## **Foldable Robotics**

Prof. Sawyer Fuller Department of Mechanical Engineering University of Washington, Seattle <u>https://faculty/washington.edu/minster/</u>

course website: <u>https://faculty.washington.edu/minster/foldable\_robotics\_2018/</u>



link: <a href="https://www.youtube.com/watch?v=ionC1toDJZI">https://www.youtube.com/watch?v=ionC1toDJZI</a>

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# what you will learn

- how to design and build your own laser-cut foldable mechanisms
- where to get parts and materials
- how to program your robot to move using a raspberry pi and off-the-shelf servos

## what is not covered

- how to use our specific laser cutter (we will operate it for you)
- kinematics, dynamics, and control of foldable structures

# why foldable robotics

fast! cutting time is just a few minutes (vs. hours for a 3D printer)

Strong						
		Cardboard	ABS plastic	Steel	<b>Carbon Fiber</b>	
	Tensile Strength (kPa)	50,000	40,000	600,000	1,240,000	
	Density (kg/m³)	750	1200	8000	1580	
	Strength-to-weight	67	33	75	785	

Cheap! laser cutter is <u>\$4k</u> \$2.5k (as of last week!), cardboard sheets (\$2), sheet tape (\$2)

no continuous revolution

# why foldable robotics

- recent advances in origami geometry e.g. Demaine et al, 1998: proved you can cut any shape with the correct fold & single cut
- nature is made of foldable things! ladybug wing folding:

 classic revolving pin joints inefficient for small <1cm mechanisms</li>







## examples





#### fabricating the basic element: a fold





## laser cutting





## uv laser cutting





## example part









## fab process



## example part drawings



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## another drawing example



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## drawing in inkscape



1. draw outline of shapes

2. draw folds & align cut

3. draw release cut

 suggestion: start with blank\_drawing.svg on course website, it has useful settings for object snap and units.



## designing mechanisms: ideas

link: https://www.youtube.com/watch?v=R5hGiN0Q5Qs

#### actuating your device with a servo and a raspberry pi



### python: the all-purpose language

- run a python program
  - ctrl-c to quit
- edit a program
  - ctrl-o to save
  - ctrl-x to exit
- example program

import time from servo import \* # servo driver

```
servo0(45)
```

time.sleep(1) servo0(0)

program flow

def mult(arg1, arg2): return arg1\*arg2

```
if test==1:
    print(`hello')
```

python servo wiggle.py

```
nano myprogram.py
```

```
# timing
```

```
# servo angle 45 deg
# range is +/-90
# wait 1 second
```

```
for deg in range(start, stop):
    servo0(deg)
```

```
# note: python blocks are space-
           # delimited! use four spaces to
            indent a sub-block
           #
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```

# more python/linux

• run python one line at a time (ctrl-d to exit)

