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POLYTECHNIC INSTITUTE OF NEW YORK UNIVERSITY

DoodleBot

ME 5643 Final Project Presentation

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December 19, 2011

Outline

- Motivation
- Theory/Mathematical Background
- Mechanical Design
- Electrical Design
- Controls and Software Design
- Bill of Materials
- Operation Guidelines
- Demo

Motivation

Following types of projects are of interest to the instructor. Feel free to explore these or similar ideas to develop your integrated term project.

1. Integrate mechanisms with sensors and actuator (smart elevator, smart exercise equipment, smart physical therapy equipment for rehabilitation, smart sports equipment/trainer, smart medical/surgical equipment, robotic manipulator, biologically inspired robotics, wheeled/legged robot behavior, etc.)
2. Develop smart sensors by incorporating signal conditioning using hardware and signal processing using software
3. Utilize microcontrollers, sensors, and actuators to automate the characterization/demonstration of diverse physical phenomenon (enhance laboratory education in Grade K-12)
4. Perform self-calibration of sensors
5. Smart kitchen aids, smart power tools, smart home appliances, smart security system, etc.
6. Ethernet-enabled microcontroller for sensing, actuation, control, communication, etc.
7. Projects that respond to societal needs (research a need and then address it).
8. Mechatronics-enabled pre-college level science experiments (physics, biology, etc.).

Robotic arm for research (build vs. buy)

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http://www.medifab.co.nz/products/arm-supports-feeding/meal-mate-robotic-feeder

http://www.richardsonproducts.com/mealbuddy.html

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http://www.nxtprograms.com/robot_arm/steps.html

http://www.instructables.com/id/Intro-and-what-youll-need/

http://www.brickset.com/detail/?set=3933-1

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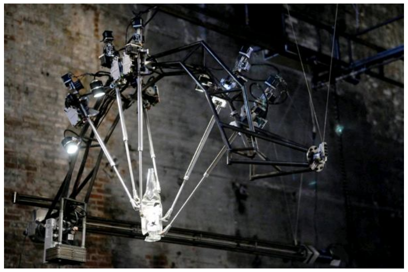
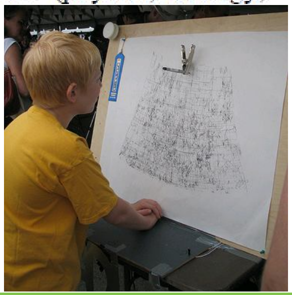
http://www.instructables.com/id/Intro-and-what-youll-need/

http://thenextweb.com/shareables/2010/12/31/the-10-robots-that-rocked-in-2010/

http://www.adafruit.com/blog/2011/12/12/measuring-angst-robotic-installation/





Theory/Mathematical Background

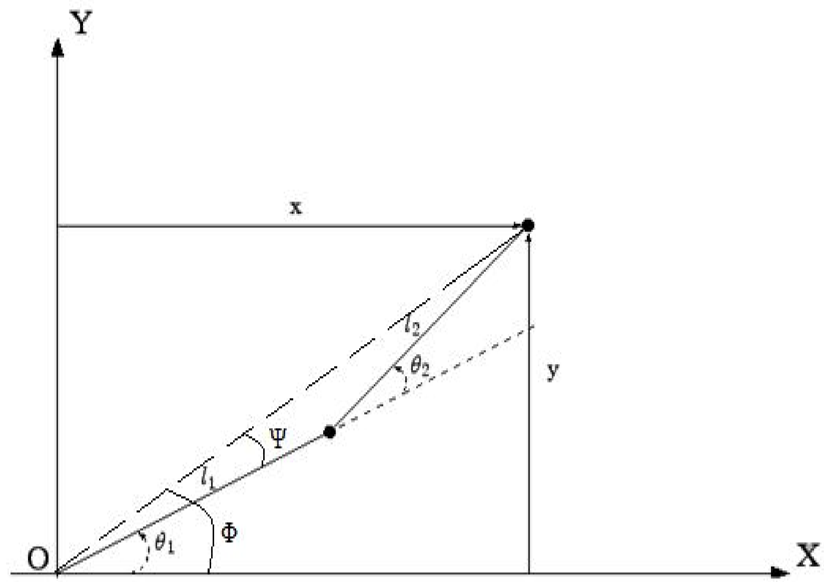
Forward kinematics

$x = l_1 \cos\theta_1 + l_2 \cos(\theta_1 + \theta_2)$
$y = l_1 \sin\theta_1 + l_2 \sin(\theta_1 + \theta_2)$

