Assembling Instructions for Nybble

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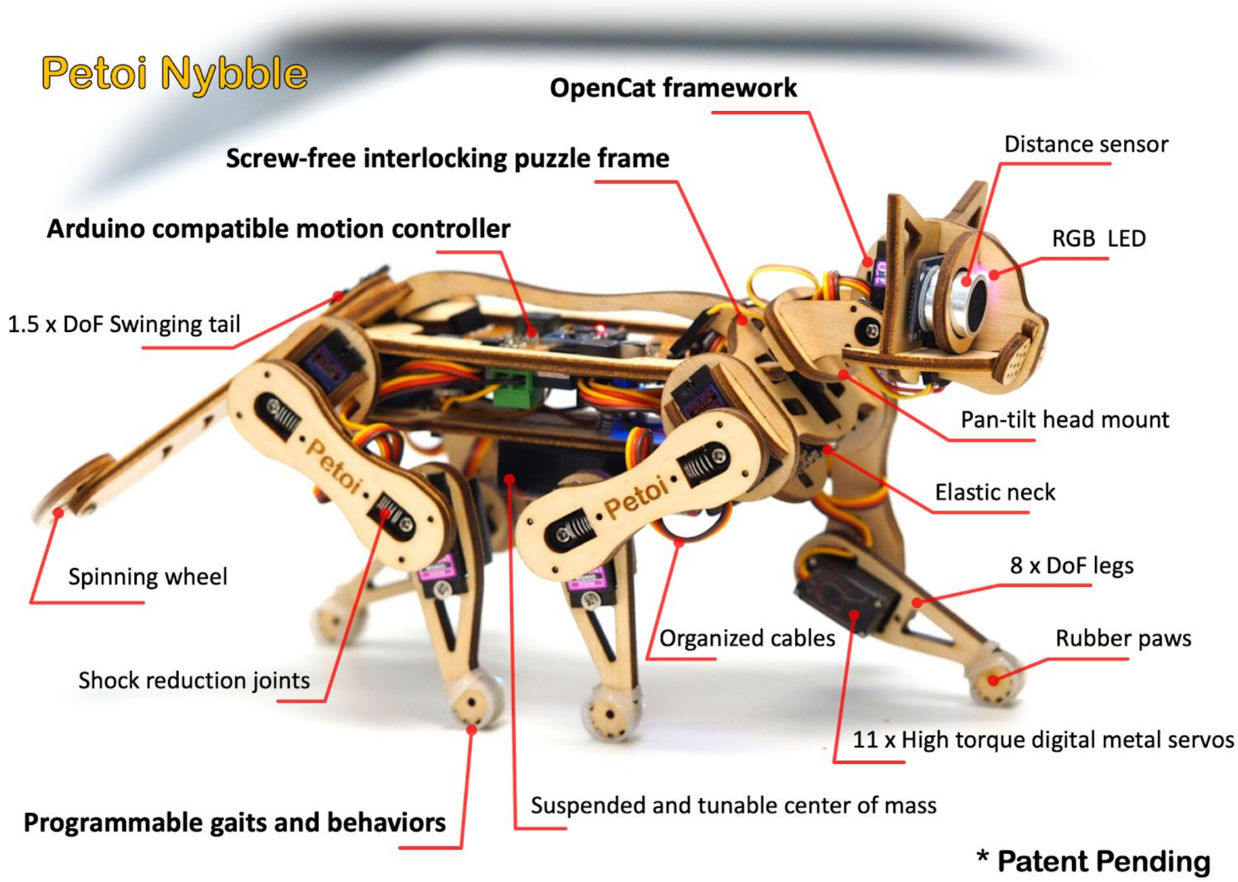
Jan. 25, 2019

To keep this instruction simple to use, I'm focusing on the assembly rather than in-depth explanation. If you have specific questions on "why" rather than "how", please post on our forum at https://www.petoi.com/forum.



The crowdfunding campaign is active on Indiegogo: igg.me/at/nybble. Our social media account is **@PetoiCamp**. Share your build with us by tagging #nybble #petoi or #opencat so that we can repost for you!

1. Tools and Preparation

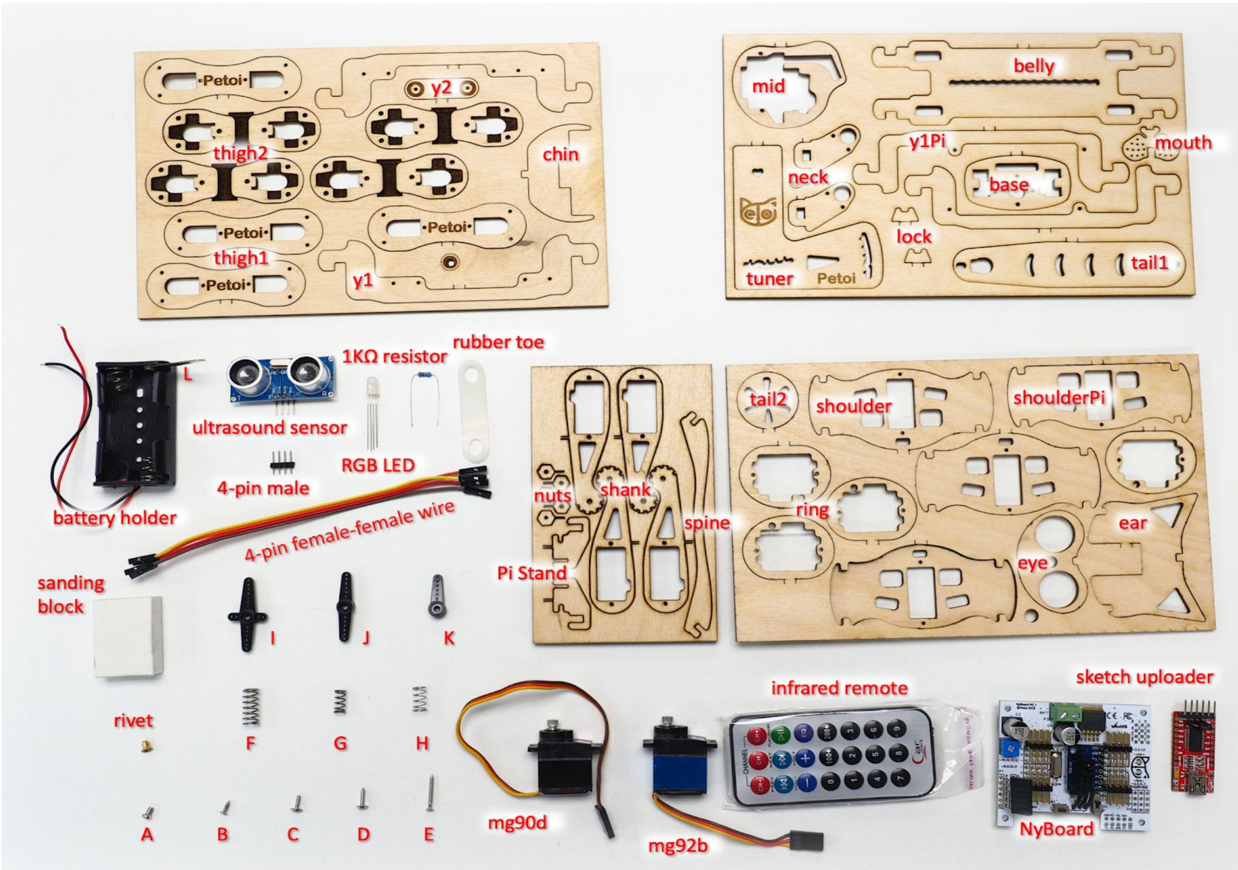
1.1. Prepare a clean desk and some small boxes to unzip the package.

It's better to work in a room without carpet or textured mosaic. Little screws and springs can magically hide themselves if dropped onto the ground.

1.2. Tools and accessories

	Tool	Notes
Required	Utility knife	Cut the tabs holding the wooden puzzle pieces
	Flat and phillips screwdrivers	
	Computer with Arduino IDE	Install the latest Arduino IDE
	USB to mini USB cable	Connect the uploader to computer. Not micro USB
	2 x 14500 Li-ion batteries	Rated 3.7V. Don't mix with regular AA batteries!
	Smart charger for batteries	
Optional	Soldering iron w/ accessories	Solder the decorative LED to ultrasound sensor
	HC-05 bluetooth module	Wirelessly upload sketch and communicate
	Color paints	Give your Nybble a unique look
	3D printer w/ accessories	Add your special design
	Arduino/Raspberry Pi kit	Add more gadgets to Nybble
	Multimeter	Test and debug
	Oscilloscope	Test and debug
	Hot glue/super glue	Avoid using them. OpenCat is designed to be soft!

2. Open box. Get familiar with the components.



There's a larger picture in the Appendix. Packaging method may vary.
This instruction will keep consistent with the current namespace.

2.1. Cut body pieces off the baseboard.

There might be some tar residue on the wooden pieces from laser cutting. Use a wet soft tissue to clean up the board.

The functional pieces are attached to the baseboard by lightly cut tabs. Though you could pop those pieces out by hand, it's highly recommended that you use a knife to cut on the back side of the tabs to avoid potential damage to the middle layer, where the fiber direction is perpendicular to the surface fiber.

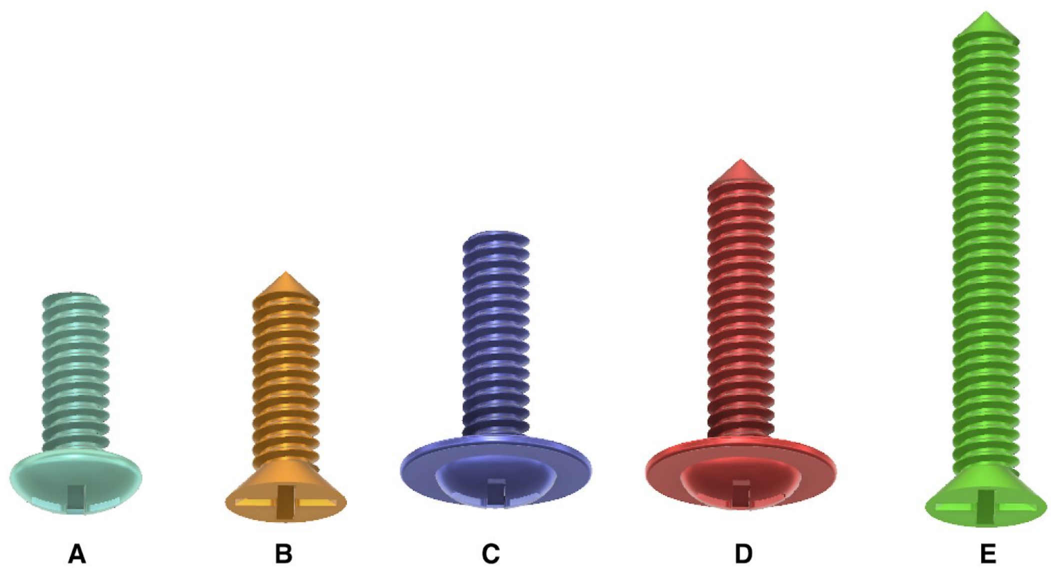
After taking out all the pieces from the baseboard, you are encouraged to bend and break the remaining structures on the baseboard, to understand the mechanical properties of plywood, such as anisotropic strength, elasticity, etc. That will give you confidence in later handling.

2.2. Remove pointy fibers.

Use the sanding foam to clean up any thorn on the pieces. Don't sand too much or it may affect the tightness between joints.

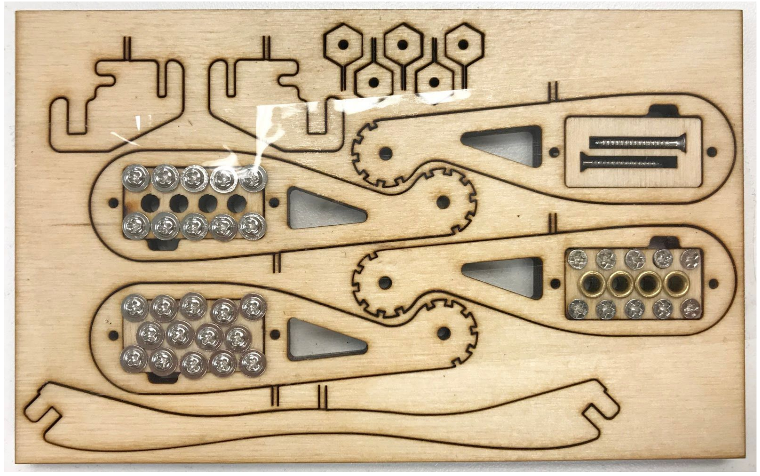
2.3. Screws

There are five different screws used in the kit. I'm coloring them differently to better indicate their locations. Not all screws are required to assemble Nybble. Not all holes on the puzzle pieces need screws. Observe the assembling animation carefully to locate them.



- A is for attaching servo arms. D (sharp tip) is for attaching servos to the frame. A and D come in each servo's accessory pouch with plastic servo arms.
- B is for attaching servo arms/circuit boards to the frame. In later versions it may be replaced by C to avoid confusion. In that case, if the hole is too small for screw C's flat tip, use screw D to pre-tap.
- C (flat tip) is for binding the thighs.
- E (always the longest) is for attaching the battery holder.