```
pi@raspberrypi:~$ python
Python 2.7.13 (default, Jan 19 2017, 14:48:08)
[GCC 6.3.0 20170124] on linux2
Type "help", "copyright", "credits" or "license" for more inform
>>> from servo import *
>>> servo1(90)
>>>
```

• list files

pi@raspber	rypi:~\$ ls	5		
Desktop	Music	python_games	<pre>slow_move.py</pre>	wiggle_servo.py
Documents	Pictures	servo.py	Templates	_
Downloads	Public	servo.pyc	Videos	

## reference



## materials

- cardboard "illustration board" or "mount board", 0.04 inches thick
  - 10x15" \$2 each <u>https://www.amazon.com/Crescent-99-</u> <u>Illustration-Board-ply/dp/B0044SCQWO</u>
  - 32x40" \$7 each <u>https://www.amazon.com/Crescent-Colored-Mat-Board-ply/dp/B0062TLDT0</u>
- sheet adhesive
  - 8x11" \$3 each <u>https://www.amazon.com/dp/B00JN9FDN8</u>
  - 6" tape roll (stronger) \$40 <u>https://www.amazon.com/dp/</u> <u>B00FARV8NG</u>



## laser cutter & raspberry pi

- laser cutter: glowforge basic \$2.5k <u>https://glowforge.com/tech-specs</u>
- we will use a raspberry pi zero, total \$48
  - raspberry pi zero, \$10.00 <u>https://www.sparkfun.com/products/14277</u>
  - servo hat \$9.95 <u>https://www.sparkfun.com/products/14328</u>
  - tall header \$1.95 <u>https://www.sparkfun.com/products/14017</u>
  - header \$0.95 <u>https://www.sparkfun.com/products/14275</u>
  - micro-usb cable 6 foot \$4.95 <u>https://www.sparkfun.com/products/10215</u>
  - micro-SD card \$19.95 <u>https://www.sparkfun.com/products/13833</u> (and only \$8 here <u>https://www.amazon.com/dp/B00200K1TS</u>)
  - optional power supply \$10 <u>https://www.amazon.com/dp/B00MARDJZ4</u>
- cheaper but more limited alternatives: maestro USB \$20 <u>https://www.sparkfun.com/products/9664</u>, or arduino \$20 <u>https://www.sparkfun.com/products/13975</u> with servo shield \$25 <u>https://www.sparkfun.com/products/14285</u> (cables extra)
- 5x micro servos at \$2 each <u>https://www.amazon.com/dp/B015H5AVZG</u>



# configuring raspberry pi

- (these have already been carried out for you)
- based on spark fun's servo hat tutorial <u>https://learn.sparkfun.com/tutorials/setting-up-the-pi-zero-wireless-pan-tilt-camera</u>
  - 1. solder headers onto pi and servo hat to connect them
  - 2. with raspberry pi booted and plugged into an HDMI-capable monitor:
    - 1. connect to U. Washington WIFI
    - 2. update linux: run "sudo apt-get update"
    - 3. enable I2C: run "sudo raspi-config" from a terminal and scroll to "interfacing options" ... "I2C", select and say "yes."
    - 4. run "sudo nano /boot/config.txt", scroll to the end of the file, add "enable\_uart=1", ctrl-x to save and exit.



### connecting to pi (windows 10)

Device Manager	_	$\times$
le Action View Help		
AWYERFULLEB896		
> 🖬 Audio inputs and outputs		
> 🍃 Batteries		
> 💻 Computer		
> 👝 Disk drives		
> 🔙 Display adapters		
> 🔐 DVD/CD-ROM drives		
> 🛺 Human Interface Devices		
> 🦷 IDE ATA/ATAPI controllers		
> 🚡 Imaging devices		
> 🥅 Keyboards		
> II Mice and other pointing devices		
> 🛄 Monitors		
rvetwork adapters		
🗸 🛱 Ports (COM & LPT)		
USB Serial Port (COM3)		
🔉 🚍 Print queues		
- Drinkers		

#### 1. plug in USB cable and open "device manager" to find which com port

#### PuTTY Configuration Category: Session Basic options for your PuTTY session Logging Specify the destination you want to connect to Terminal Serial line Speed Keyboard Bell COM3 115200 Features Connection type Window ○ Telnet ○ Rlogin ○ SSI Serial O Raw Appearance Behaviour Load, save or delete a stored session Translation Saved Sessions Selection Colours Connection Default Settings Load Data Proxy Save Telnet Rlogin Delete + SSH Serial Close window on exit: Always Never Only on clean exit About Open Cancel

2. download and run putty.exe, choose "serial" as connection type, enter in COM# and 115200

 $\Box$ 

Х

3. making sure pi has booted (~2 minutes):

login: "pi" password" "raspberry"

#### 🖉 COM3 - PuTTY

Raspbian GNU/Linux 9 raspberrypi ttyS0 raspberrypi login: pi Password: Last login: Wed Apr 18 23:18:20 UTC 2018 on tty1 Linux raspberrypi 4.9.41+ #1023 Tue Aug 8 15:47:12 BST 2017 armv61

The programs included with the Debian GNU/Linux system are free software; the exact distribution terms for each program are described in the individual files in /usr/share/doc/\*/copyright.

Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent permitted by applicable law. pi@raspberrypi:~\$

## foldable robotics lab session assignment

course website (with slides and files): <u>https://faculty.washington.edu/minster/foldable\_robotics\_2018/</u>

- 1. cut and assemble a basic hinge from a provided drawing
- 2. perform a basic servo motion
  - to download a servo program from course website to your raspberry pi, use

wget <u>http://faculty.washington.edu/minster/foldable\_robotics\_2018/</u> files/servo.py

- 3. cut and fab a more advanced design (open-ended)
  - add servo control
  - make your own design

#### You can take home what you make! (servos excepted)

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#### ideas

- sarrrus linkage lacksquare
- wing motion using spherical 5-bar lacksquarewood2004 http://citeseerx.ist.psu.edu/viewdoc/ download?



• muira pattern



flower pattern ●

Е



crane  $\bullet$ 



robotic gripper lacksquare



icosahedron ullet





## Ice-breaker activity: meet your group

- be prepared to answer either (1-2 minutes per person):
  - if you could be any animal, what would you be and why?
  - or, if you could have an endless supply of any food, what would you



## Next

#### walk over to Fuller Lab, Mechanical Engineering Building Room 113



## examples



https://www.youtube.com/watch?v=VxSs1kGZQqc