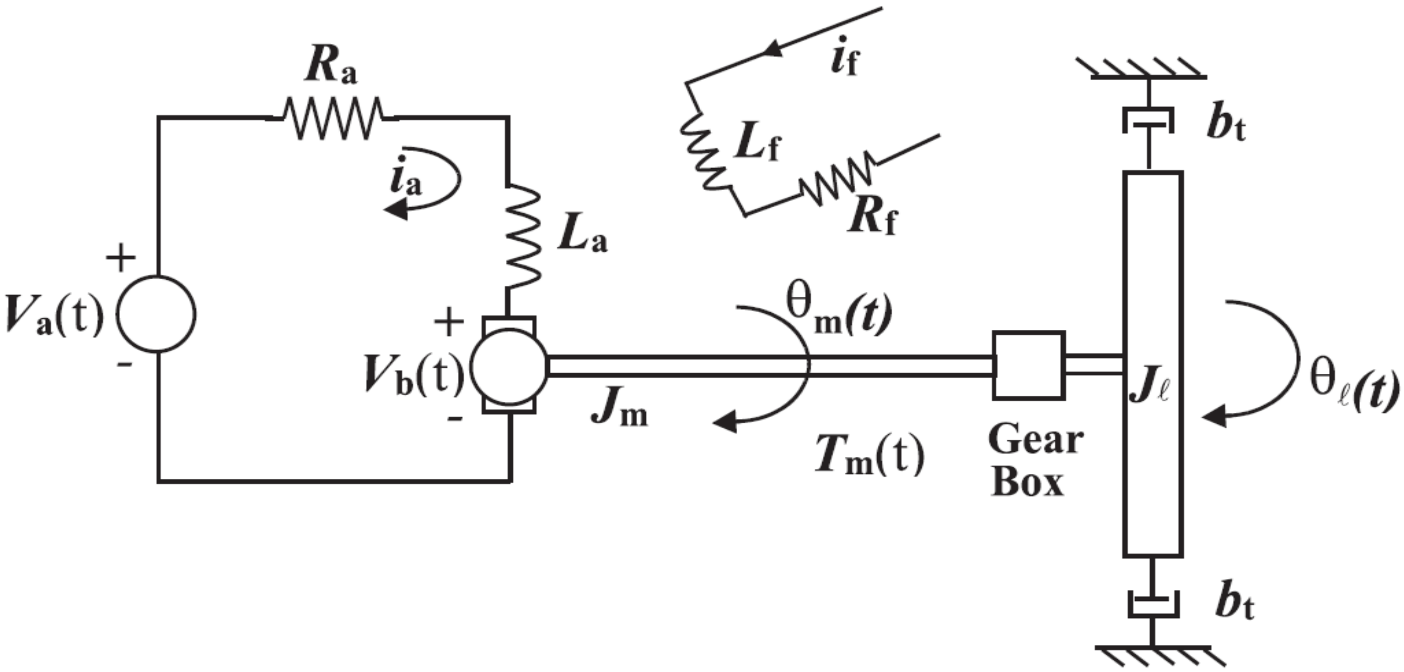
Inverse kinematics

$\theta_1 = \text{arcos}\left(\frac{x^2 + y^2 - l_1^2 - l_2^2}{2 l_1 l_2}\right)$

$\theta_2 = \Phi - \Psi$
$\Phi = \text{atan2}(y, x)$
$\Psi = \text{atan2}(l_2 \sin\theta_2, l1 + l_2 \cos\theta_2)$



DC-Motor



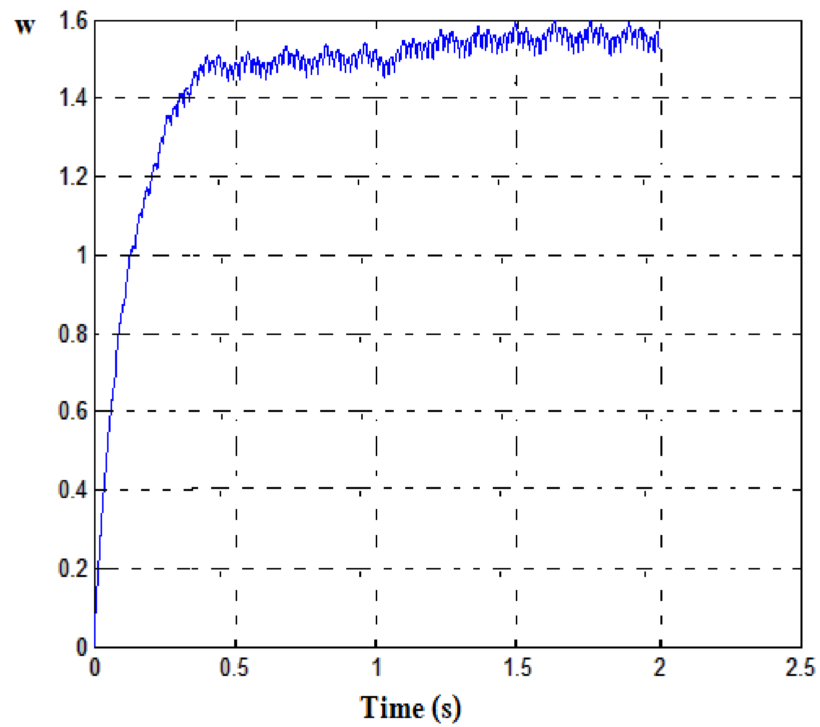
R_a
i_a
L_a
$V_a(t)$
+
-
+
$V_b(t)$
-
i_f
L_f
R_f
b_t
$\theta_m(t)$
J_m
$T_m(t)$
Gear
Box
J_ℓ
$\theta_\ell(t)$
b_t