For earlier packages, B, C and E are located in the Shank board within the multi-punched blocks shown here:



2.4. Springs

There are three different springs: F, G, H.

- The big spring F is used for elastic connection in the thigh. There's one spare unit;
- The hard short spring G is for the neck. It could be replaced by spring F;
- The soft short spring H is for attaching the battery holder.

3. Assemble the frame

3.1. Head and neck

3.1.1. Part list

Part List

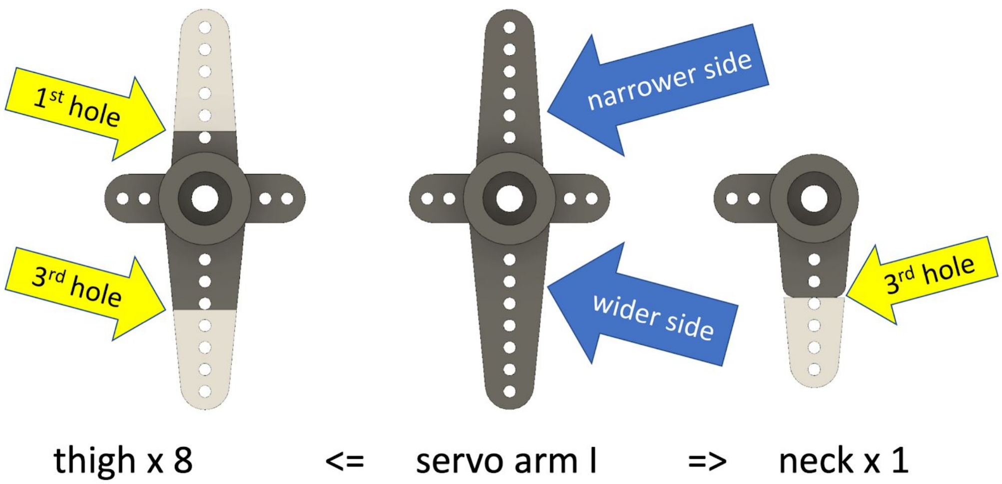
mid	
ear	
mouth	
eye	
chin	
mg90d	
screw D	x 2
base	
neck	x 2
lock	x 2
servo arm I	
servo arm J	
screw B	x 4

3.1.2. Solder on the optional LED to ultrasound sensor.

The obstacle avoidance algorithm using the ultrasound sensor has not yet been integrated in the code. The optional RGB LED can be soldered to the four pins of the ultrasound sensor (instructions) to indicate its working status, or can be programmed as decorative lights.

3.1.3. Trim the servo arms for attaching servos.

Pay attention to the width difference between servo arm I's two long sides, as well as the trimming location (using screw holes as references).

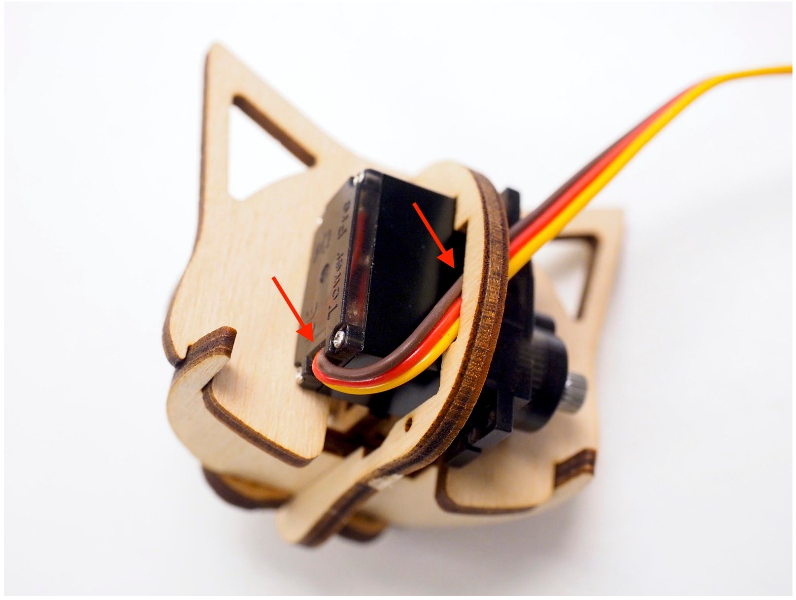


Most of the servo arms on the model are trimmed from the cross shaped arm I. Since there will be more unused straight arms, you can practice trimming with them first.

An alternative method to trimming is using a half burned knife to cut the plastic parts off. Leave a little bit longer length because melted plastic will have rounded edge.

3.1.4. Assemble the head group.

Note that the base should only be partially assembled for later calibration. Otherwise it will be difficult to insert the servo between neck pieces. Also notice how the servo wire is organized in the head. Assemble the head group as shown in the head animation

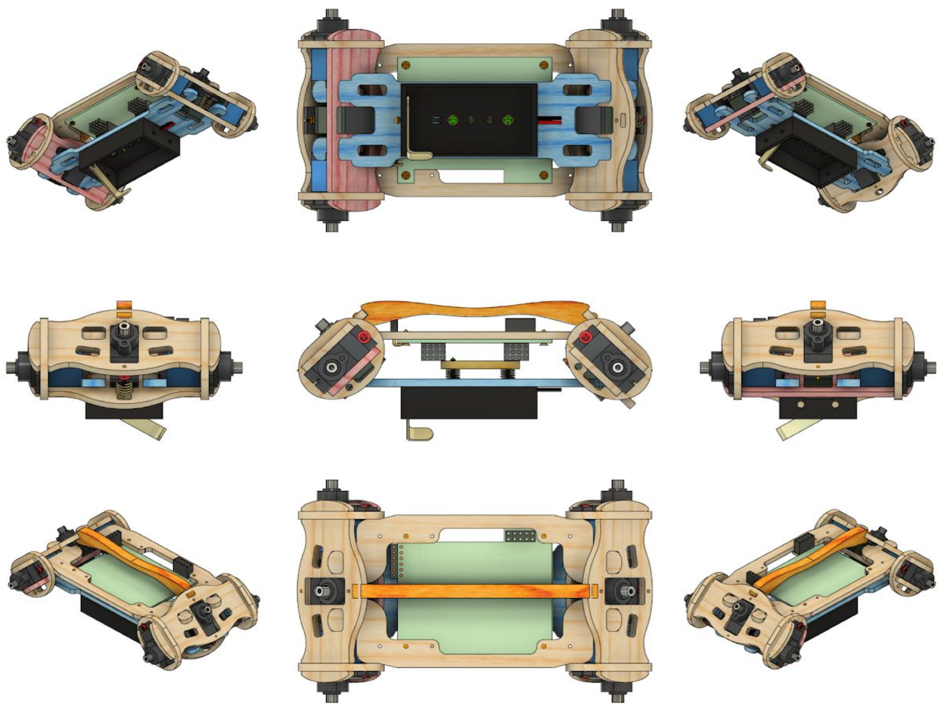


3.1.5. DO NOT connect the head with neck yet, because the tilt servo on the head has to be calibrated.

3.2. Body

3.2.1. Part list

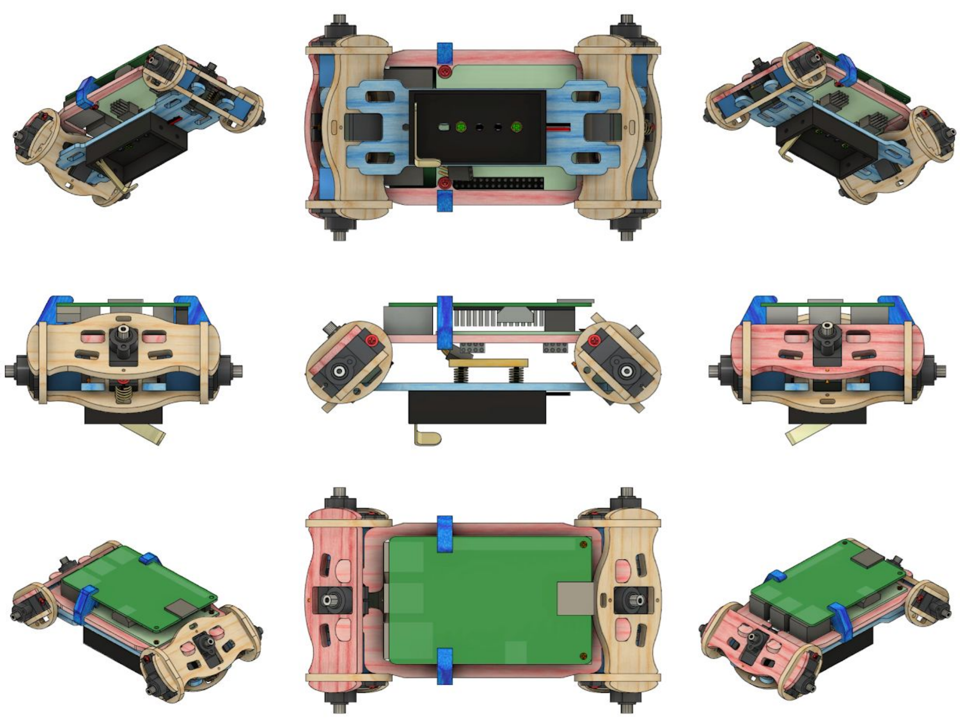
- NyBoard only



Part List

belly	
ring	x 4
mg92b	x 4
mg90d	x 2
shoulder	x 3
shoulderPi	
y1	x 2
y2	
battery holder	
rivet	x 2
spring G	
spring H	x 2
screw D	x 4
screw E	x 2

- NyBoard with Raspberry Pi: use y1Pi to replace y1, and add Pi Stand. Pay attention to the location of pink pieces.



Part List

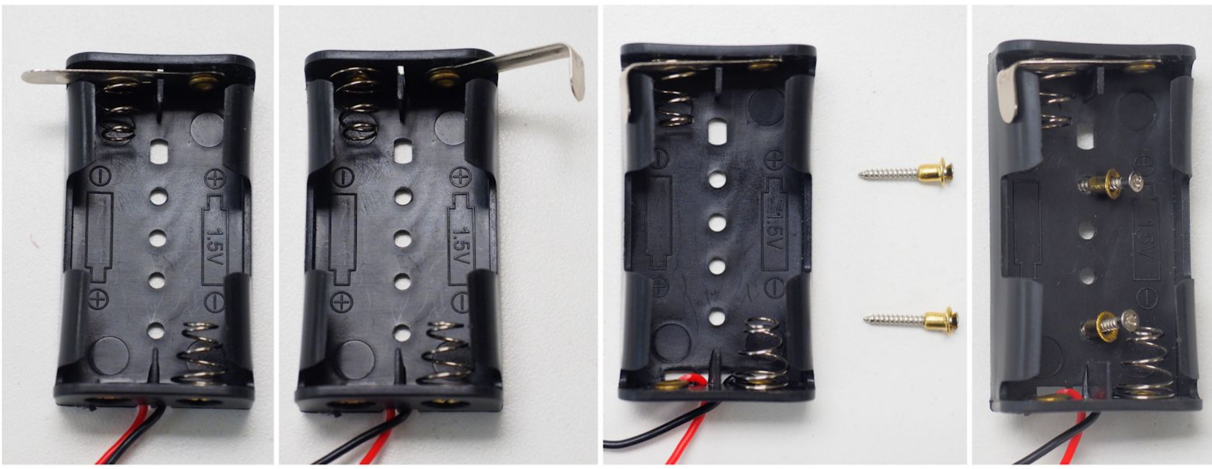
belly	
ring	x 4
mg92b	x 4
mg90d	x 2
shoulder	x 3
shoulderPi	
y1Pi	x 2
Pi Stand	x 2
y2	
battery holder	
rivet	x 2
spring G	
spring H	x 2
screw D	x 4
screw E	x 2

- Other controllers

I also included 5 x 1”/4 nuts for mounting other circuit boards.

3.2.2. Install the adjustable battery holder to belly

Bend the hinge L of battery holder to 90 degree, close to the wall. It functions as a switch. Insert the long screw E through the rivet so that you can better handle the rivet. Insert and push the rivet into the hole on the bottom of the battery holder. Pay attention to the holes’ locations.

