylic sheet	McMaster	8560K268	$76.41	1	$76.41
2	0.25” acrylic sheet	McMaster	8560K355	$25.41	1	$25.41
3	Acrylic cement	McMaster	7528A13	$13.67	1	$13.67
4	Set screw for drive wheel, 50 pack	McMaster	94355A238	$2.86	1	$2.86
5	1/8” diameter × 12” length driveshaft	McMaster	1257K39	$5.00	2	$10.00
6	1/8” ID shaft collars	McMaster	9414T3	$0.59	24	$14.16
7	1/8” ID PTFE bushings	McMaster	6377K49	$1.70	16	$27.20
8	1/8” adhesive-backed neoprene	McMaster	8463K421	$7.34	1	$7.34
9	1/4”-20 flathead bolts, 20-pack	McMaster	90015A414	$7.86	1	$7.86
10	1/4”-20 wingnuts, pack of 25	McMaster	92001A321	$8.48	1	$8.48
11	1/4” drill bit for plastics	McMaster	27465A84	$5.16	1	$5.16
12	1.5” diameter 6061 aluminum bar stock	McMaster	8974K181	$12.78	1	$12.78
13	Nylon spacer standoffs	McMaster	93657A038	$12.78	32	$26.56
	Total					**$237.89**

References

[1] C. Richard, A. Okamura, and M. Cutkosky, “Getting a feel for dynamics: using haptic interface kits for teaching dynamics and controls,” in *ASME IMECE 6th Annual Symposium on Haptic Interfaces*, (Dallas, TX), pp. 15–21, Citeseer, Nov 1997.

[2] R. Gillespie, M. Hoffman, and J. Freudenberg, “Haptic interface for hands-on instruction in system dynamics and embedded control,” in *IEEE Virtual Reality Conference*, IEEE Computer Society, 2003.

[3] C. Wong and A. Okamura, “The snaptic paddle: a modular haptic device,” in *Eurohaptics Conference, 2005 and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2005. World Haptics 2005. First Joint*, pp. 537–538, IEEE, 2005.

[4] K. Bowen and M. O’Malley, “Adaptation of haptic interfaces for a labview-based system dynamics course,” in *14th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, pp. 147–152, IEEE Computer Society, 2006.