τ

DC-Motor

DC-Motor transfer function

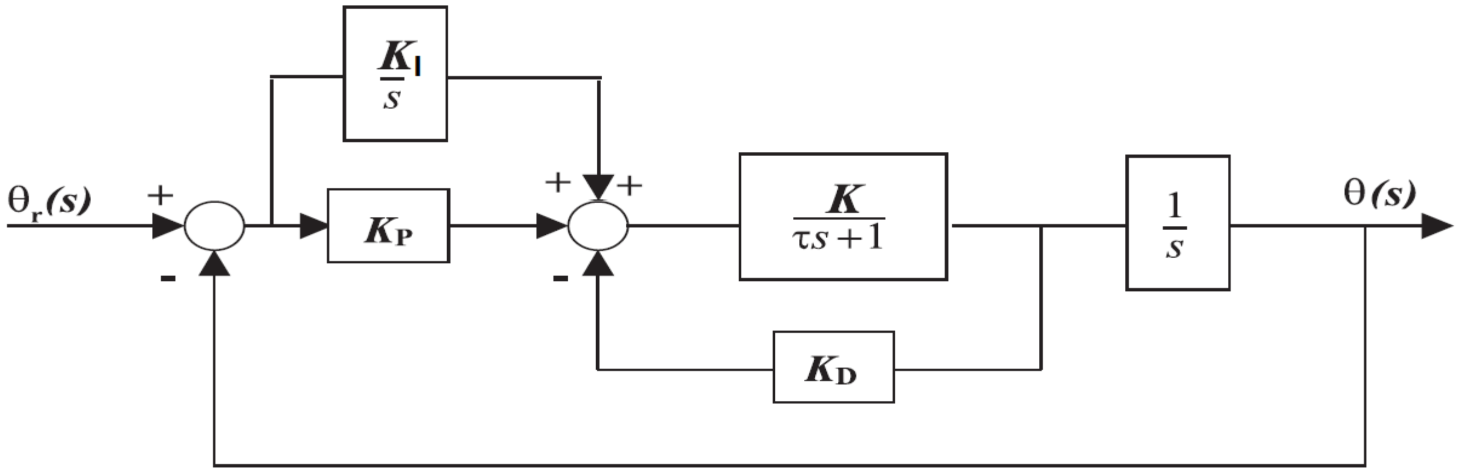
$$\frac{w_l(s)}{V_a(s)} = \frac{K}{\tau s+1}$$



Tau = time for 63.2% of w

FVT: $= \lim_{s\to 0} \frac{k}{s(\tau s+1)}$ = K

PID controller



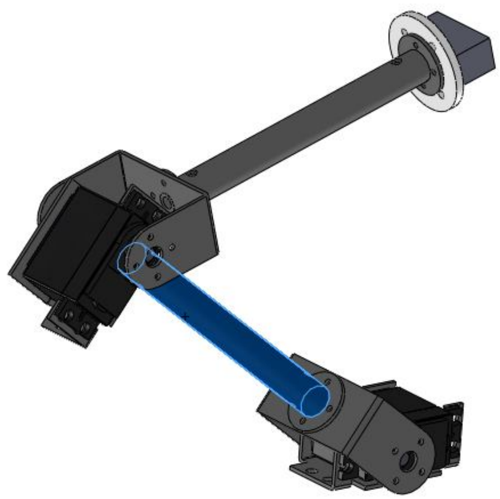
$$U(t) = K_p\, e(t) + K_I \int e(t)dt + K_D \frac{de(t)}{dt}$$

The closed loop transfer function is:

$$\frac{\theta_s}{\theta_r} = \frac{K_p K s + K_i K}{\tau s^3 + (1+K\,K_D)s^2 + KK_P s + KK_i}$$

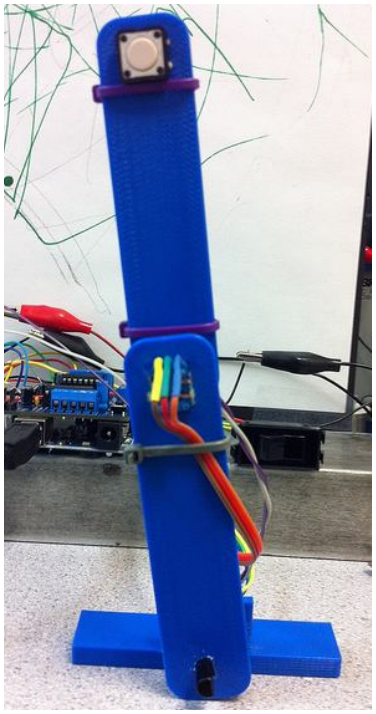
Mechanical Design – Slave Arm

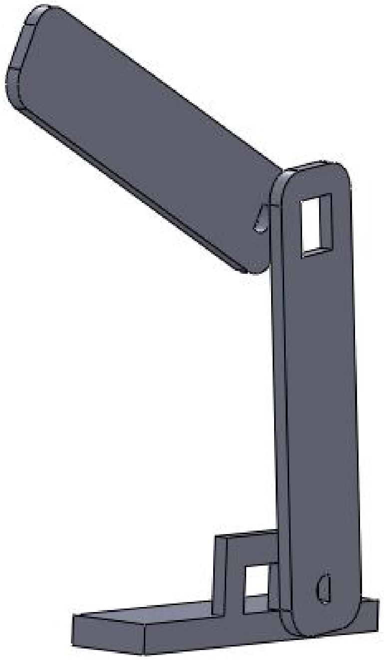
- Solidworks
- Off the shelf parts for slave arm
  - CAD files available: http://www.lynxmotion.com/s-5-ses-3d-models.aspx
- Base machined in basement shop