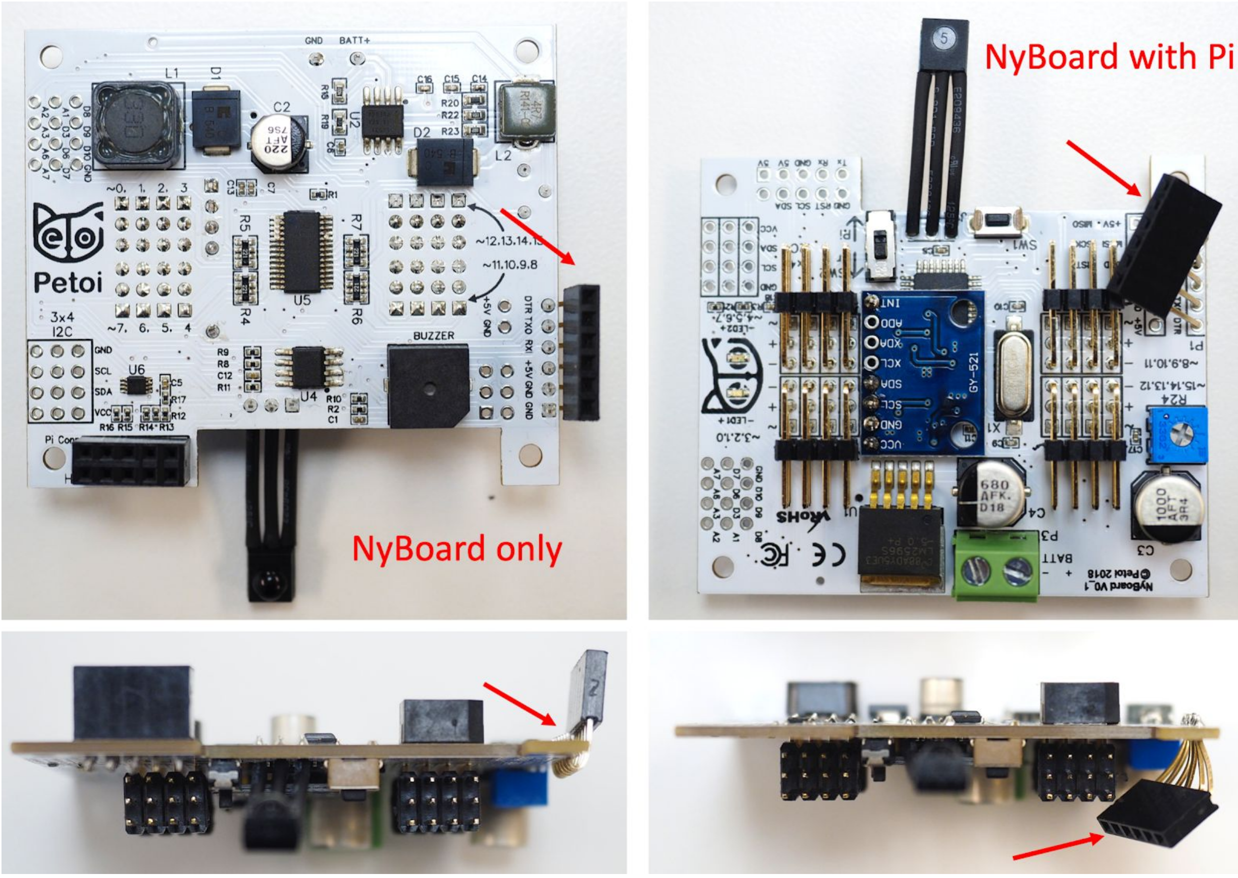


The spring attached structure of the battery holder is used for shifting the center of mass when fine tuning gaits.

The battery holder is generic for AA (1.5V) batteries. But Nybble uses 3.7V Li-ion batteries.

3.2.3. Assemble the body group

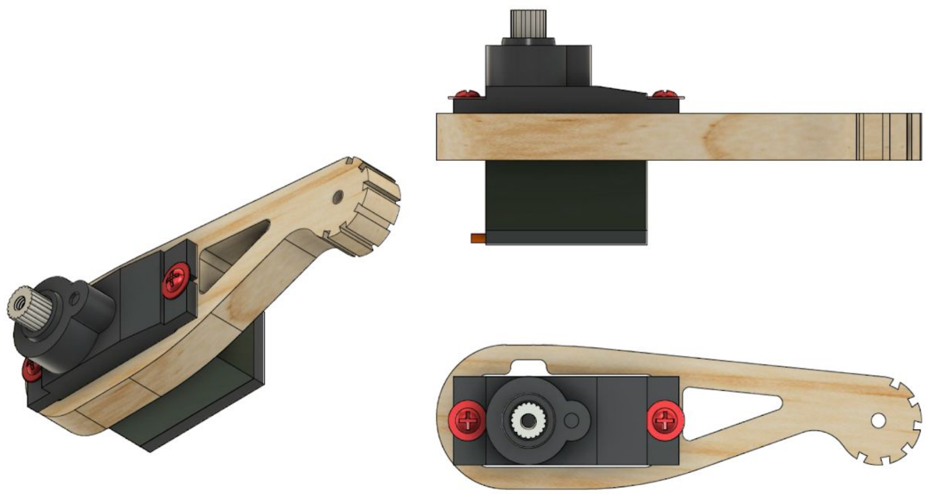
Pay attention to the long pins of infrared receiver and FTDI port. They are designed to be bent to favorable directions. Don’t bend the pins too often or it will lead to metal fatigue.



3.2.4. Observe the [adjusted configuration]() if you want to mount a Raspberry Pi. Assemble the body group as shown in the [body animation]().

3.3. Shank

3.3.1. Part list



Part List

shank	x 4
rubber toe	x 4
mg90d	x 4
screw D	x 8

3.3.2. Attach the rubber to the tip of the shank.

The serrated structure on the tip of shank is already good for walking. The rubber toe is optional to increase friction and soften each step.

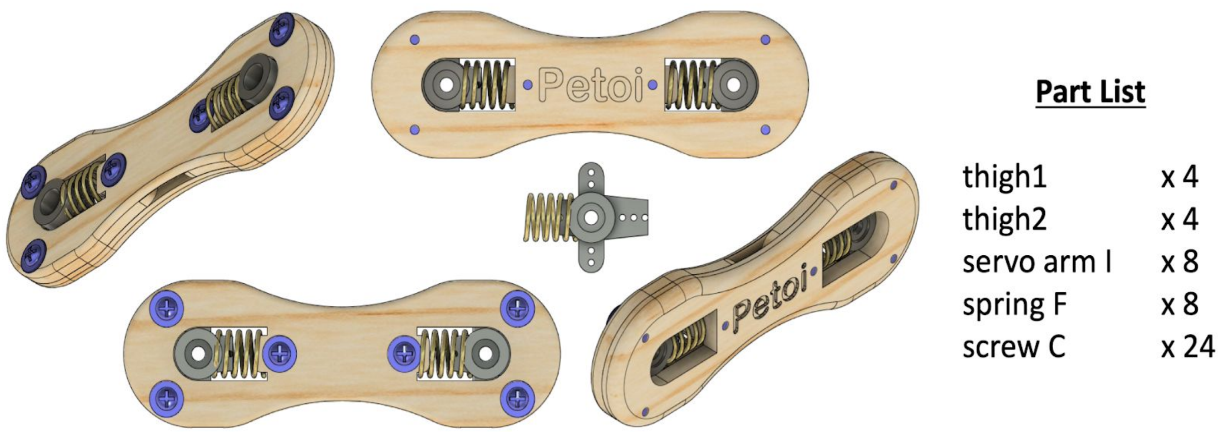
3.3.3. Insert the servo into the slot on the shank.

Pay attention to the direction that the wire is twisted. The small dent on the long edge is designed to let wire go through. Think about symmetry of the four legs.

3.3.4. Assemble the shank as shown in the [shank animation](). Don't install the servo screw A yet.

3.4. Thigh

3.4.1. Part list

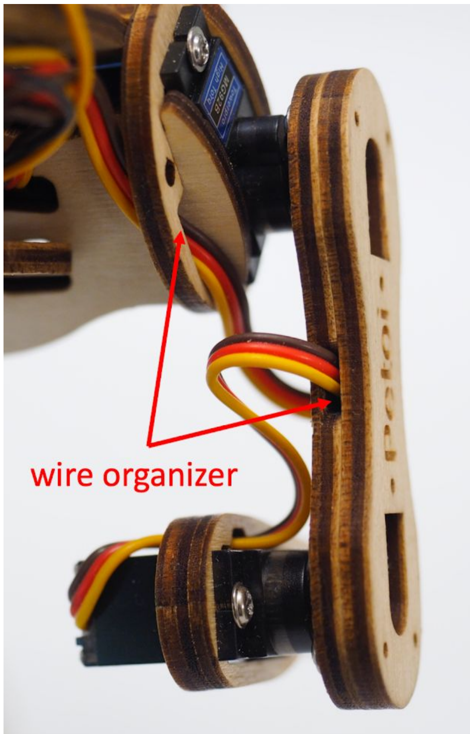


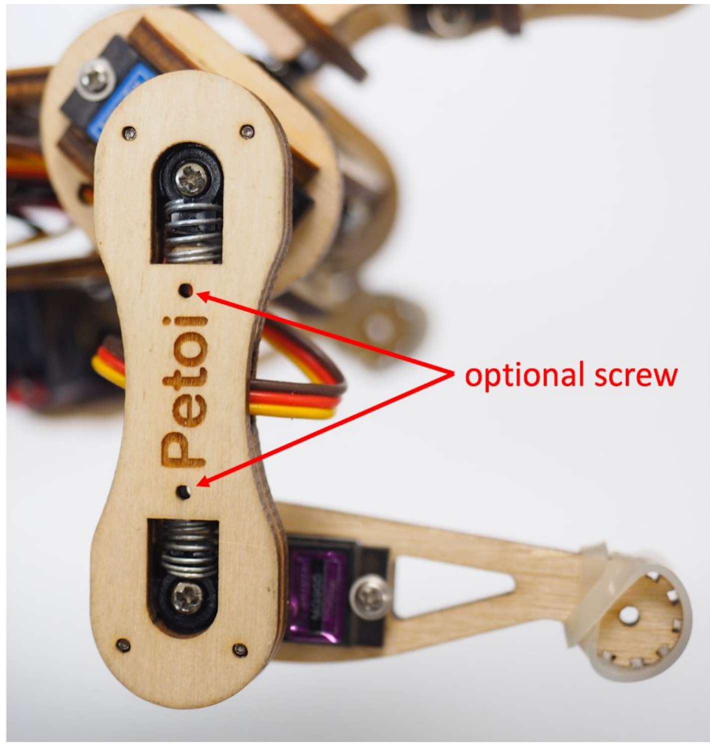
3.4.2. Trim the servo arms for attaching servos.

The location has been shown in the [Head and Neck]() section. The trimmed narrower servo arm is designed to be inserted into spring F.

3.4.3. Assemble the thigh.

Before closing thigh1 and thigh2, put the wire of the shank through the slot in the middle of the thigh. Think about symmetry of the four legs.





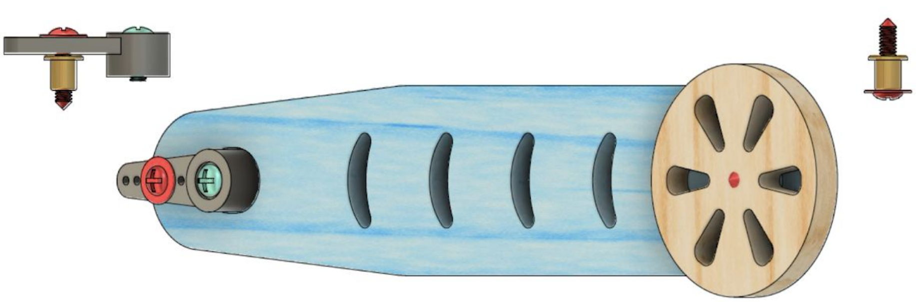
The servo arm should be able to slide in the track on thigh2 with subtle friction after thigh1 and thigh2 are screwed together. You can tune the tightness of screw C to achieve proper friction. If you need more control on the tightness:

- Scratch the track using a flat screw driver to reduce friction.
- Apply a little paper glue in the track and let dry to increase friction.

Assemble the thigh as shown in the thigh animation.

3.5. Tail

3.5.1. Part list



Part List

tail1	
tail2	
servo arm K	
rivet	x 2
screw D	x 2

3.5.2. Assemble the tail.

The screw D is installed in the third hole counted from the center of the servo arm K. Pay attention to the order that every piece are stacked. The wheel (tail2) should be able to rotate with little friction, and the whole tail should be able to tilt by a small degree.

Assemble the tail as shown in the [tail animation].

3.5.3. DO NOT connect the tail to body yet.

3.6. DO NOT screw neck and legs to the body's servos yet

4. Configure Arduino IDE and NyBoard

4.1. NyBoard

4.1.1. Read the user manual for [NyBoard V0].

4.1.2. Dial the potentiometer clockwisely to start from the lowest voltage.

Higher voltage will increase the servos' torque, making Nybble move faster. The downside is it will increase current draw, reduce battery life, affect the stability of circuit, and increase the wearing of the servos. Based on my tests, 5.5V seems to result in a balanced performance.

4.1.3. Dial the I^2C switch (SW2) to Ar.

The I^2C switch changes the master of I^2C devices (gyro/accelerometer, servo driver, external EEPROM). On default "Ar", NyBoard uses the on-board ATmega328P as the master chip; On "Pi", NyBoard uses external chips connected through the I^2C ports (SDA, SCL) as the master chip.

4.2. Downloads and installations

Note: You will need the newest Arduino IDE to set up the environment. Older versions tend to compile larger hex files that may exceed the memory limit.

If you have previously added other libraries and see error message "XXX library is already installed", I would recommend you delete them first (instruction: https://stackoverflow.com/questions/16752806/how-do-i-remove-a-library-from-the-arduino-environment). Due to different configurations of your Arduino IDE installation, if you see any error messages regarding missing libraries during later compiling, just google and install them to your IDE.

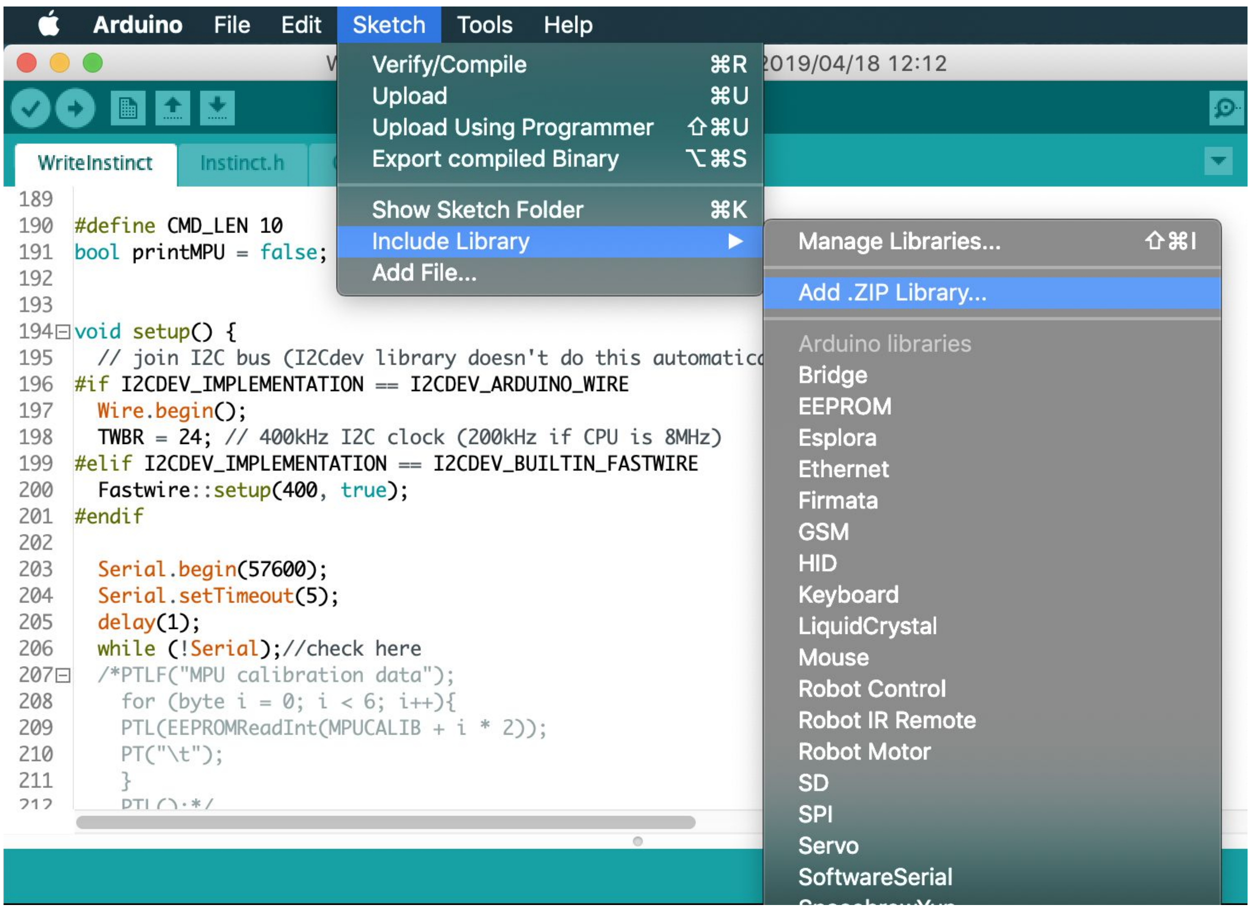
4.2.1. Install through library manager

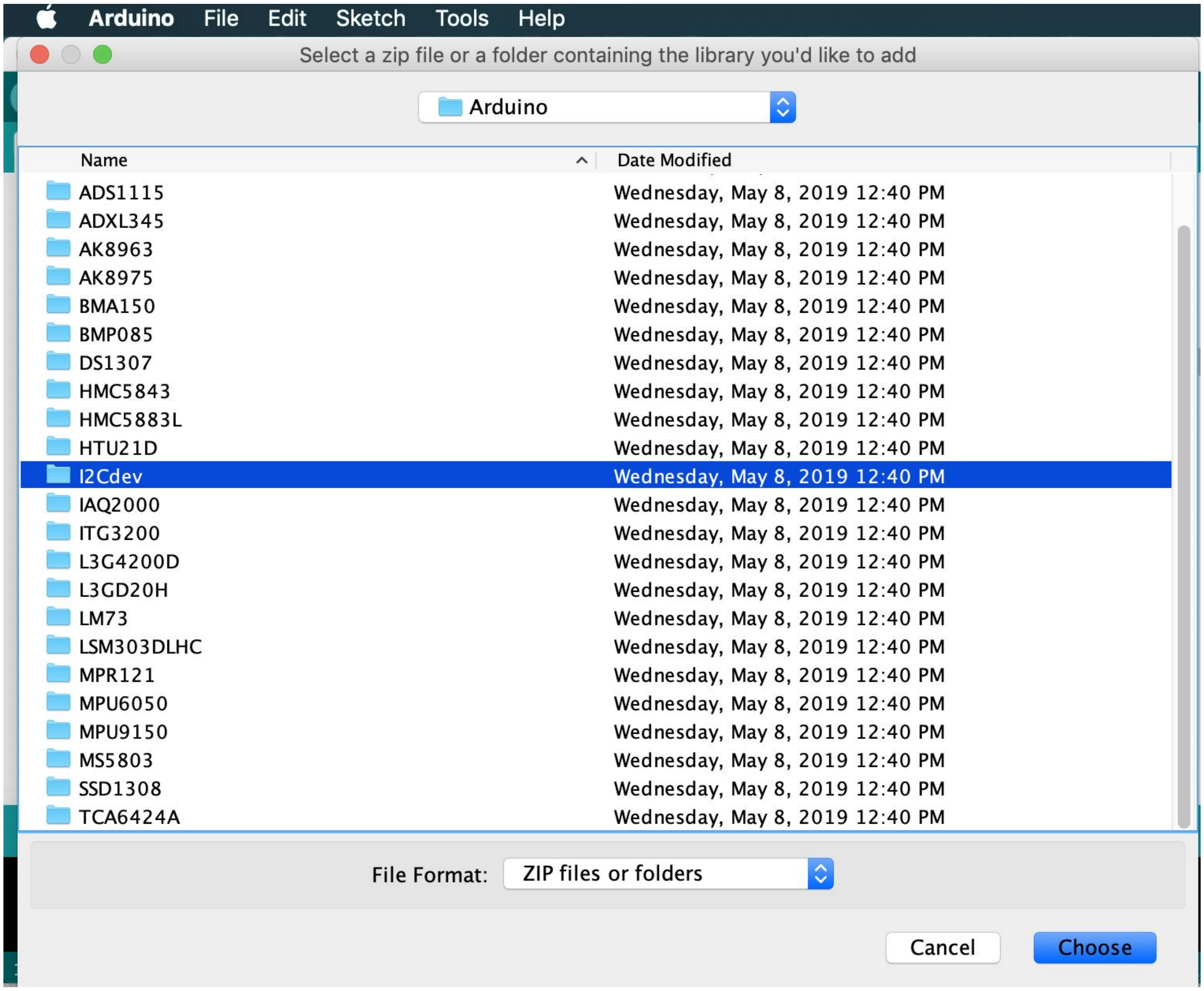
Go to the library manager of Arduino IDE (instruction: https://www.arduino.cc/en/Guide/Libraries), search and install **Adafruit PWM Servo Driver**, **IRremote** and **QList**.

4.2.2. Install by adding .ZIP library

Go to https://github.com/jrowberg/i2cdevlib, download the zip file and unzip. You can also git clone the whole repository.

Use **Add .ZIP Library** to find **Arduino/MPU6050/** and **Arduino/I2Cdev/**. Click on the folders and add them one by one. They don't have to be **.ZIP** files.





4.2.3. Create and add NyBoard

- Locate the files

  Mac location:

  /Users/UserName/Library/Arduino15/packages/arduino/hardware/avr/version#/

  Or:

  /Applications/Arduino.app/Contents/Java/hardware/arduino/avr

  To access, right click on Arduino.app and choose Show Package Contents

  Windows location:

  C:\Program Files(x86)\Arduino\hardware\arduino\avr\

  Linux

Fedora: boards.txt is symlinked under:

/etc

Arch: boards.txt is found at:

/usr/share/arduino/hardware/archlinix-arduino/avr/

Ubuntu: ?

- Make a copy of **boards.txt** in case you want to roll back.
- Create new **boards.txt**.

You can download my **boards.txt** file, or:

Edit your **boards.txt** with admin privilege. Find the section of

pro.name=Arduino Pro or Pro Mini

and insert the

Arduino Pro or Pro Mini (5V, 20 MHz) w/ ATmega328P

code block. Save and quit your editor.

```
##############################################################

pro.name=Arduino Pro or Pro Mini

pro.upload.tool=avrdude
pro.upload.protocol=arduino

pro.bootloader.tool=avrdude
pro.bootloader.unlock_bits=0x3F
pro.bootloader.lock_bits=0x0F

pro.build.board=AVR_PRO
pro.build.core=arduino
pro.build.variant=eightanaloginputs

## Arduino Pro or Pro Mini (5V, 20 MHz) w/ ATmega328P
## --------------------------------------------------
pro.menu.cpu.20MHzatmega328=ATmega328P (5V, 20 MHz) NyBoard

pro.menu.cpu.20MHzatmega328.upload.maximum_size=30720
pro.menu.cpu.20MHzatmega328.upload.maximum_data_size=2048
pro.menu.cpu.20MHzatmega328.upload.speed=57600

pro.menu.cpu.20MHzatmega328.bootloader.low_fuses=0xFF
pro.menu.cpu.20MHzatmega328.bootloader.high_fuses=0xDA
pro.menu.cpu.20MHzatmega328.bootloader.extended_fuses=0xFD
```

pro.menu.cpu.20MHzatmega328.bootloader.file=atmega/ATmega328_20MHz.hex

pro.menu.cpu.20MHzatmega328.build.mcu=atmega328p
pro.menu.cpu.20MHzatmega328.build.f_cpu=20000000L

Arduino Pro or Pro Mini (5V, 16 MHz) w/ ATmega328P
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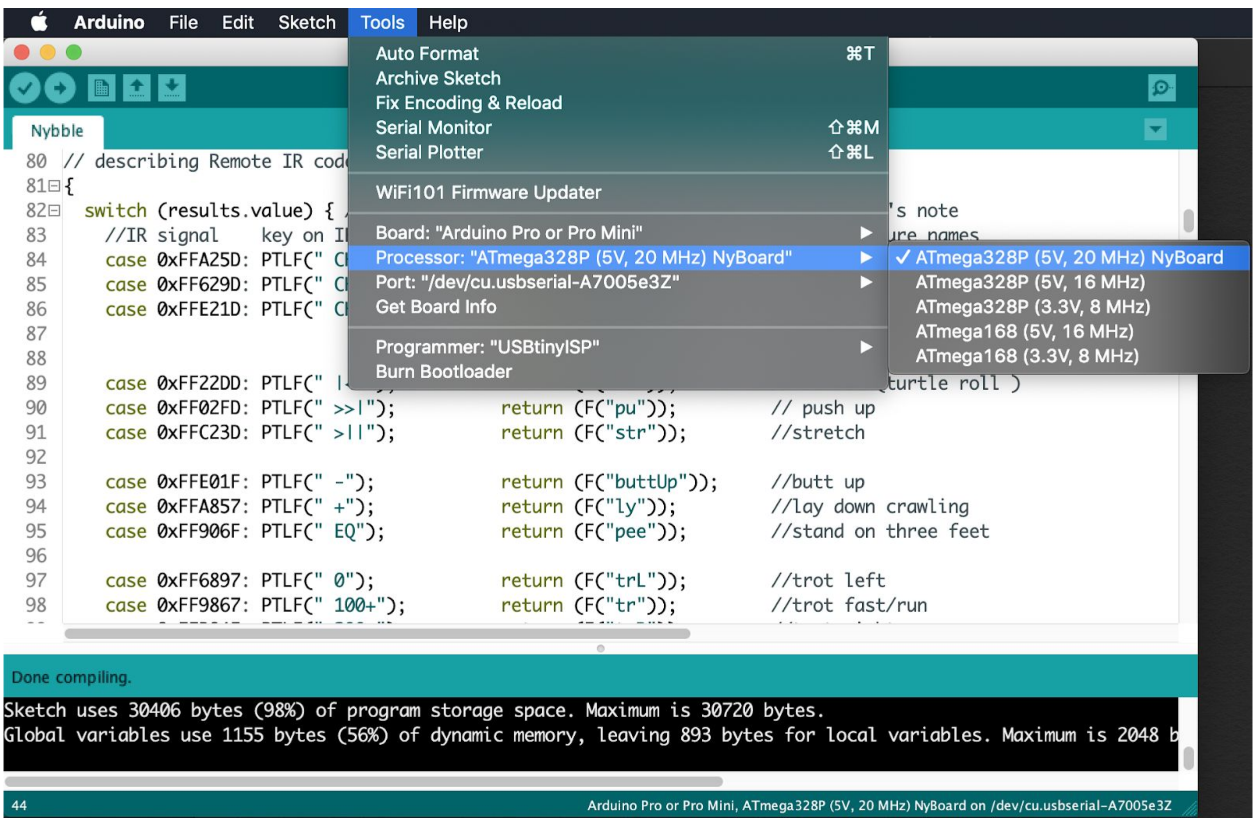
...