Mechanical Design – Master Arm

- Solidworks
- Master arm parts printed on Dimension 3D printer in ME department
- Functions as user interface to monitor and control slave arm



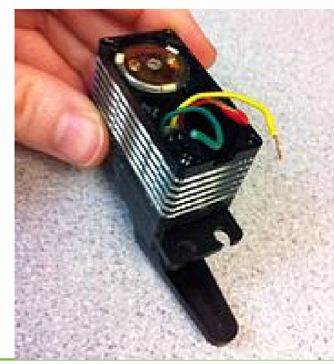


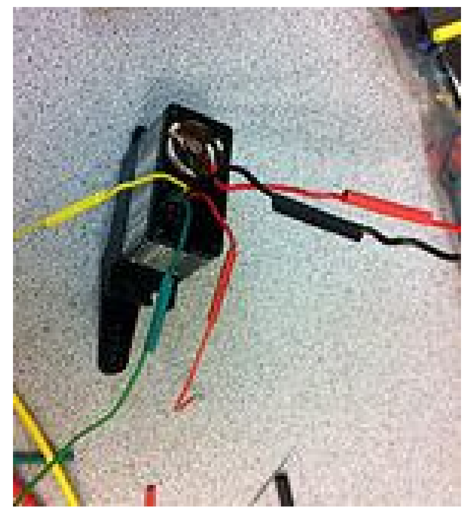
Electrical Design

- Motors
  - Hacked HS-4950TH Servos
  - Necessary torque: 5oz*14in=70 in-oz
  - 5V Power from fixed benchtop supply

http://servocity.com/html/hs-7950th_servo.html

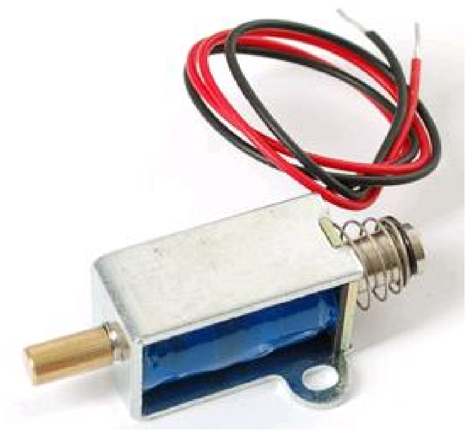
Detailed Specifications	
Control System:	+Pulse Width Control 1500usec Neutral
Required Pulse:	4.8-7.4 Volt Peak to Peak Square Wave
Operating Voltage Range:	4.8-7.4 Volts
Operating Temperature Range:	-20 to +60 Degree C (-68F to +140F)
perating Speed (4.8V):	**0.18 sec/60° at no load**
Operating Speed (6.0V):	**0.15 sec/60° at no load**
Operating Speed (7.4V):	**0.13 sec/60° at no load**
Stall Torque (4.8V):	**344oz/in. (22kg.cm)**
Stall Torque (6.0V):	**402oz/in. (29kg.cm)**
Stall Torque (7.4V):	**486oz/in. (35kg.cm)**
Operating Angle:	45 Deg. one side pulse traveling 400usec
360 Modifiable:	Yes
Direction:	Clockwise/Pulse Traveling 1500 to 1900usec
Idle Current Drain (4.8V):	9mA at stop
Idle Current Drain (6.0V):	9mA at stop
Current Drain (4.8V):	220mA/idle and 3.8 amps at lock/stall
Current Drain (6.0V):	300mA/idle and 4.8 amps at lock/stall
Dead Band Width:	1usec
Motor Type:	Coreless Carbon Brush
Potentiometer Drive:	6 Slider Indirect Drive
Bearing Type:	Dual Ball Bearing MR106
Gear Type:	Titanium Gears