- Download ATmega328_20MHz.hex and put it in your Arduino folder ./bootloaders/atmega/. You should see other bootloaders with .hex suffix in the save folder.
- Restart your Arduino IDE. In **Tools->Boards**, select Arduino Pro or Pro Mini. You should find ATmega328P (5V, **20** MHz) in Processor menu.



- Note: If you cannot find the board, your Arduino IDE may be using the boards.txt in another path. Search boards.txt in all the folders on your computer. Find out the right file that's in effect.

4.2.4. Burn the bootloader (only if the bootloader of NyBoard collapsed)

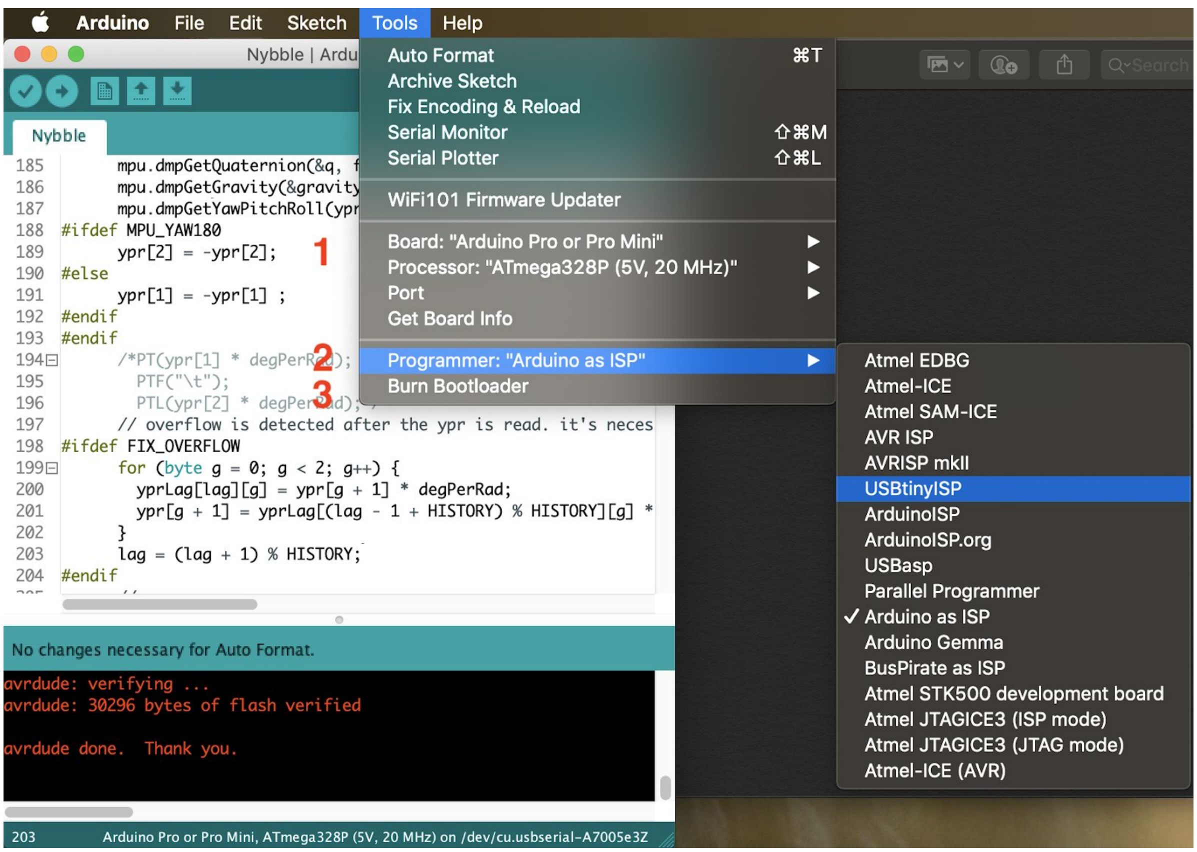
- [What is a bootloader?]()

Every NyBoard has to go through functionality checks before shipping, so they should already have compatible bootloader installed. However, in rare cases, the bootloader may collapse then you won't be able to upload sketch through Arduino IDE.

Well, it's not always the bootloader if you cannot upload your sketch:

- Sometimes your USB board will detect a large current draw from a device and deactivate the whole USB service. You will need to restart your USB service, or even reboot your computers;
- You need to install the driver for the FTDI USB 2.0 to UART uploader;
- You haven't selected the correct port;
- Bad contacts;
- Bad luck. Tomorrow is another day!

If you really decide to re-burn the bootloader:

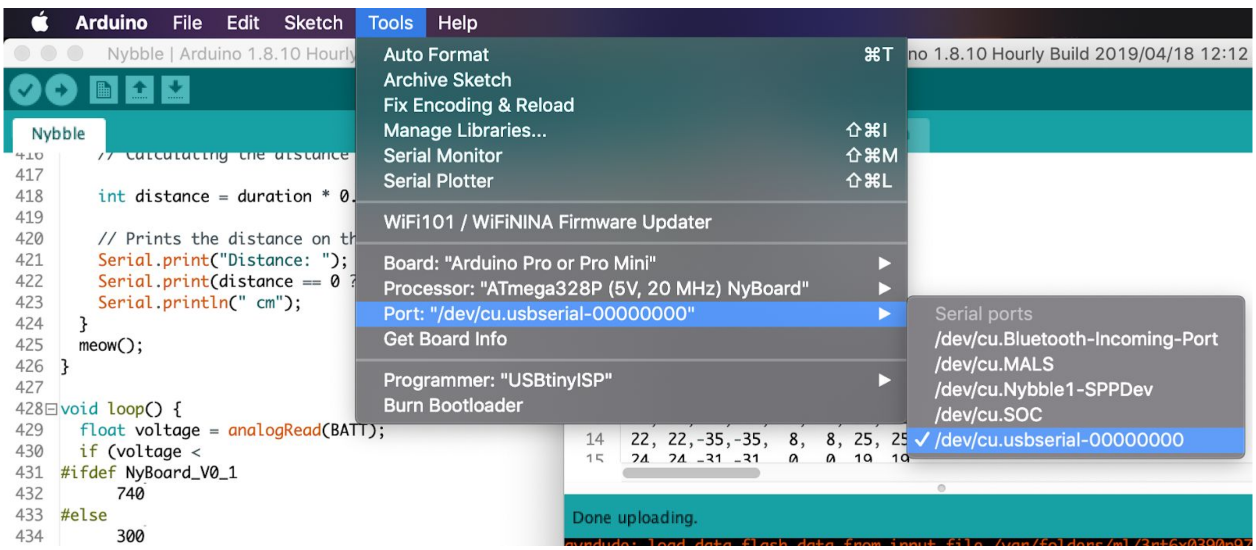


- Select the **ATmega328P (5V, 20 MHz)** board under the **Tool** tab of Arduino IDE.

- Select your ISP (In-System Programmer). The above screenshot shows two popular programmers: the highlighted **USBtinyISP** is a cheap bootloader you can buy, while the checked **Arduino as ISP** can let you use a regular Arduino as ISP!
- Burn bootloader. If it's your first time doing so, wait patiently until you see several percent bars reach 100% and no more messages pop up for one minute.

4.2.5. Connect FTDI uploader

Connect your computer with the FTDI uploader (the red chip with 6 male pins) through USB-miniUSB cable. The uploader has three LEDs, power, Tx and Rx. Right after connection, the Tx and Rx should blink for one second indicating initial communication, then dim. Only the power LED should keep litting up. You can find a new port under **Tool->Port** as “/dev/cu.usbserial-xxxxxxxx” (Mac) or “COM#” (Windows).



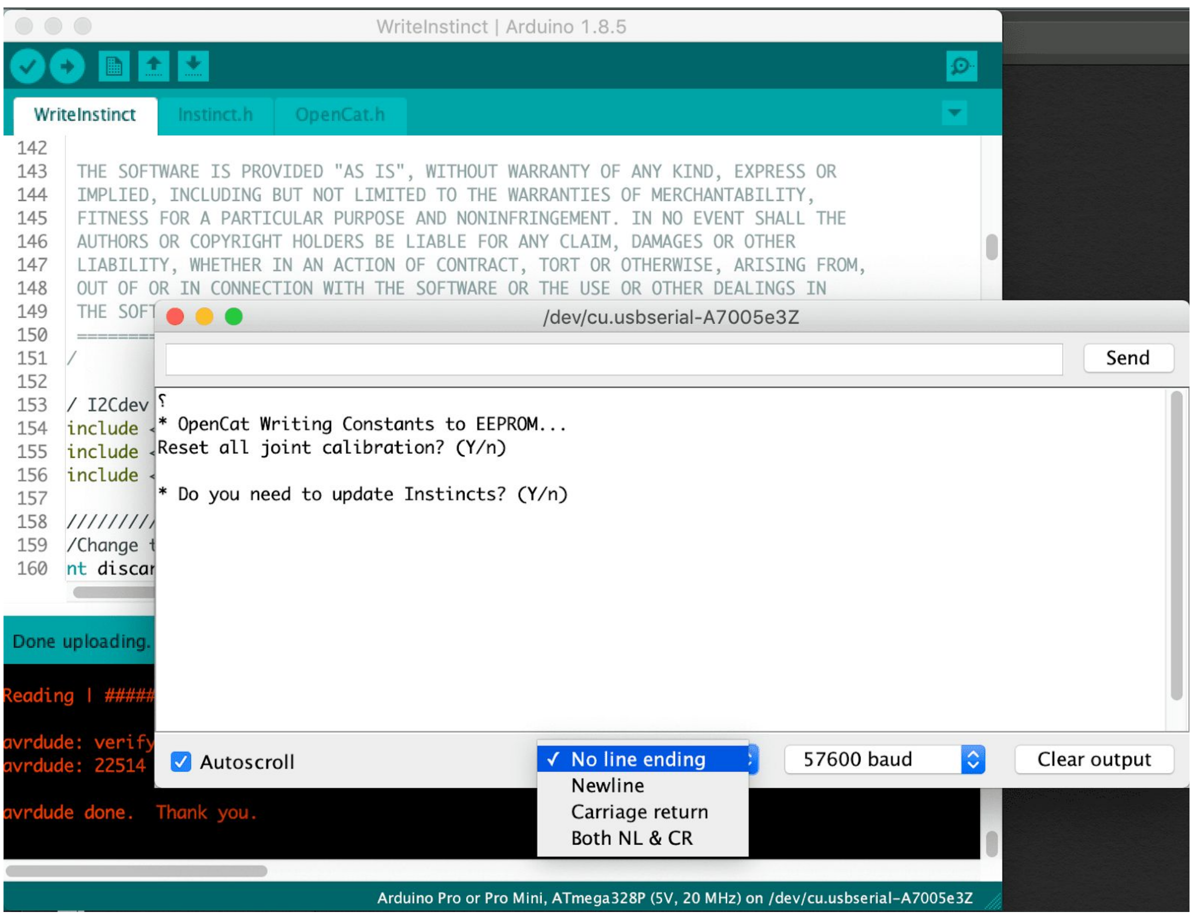
If Tx and Rx keep litting up, there’s something wrong with the USB communication. You won’t see the new port. It’s usually caused by overcurrent protection by your computer, if you’re not connecting NyBoard with external power supply and the servos move all at once.

4.2.6. Connect bluetooth uploader (optional)

It’s possible to program and communicate with Nybble wirelessly. Check out the bluetooth instruction on the OpenCat forum (PetoiCamp).

4.2.7. Download OpenCat package

- Download a fresh OpenCat repository from GitHub. It's better if you utilize GitHub's version control feature. Otherwise make sure you download the WHOLE FOLDER every time. All the codes should be the same version to work together.
- Open any testX.ino sketch with prefix "test". (I recommend using **testBuzzer.ino** as your first test sketch)
- Choose board as **Arduino Pro or Pro Mini** and compile. There should be no error messages. Upload the sketch to your board and you should see Tx and Rx LEDs blink rapidly. Once they stop blinking, messages should appear in the serial monitor. Make sure that your baud rate setting (57600) and board frequency(16MHz or 20MHz) matches with the configuration.
- If there're input prompts, make sure you set "No line ending". Otherwise the invisible '\n' or '\r' characters will confuse the parsing functions.



4.3. Arduino IDE as interface

With the FTDI to USB converter connecting NyBoard and Arduino IDE, you have the ultimate interface to communicate with NyBoard and change every byte on it.

I have defined a set of serial communication protocol for NyBoard:

OpenCat
Communication Protocol and Parsing

Interface		Token	Encoding	Parameters		Format	Bytes	Function
RasPi Serial Port	Arduino Serial Monitor	'h'	Ascii			char	1	print **h**elp information
		'c'		idx*,angle**	'\n'	string	strlen + 2	**c**alibrate servo$_{idx}$ by angle
		'm'		idx*,angle**	'\n'	string	strlen + 2	**m**ove servo$_{idx}$ to angle
		'j'				char	1	show all 16 **j**oint angles
		'd'				char	1	shut **d**own servos
		'p'				char	1	**p**ause motion
		'a'				char	1	**a**bandon calibration
		's'				char	1	**s**ave calibration
		'k'		abbreviation	'\n'	string	strlen + 2	load s**k**ill
		'w'		command	'\n'	string	strlen + 2	some future command **w**ords
		'r'				char	1	**r**eset board
		'i'	Binary	len, idx$_1$, a_1, ..., idx$_N$	a_N	string	len + 2	list of **i**ndexed rotation angles
		'l'		a_1, a_2, ...	a_{DoF}	string	DoF + 1	**l**ist of all DoF rotation angles

* index range: 0 ~ (DoF - 1)

** angle range: -90 ~ 90. fits in the range of signed char (-128 ~ 127). Also depends on the servos' parameters

All the token starts with a single Ascii encoded character to specify its parsing format. They are case-sensitive and usually in lower case.

Note: Some tokens haven't been implemented, such as 'h'. Token 'i' and 'l' still have some bugs.

4.4. Raspberry Pi serial port as interface (only if you are going to use Pi as a master controller)

As shown in the serial protocol, the arguments of tokens supported by Arduino IDE's serial monitor are all encoded as Ascii char strings for human readability. While a master computer (e.g. RasPi) supports extra commands, mostly encoded as binary strings for efficient encoding.

4.4.1. Config Raspberry Pi serial port

In Pi's terminal, type `sudo raspi-config`

Under **Interface** option, find **Serial**. Disabled the serial login shell and enable the serial interface.

[A good tutorial on Instructable]

If you plug Pi into NyBoard's 2x5 socket, their serial ports should be automatically connected at 3.3V. Otherwise pay attention to the Rx and Tx pins on your own AI chip, and its voltage rating. The Rx on your chip should connect to the Tx of NyBoard, and Tx should connect to Rx.

4.4.2. Change the permission of ardSerial.py

If you want to run it as bash command, you need to make it executable:

`chmod +x ardSerial.py`

You may need to change the proper path of your Python binary on the first line:

`#!/usr/bin/python`

4.4.3. Use **ardSerial.py** as the commander of Nybble

You need to UNPLUG the FTDI converter if you want to control Nybble with Pi's serial port.

Typing `./ardSerial.py <args>` is almost equivalent to typing `<args>` in Arduino's serial monitor.

For example, `./ardSerial.py kcr` means "perform s**k**ill **cr**awl".

Both **ardSerial.py** and the parsing section in **Nybble.ino** need more implementations to support all the serial commands in the protocol.

Note: Reduced motion capability when connected to Pi!

With the additional current draw by Pi, Nybble will be less capable for intense movements, such as trot (the token is “ktr”). The system is currently powered by two 14500 batteries in series. You may come up with better powering solutions, such as using high drain 7.4 Lipo batteries, or 2S-18650. There're a bunch of considerations to collaborate software and hardware for a balanced performance. With Nybble's tiny body, it's better to serve as a platform for initiating the communication framework and behavior tree rather than a racing beast.

4.5. Battery

Though you can program NyBoard directly with the FTDI uploader, external power is required to drive the servos.

When powering the NyBoard with only USB FTDI, there's obviously charging and uncharging in the servo's capacitor and cause the yellow LED to pulse. However the USB's current is not sufficient to keep the servos working. The servo circuit has to be powered by external batteries to work properly.

4.5.1. Voltage

NyBoard requires 7.4~12V external power to drive the servos. That's usually two li-ion or li-poly batteries connected in series. A single battery is 4.2V when fully charged and can work normally until voltage drops to 3.6V. That's about 7.2V with two batteries connected in series. Before installation, dial the potentiometer on NyBoard clockwisely to try minimum output first for best output stability. You can turn it up depending on your future needs.

Note:

When looking for batteries, search for keywords "14500 3.7V li-ion battery". I've noticed that the overcurrent protection of some batteries could be triggered by peak current draw(usually >2.5A), causing NyBoard to reset. Try find batteries with higher discharge rating.

4.5.2. Dimensions

The included battery holder is sized for 14500 batteries, that's 14 mm in diameter, and 50 mm in length. 50 ± 1 mm should still fit in. They are the same size as AA batteries, but much more powerful. Make sure not to use them in regular AA devices. If you are in the US, we have tested with EBL 14500 li-ion batteries.

You can also design other battery holders to carry larger batteries for better performance. That's especially necessary if you mount a Raspberry Pi or want Nybble run faster.

4.5.3. Connection

Be careful with the polarity when connecting the power supply. **Reversed connection may damage NyBoard!** Make sure you can find the positive (+) and negative (-) sign on both the NyBoard's power terminal and your power supply.

Loosen the screws of the power block. Insert the wires of the battery holder then tighten the screws. When turn the switch on, both the blue LED (for chip) and the yellow LED (for servo) should lit up.

4.5.4. Battery life varies according to usage

It can last hours if you're mainly coding and testing postures, or less than 30 mins if you keep Nybble running.

When the battery is low, the yellow LED will blink slowly. Although NyBoard can still drive one or two servos, it will be very unstable to drive multiple servos at once. That will lead to repeatedly restarting the program, or awkward joint rotations. In rare cases, it may even alter the bits in EEPROM. You will need to reupload the codes and re-save the constants to recover.

4.5.5. Charging

You will need compatible smart chargers for the batteries. Keep batteries attended during charging.

4.5.6. After use

After playing, remember to remove the batteries from battery holder to avoid over discharging.

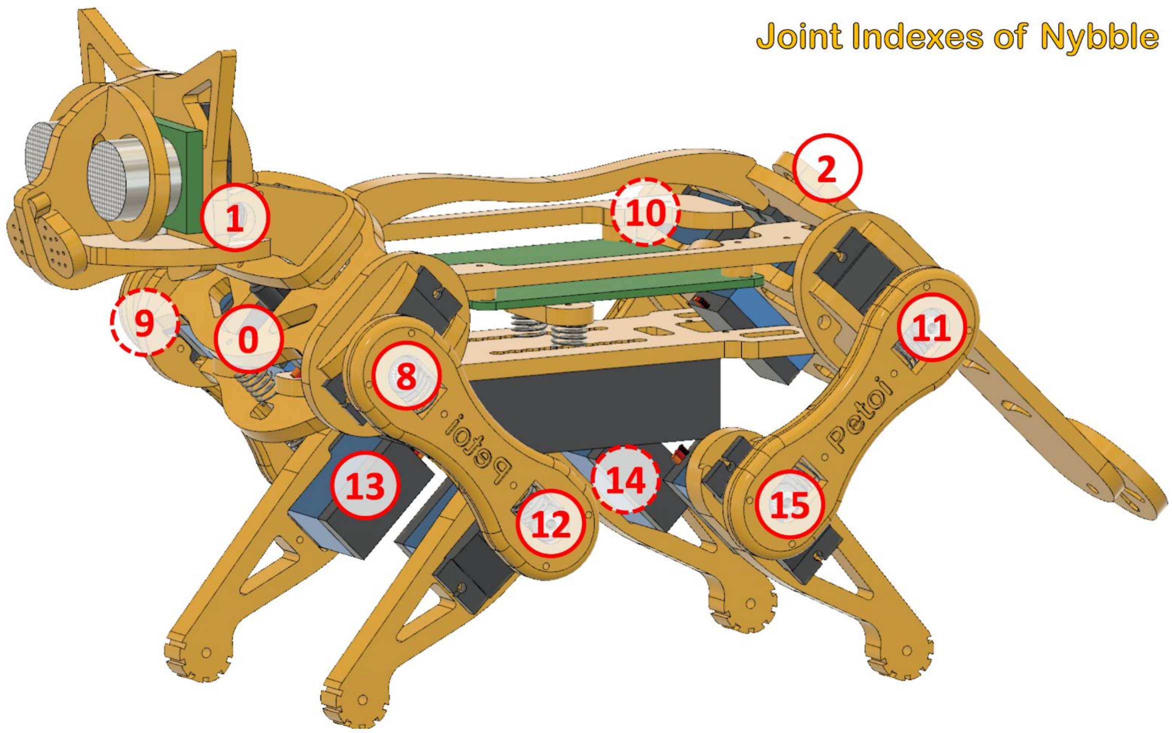
4.5.7. Signal Interference

It's ok to connect both FTDI and battery at the same time. You can type in serial commands while the battery is connected. I do notice that the USB serial port could be disabled randomly. I think that's due to the sudden current draw by servos. It will trigger the computer’s over current protection and disable the USB port. In that case, you can change the USB port you're connecting to, reset the USB bus, or restart the computer. So actually it’s better to power the board by battery before plug in the FTDI.

5. Connect servos

5.1. Joint map

Nybble's servos are connected to NyBoard's PWM pins symmetrically and resembles the nerves along the spinal cord. Though Nybble doesn't have shoulder roll DoF, those indexes(4~7) are reserved for the full OpenCat framework.



Use h for head, t for tail, r for shoulder roll joint, s for shoulder pitch joint, k for knee joint, F for front, H for hind, L for left, R for right, the full joints map of OpenCat is:

Joint Map of OpenCat

-- Top view on the back

left-hand ← → right-hand

Joint	Joint Index	PWM Pin		PWM Pin	Joint Index	Joint
hPan	0	7		0	1	hTilt
rFL	4	6		1	5	rFR
sFL	8	5		2	9	sFR
kFL	12	4		3	13	kFR
kHL	15	11		12	14	kHR
sHL	11	10		13	10	sHR
rHL	7	9		14	6	rHR
tPan	2	8		15	3	N/A

Abbreviation	Joint
h	head
t	tail
r	shoulder roll
s	shoulder pitch
k	knee

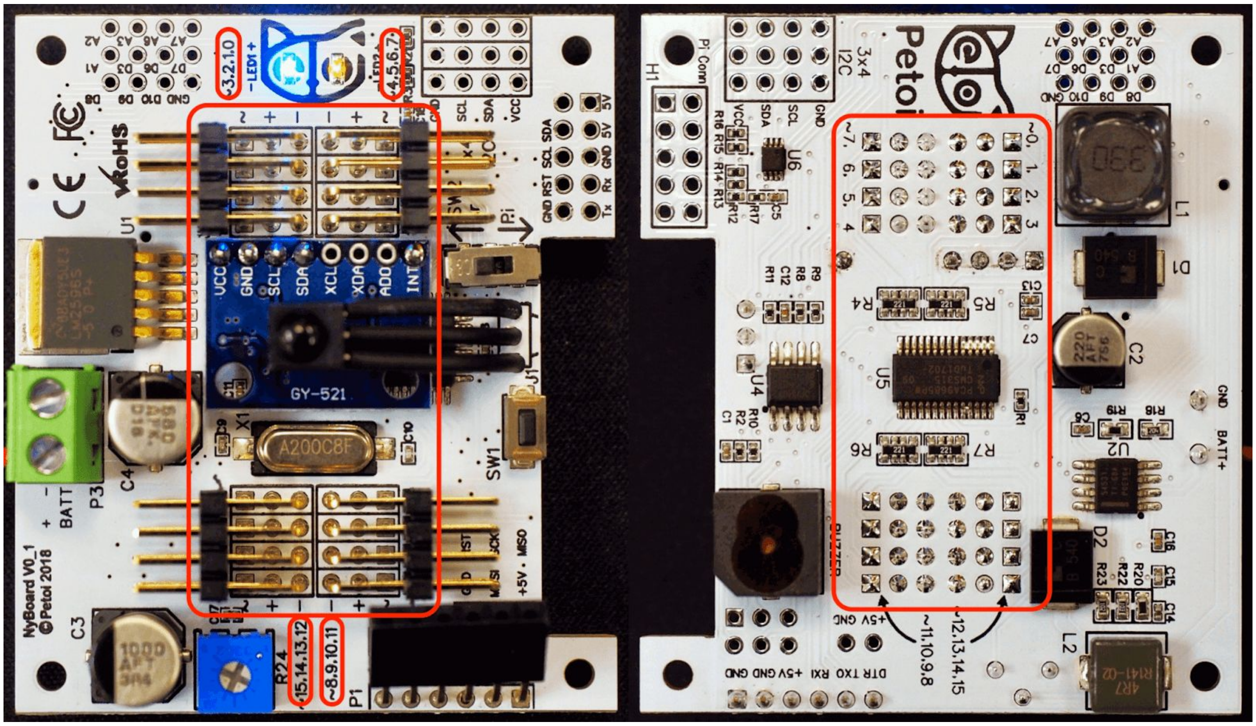
Abbreviation	Direction
F	Front
H	Hind
L	Left
R	Right