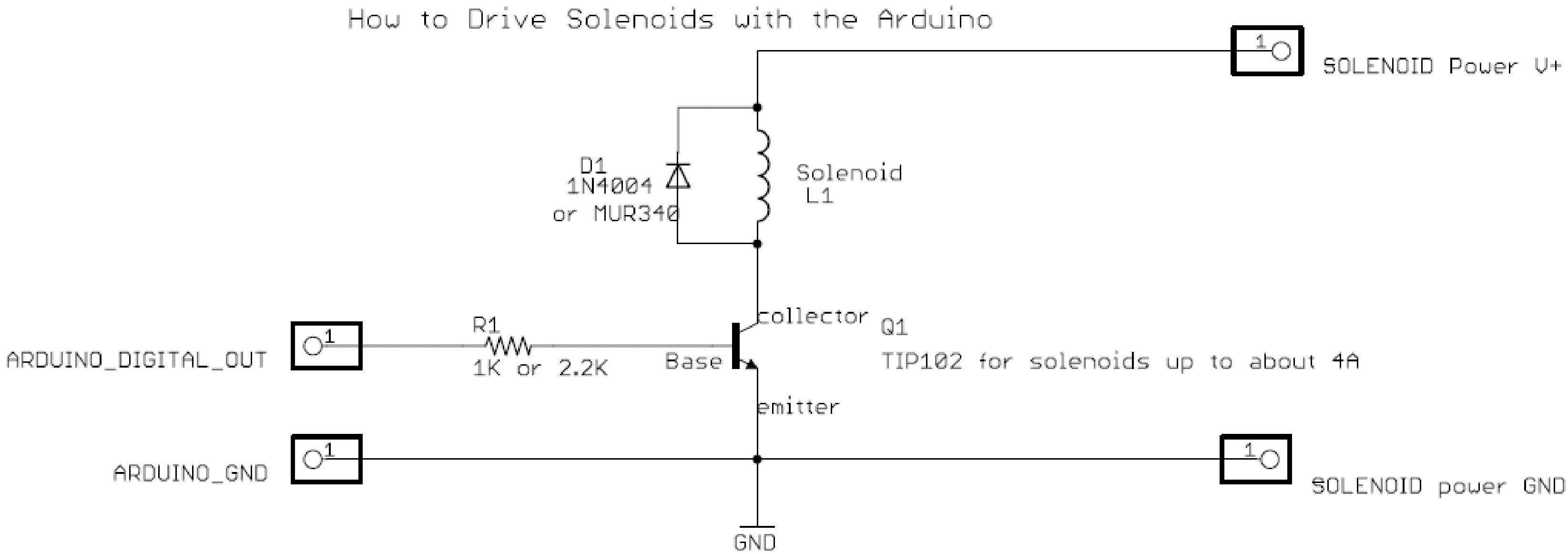
Electrical Design

- Solenoid
  - 24V power from variable benchtop supply



https://www.adafruit.com/products/412

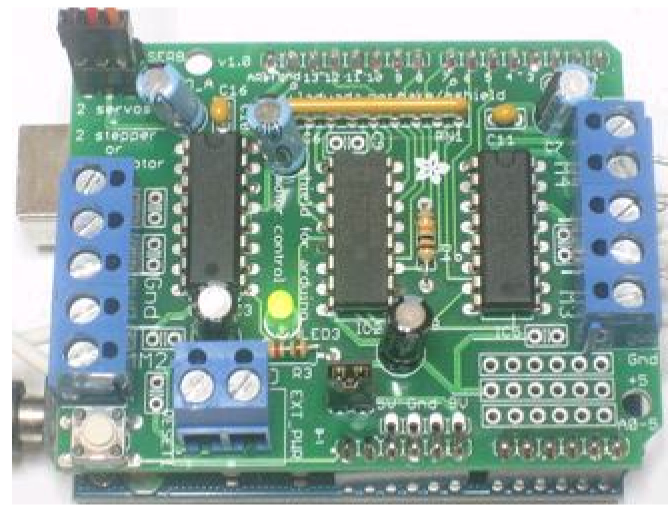
- 24 DC operation (you can use 9-24 DC volts, but lower voltage results in weaker/slower operation)
- Push or pull type with 5.5 mm throw
- DC coil resistance: 100 ohms
- 5 Newton starting force (24VDC)
- 1.4 oz / 39 grams



Electrical Design

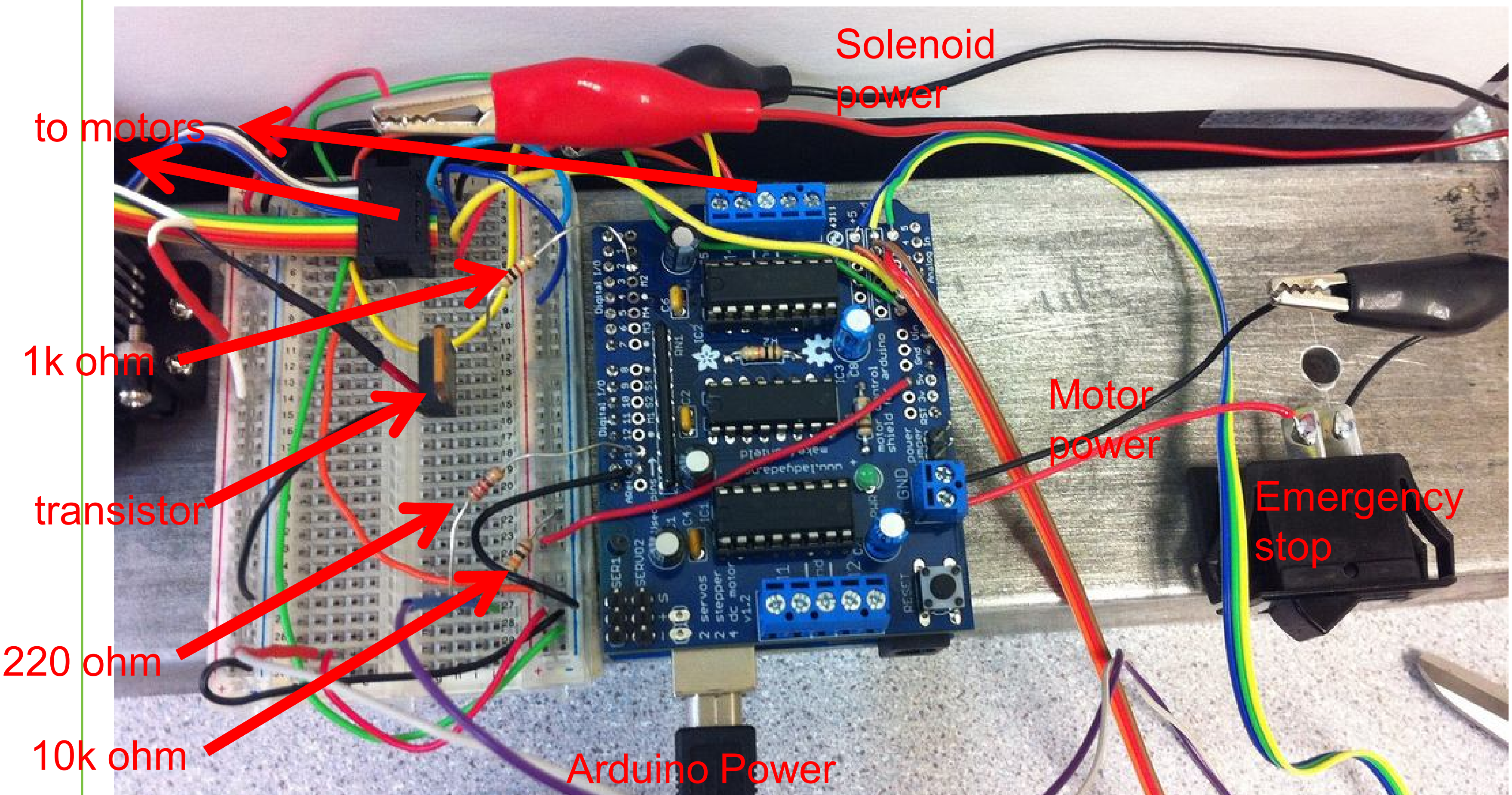
- Arduino
  - Powered through USB
- Motor shield
  - Upgraded with SN754410 h-bridges
  - Speed control through PWM
- Emergency Stop