Encoding Array

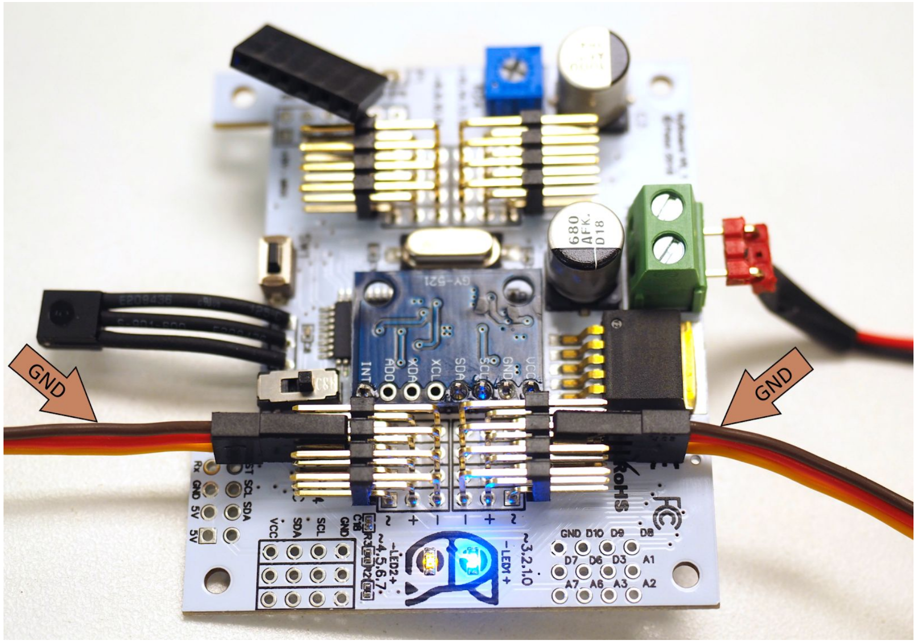
Joint Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Virtual
PWM Pin	7	0	8	15	6	1	14	9	5	2	13	10	4	3	12	11	Hardware

5.2. Plug in the servos

Observe the indexing pattern to connect servos with correct PWM pins. Be careful with the wires' direction. The brown wire of servo is GND, while the GND on NyBoard V0_1 are along the centerline. On NyBoard V0_2 they are opposite.



A quick check is that all the brown wires should be on top of the other two wires. On NyBoard V0_2 the yellow wires should be on top of the other two wires.



6. Calibration

Calibration is vital for Nybble to work properly.

In previous sections, we have prepared those body parts but haven't screw them onto servos. If we don't calibrate the servos before attaching them, they may rotate to any direction, get stuck, and cause damage to either the servos or body parts.

The calibration has four steps: 1.Write constants to the board; 2. Power on the circuit, let servos rotate freely to zero angle/calibration state; 3. Attach body parts to the servos; 4. Fine tune the offsets in software.

6.1. Write constants

6.1.1. There are three types of constants to be saved to NyBoard:

- Assembly related definitions, like joint mapping, rotation direction, sensor pins. They are pretty fixed and are mostly defined in **OpenCat.h**. They are even kept consistent with my future robots;
- Calibration related parameters, like MPU6050 offsets and joint corrections. They are measured in realtime and are saved in on-board EEPROM. They only need to be measured once;
- Skill related data, like postures, gaits, and pre-programmed behaviors. They are mostly defined in **Instinct.h**. You can add more customized skills too.

6.1.2. Upload and run **WriteInstinct.ino**.

The role for **WriteInstinct.ino** is to write constants to either onboard or I^2C EEPROM, and save calibration values. It will be overwritten by the main sketch **Nybble.ino** afterward.

After finish uploading **WriteInstinct.ino**, open the serial monitor. You will see several questions:

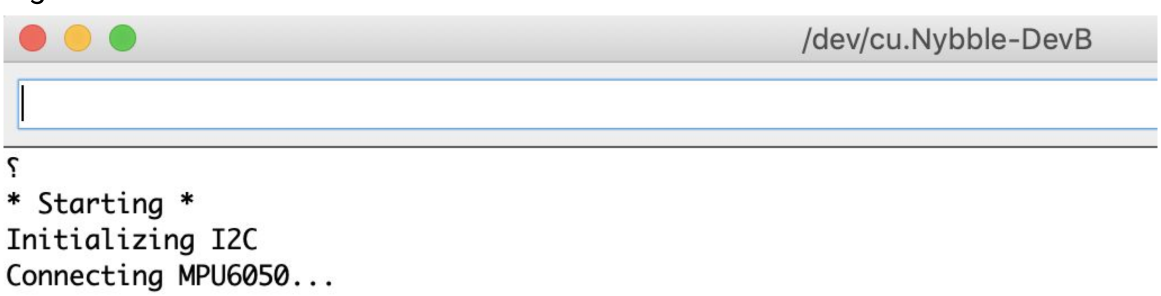
- Reset all joint calibration? (Y/n)

  If you have never calibrated the joints, or if you want to recalibrate the servos with fresh start, type ‘Y’ to the question. The ‘Y’ is CASE SENSITIVE!
- Do you need to update Instincts? (Y/n)”

  If you have modified the Instinct.h in any way, you should type ‘Y’. Though it’s not always necessary once you have a deeper understanding of the memory management.
- Calibrate MPU? (Y/n)

  If you have never calibrated the MPU6050, i.e. the gyro/accelerometer sensor, type ‘Y’.

Sometimes the program could hang at the connection stage. You can close the serial monitor and reopen it, or press the reset button on NyBoard, to restart the program.



6.2. Enter calibration mode

The calibration state is defined as the middle point of servo’s reachable range. Calibration for servos can be done in either **WriteInstinct.ino** or **Nybble.ino**. I recommend you do it with **WriteInstinct.ino** in case there’s something wrong with the constants.

You MUST plug in all the servos and battery for proper calibration. Then in the serial monitor, type ‘c’ to enter calibration mode. The servos should rotate, make noise, then stop. You will see the calibration table:

```
c

0,    1,    2,    3,    4,    5,    6,    7,    8,    9,    10,   11,   12,   13,   14,   15,
-1    -1    -1    -1    -1    -1    -1    -1    -1    -1    -1    -1    -1    -1    -1    -1
c0    0
```

The first row is the joint indexes, the second row is their calibration offsets:

Index	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Offset	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Initial values are “-1”, and should be changed by later calibration.

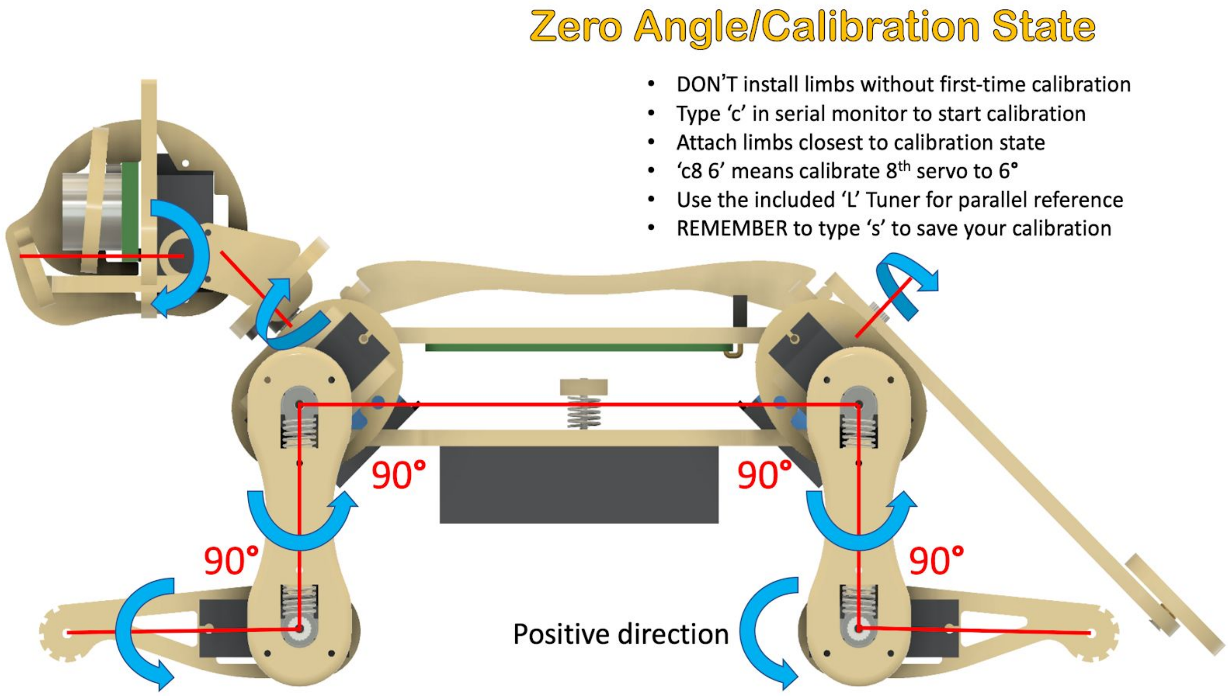
Note: The servos are using potentiometer in feedback loop for position control. When holding at static position, they tend to vibrate around target angle. This Parkinson’s will develop after a short period of use. It won’t affect much during continuous motion. Better servos without this troubles could cost 10 times more. So replacing failed unit is a more cost effective solution.

6.3. Attach head, tail, and legs.

6.3.1. Coordinate system

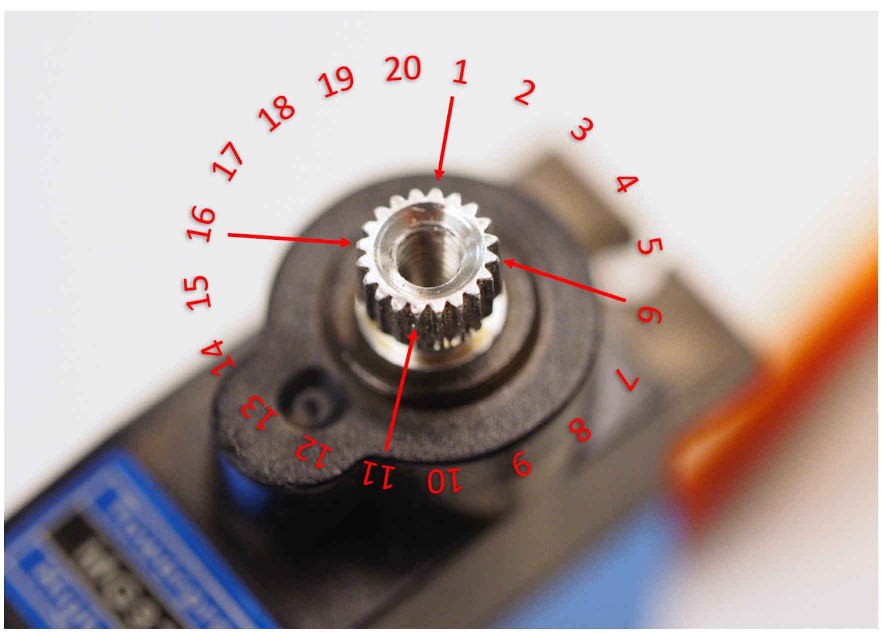
With all servos rotated to their zero angle, now attached the head, tail, and legs prepared in previous section to the body. They are generally perpendicular to their linked body frames. Avoid rotating the servo shaft during the operation.

Rotating the limbs counter-clockwise from their zero state will be positive (same as in polar coordinates). The only exception is the tilt angle for head. It’s more natural to say head up, while it’s the result from rotating clockwisely.



6.3.2. Understand the angle divisions

If we take a close look at the servo shaft, we can see it has a certain number of teeth. That's for attaching the servo arms, and avoid sliding in the rotational direction. In our servo sample, the gears are dividing 360 degrees to 20 sectors, each taking **18** degrees. That means we cannot always get exact perpendicular installation. But try to get them as close as possible to their zero states. Use screw A to fix the limbs onto servos.