http://arduino.cc/en/Main/ArduinoBoardUno

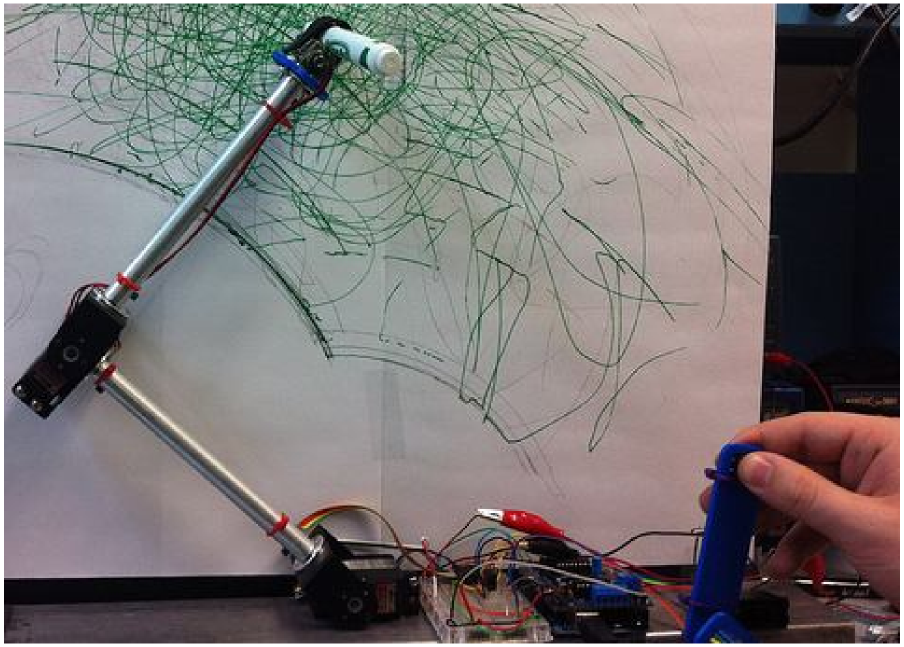


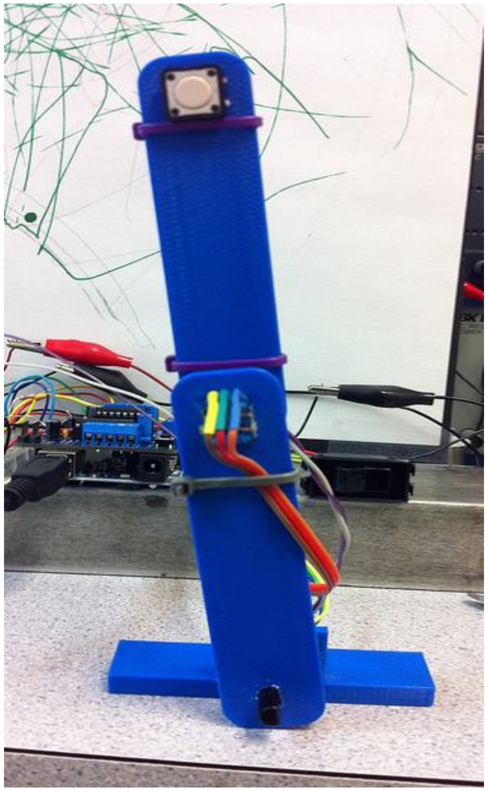
http://www.adafruit.com/products/81

Electrical Design



Controls and Software Design





Angle reading, constraining, and mapping

```
void loop() {
  // read the values from all the pots
  masterElbowAngle = analogRead(MasterElbowPin);
  slaveElbowAngle = analogRead(SlaveElbowPin);
  masterShoulderAngle = analogRead(MasterShoulderPin);
  slaveShoulderAngle = analogRead(SlaveShoulderPin);

  // constrain master and slave to ignore out of range values
  masterElbowAngle = constrain(masterElbowAngle, MasterElbowCW, MasterElbowCCW);
  masterShoulderAngle = constrain(masterShoulderAngle, MasterShoulderCW, MasterShoulderCCW);
  slaveElbowAngle = constrain(slaveElbowAngle, SlaveElbowCW, SlaveElbowCCW);
  slaveShoulderAngle = constrain(slaveShoulderAngle, SlaveShoulderCCW, SlaveShoulderCW);

  // now map the angles so they correspond correctly
  masterElbowAngle = map(masterElbowAngle, MasterElbowCCW, MasterElbowCW, 45, 135);
  slaveElbowAngle = map(slaveElbowAngle, SlaveElbowCCW, SlaveElbowCW, 45, 135);
  masterShoulderAngle = map(masterShoulderAngle, MasterShoulderCCW, MasterShoulderCW, 0, 135);
  slaveShoulderAngle = map(slaveShoulderAngle, SlaveShoulderCCW, SlaveShoulderCW, 0, 135);
```

P D control

```
unsigned long now=millis();
delT=double(now-lastT);
lastT=now;
elbowError = (slaveElbowAngle - masterElbowAngle);
deltaElbow = (elbowError-lastElbow)/delT;
pwmElbow = P_Elbow * elbowError + difconstE*deltaElbow;
lastElbow=elbowError;
pwmElbow = abs(pwmElbow);
pwmElbow = constrain(pwmElbow, lowL, 255);

elbow.setSpeed(pwmElbow);     // set the speed
```

Run Motor

```
if ( slaveElbowAngle > (masterElbowAngle + range)) {
  elbow.run(FORWARD);      // turn it on going forward
}
else if ( slaveElbowAngle < (masterElbowAngle - range)) {
  elbow.run(BACKWARD);      // turn it on going forward
}
else elbow.run(RELEASE);      // stopped
```

Drive Solenoid

```
// DRIVE SOLENOID
isPressed = digitalRead(DrawPin);
digitalWrite(SolenoidPin, isPressed);
```

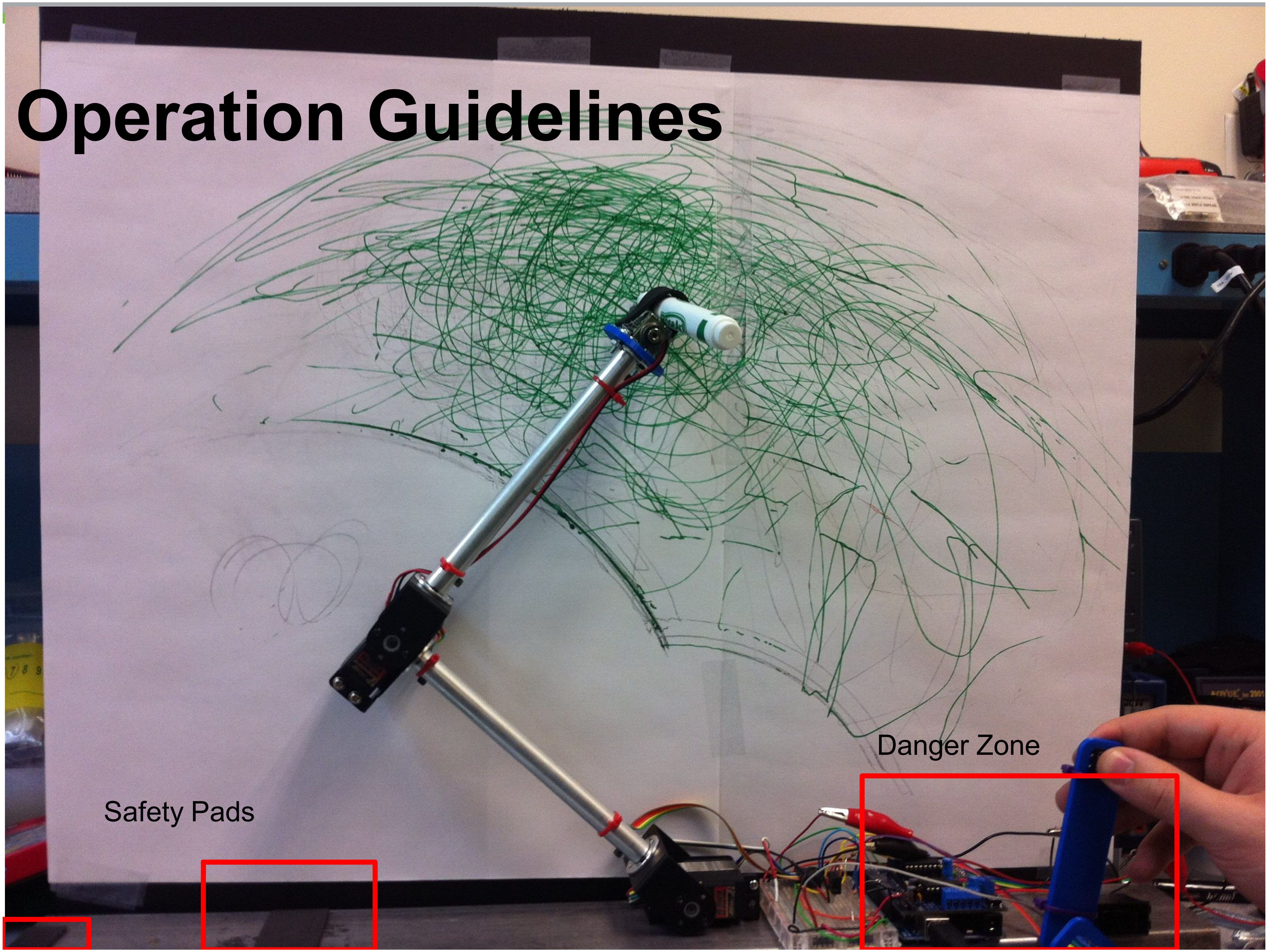
Bill of Materials – our cost

	Vendor	Part number	Description	# in pack	Quantity	Price (1)	Subtotals (1)
Slave arm hardware	Lynxmotion	ASB-04	Aluminum Multi-Purpose Servo Bracket	2	1	$11.95	$11.95
	Lynxmotion	ASB-09	Aluminum "C" Servo Bracket with Ball Bearings	2	1	$12.90	$12.90
	Lynxmotion	HUB-08	Aluminum Tubing Connector Hub	2	2	$8.00	$16.00
	Lynxmotion	AT-04	Aluminum Tubing - 6"	1	2	$3.60	$7.20
	Adafruit	ID: 412	Solenoid	1	1	$9.95	$9.95
	Servocity	HS-7950TH	High Torque Digital Servo Motor	1	4	$119.99	$0.00
	McMaster	1630T332	Aluminum c-channel base	1	1	$15.06	$0.00
Slave arm electronics	Adafruit	ID: 81	Motorshield	1	1	$19.50	$19.50
	Sparkfun	COM-00315	SN754410 h-bridge	1	2	$2.35	$4.70
	Adafruit	ID: 50	Arduino UNO	1	1	$30.00	$30.00
	Mouser	511-TIP102	TIP102 (for solenoid)	1	1	$0.80	$0.80
	Sparkfun	COM-08589	Diode 1N4001	1	1	$0.15	$0.15
	McMaster	7395K44	Illuminated rocker switch	1	1	$7.02	$7.02
Master arm	Sparkfun	COM-09288	Rotary Potentiometer - Linear (10k ohm)	1	2	$0.95	$1.90
	Sparkfun	COM-09190	Momentary pushbutton	1	1	$0.50	$0.50
	SolidConcepts		3D printed parts	1	1	$0.00	$0.00
Other	Sparkfun	CAB-10647	Ribbon Cable - 10 wire (15ft)	1	1	$0.99	$0.99
			Misc. jumper wire, resistors, connector,etc.			$0.00	$0.00
	Art Store		Foam core, padding, sketch paper, marker			$25.00	$25.00
						Total	$148.56

Bill of Materials – cost at 100

	Vendor	Part number	Description	# in pack	Quantity	Price (100)	Subtotals (100)
Slave arm hardware	Lynxmotion	ASB-04	Aluminum Multi-Purpose Servo Bracket	2	1	$10.76	$10.76
	Lynxmotion	ASB-09	Aluminum "C" Servo Bracket with Ball Bearings	2	1	$11.61	$11.61
	Lynxmotion	HUB-08	Aluminum Tubing Connector Hub	2	2	$7.20	$14.40
	Lynxmotion	AT-04	Aluminum Tubing - 6"	1	2	$3.24	$6.48
	Adafruit	ID: 412	Solenoid	1	1	$7.96	$7.96
	Servocity	HS-7950TH	High Torque Digital Servo Motor	1	4	$16.99	$67.96
	McMaster	1630T332	Aluminum c-channel base	1	1	$15.06	$15.06
Slave arm electronics	Adafruit	ID: 81	Motorshield	1	1	$15.60	$15.60
	Sparkfun	COM-00315	SN754410 h-bridge	1	2	$1.88	$3.76
	Adafruit	ID: 50	Arduino UNO	1	1	$25.46	$25.46
	Mouser	511-TIP102	TIP102 (for solenoid)	1	1	$0.53	$0.53
	Sparkfun	COM-08589	Diode 1N4001	1	1	$0.12	$0.12
	McMaster	7395K44	Illuminated rocker switch	1	1	$7.02	$7.02
Master arm	Sparkfun	COM-09288	Rotary Potentiometer - Linear (10k ohm)	1	2	$0.76	$1.52
	Sparkfun	COM-09190	Momentary pushbutton	1	1	$0.40	$0.40
	SolidConcepts		3D printed parts	1	1	$5.00	$5.00
Other	Sparkfun	CAB-10647	Ribbon Cable - 10 wire (15ft)	1	1	$0.79	$0.79
			Misc. jumper wire, resistors, connector,etc.			$2.00	$1.50
	Art Store		Foam core, padding, sketch paper, marker				
						Total	$195.92

Operation Guidelines



Conclusion and Future Work

- Give back to Open Hardware community
  - Publish on Instructables.com
- Low cost assistive feeder design
- Maker Faire
- Research platform for Applied Dynamics & Optimization Lab