6.4. Find and save calibration offsets

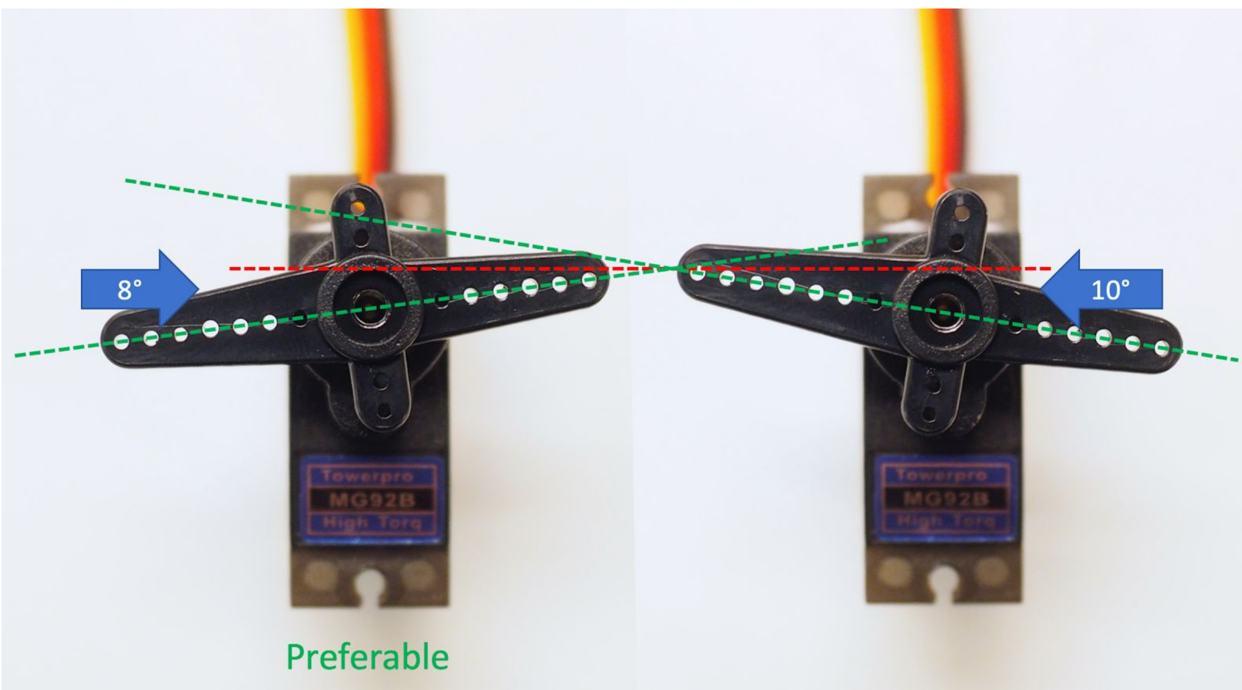
6.4.1. Fine tune the calibration on software side

The command for calibration (refer to the serial communication protocol for NyBoard) is formatted as cIndex Offset. Notice that there's a space between Index and Offset.

For example, c8 6 means giving the 8th servo an offset of 6 degrees. Find the best offset that can bring the limb to zero state.

Note that if you find the absolute value of offset is larger than 9, that means you are not attaching the limb closest to its zero state. That will result in decreased reachable range of the servo on either side. Take off the limb and rotate it by one tooth. It will result in an opposite but smaller offset.

For example, if you have to use -13 as the calibration value, take the limb off, rotate by one tooth then attach back. The new calibration value should be around 5, i.e., they sum up to 18. Avoid rotating the servo shaft during this adjustment.

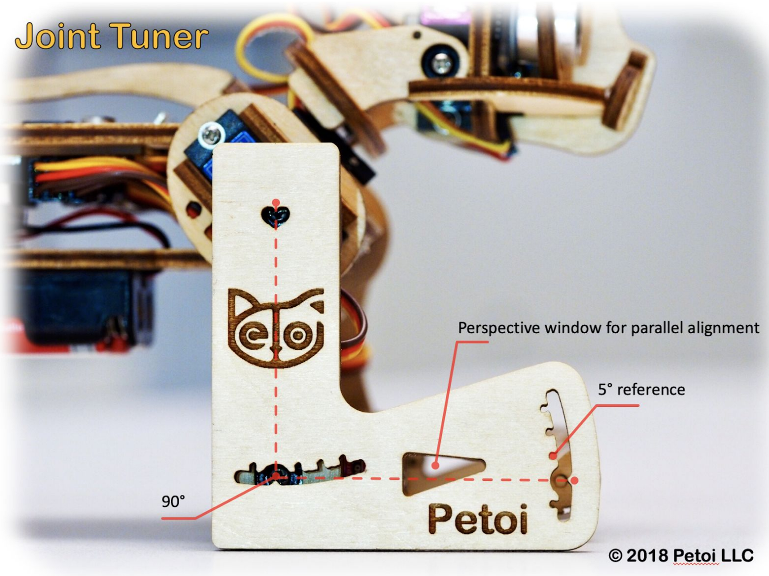


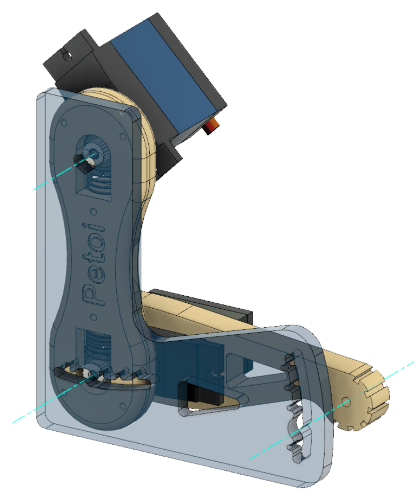
After calibration, remember to type 's' to save the offsets. Otherwise they will be forgotten when exiting the calibration state. You can even save every time after you're done with one servo.

6.4.2. ‘L’ shaped joint tuner

When watching at something, the observation will change from different perspectives. That’s why when measuring length, we always want to read directly above the ruler.

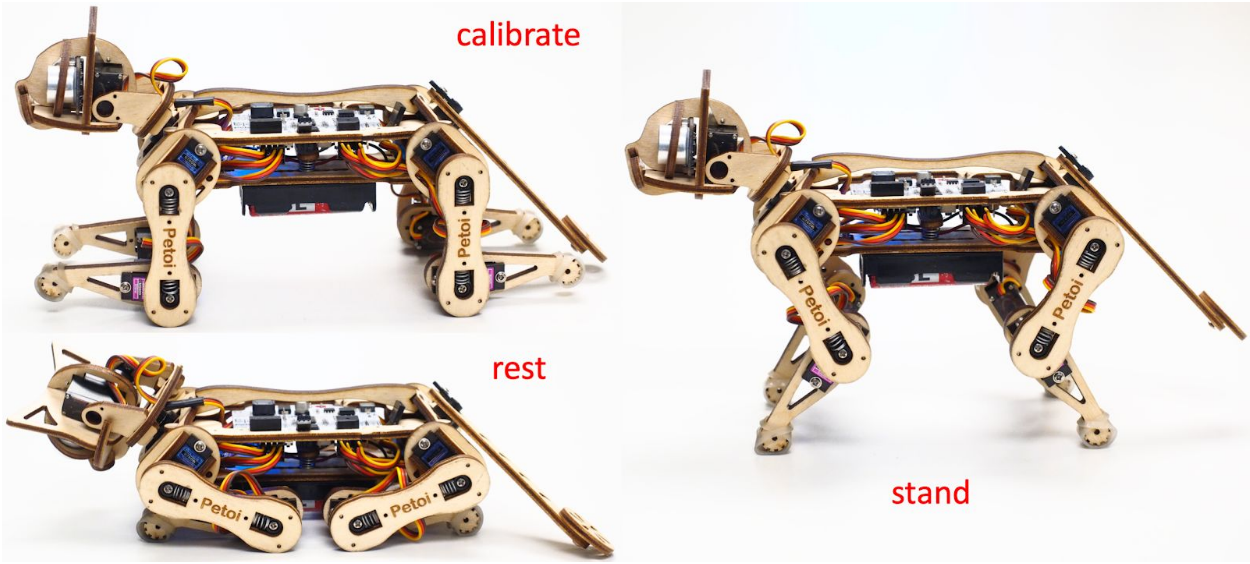
It’s especially important that you keep parallel perspective when calibrating Nybble. Use the 'L' shaped joint tuner as a parallel reference to avoid reading errors. Align the tips on the tuner with the center of the screws in shoulder and knee joints, and the little hole on the tip of the foot. Look along the co-axis of the centers. For each leg, calibrate shoulder servos (indexed 8~11) first, then the knee servos(indexed 12~15). When calibrating the knee, use the matching triangle windows on both the tuner and shank to ensure parallel alignment.





6.4.3. Validation

After calibration, type ‘d’ or ‘kbalance’ to validate the calibration. It will result in Nybble symmetrically moving its limbs between rest and stand state.



6.4.4. Center of mass

Try to understand how Nybble keeps balance even during walking. If you are adding new components to Nybble, try your best to distribute its weight symmetrically about the spine. You may also need to slide the battery holder back and forth to find the best spot for balancing.

7. Play with Nybble (default usage)

7.1. Control with Arduino IDE

The quotation mark just indicates they are character strings. Don't type quotation mark in the serial monitor.

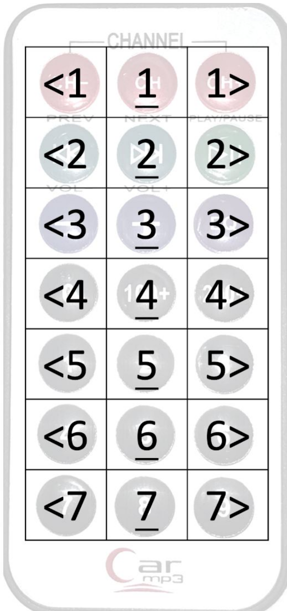
- "ksit"
- "m0 30"
- "m0 -30"
- "kbalance"
- "ktr"
- "ktrL"
- "d"

7.2. Control with Infrared remote

7.2.1. Key map

Only the position of the buttons matters, though those symbols can help you remember the functionalities. I'm going to define position related symbols to refer to those keys.

I'm using abbreviations for key definitions to reduce SRAM usage. The following map is just an illustration. Check function **String translateIR(){...}** in **Nybble.ino** for the actual key definitions. I always change the definitions for fun. They are also open to your customization.



sit	rest	hi
buttUp	balance	stretch
pee	trot	pushup
walkLeft	walkRight	walkLeft
crawLeft	crawl	crawRight
backLeft	back	backRight
turbo	bound	turtleroll

7.2.2. Check out the following featured motions

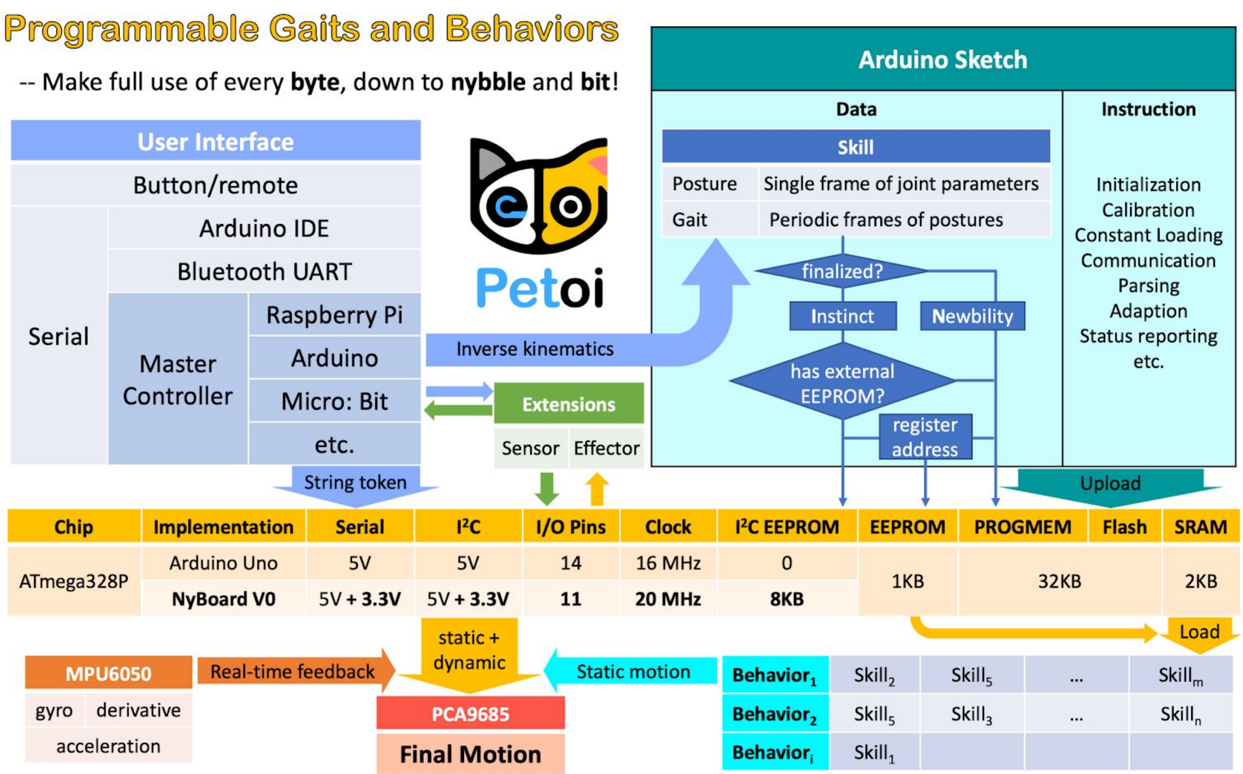
- Button 1 shuts down the servos and send Nybble to sleep. It's always safe to click it if Nybble is doing something **AWKWARD**. I'm serious. There's still some ghost in the system I don't fully understand.
- Button 2 is the neutral standing posture. You can push Nybble from side, or make it stand up will hind legs and tail. You can test its balancing ability on a fluctuating board. Actually balancing is activated in most postures and gaits.
- Lift Nybble at the middle of its spine so that all its legs can move freely in the air. Click all the buttons on the IR remote to see what they do. Then put Nybble on a wide flat table and try those buttons again. Different surface have different friction and will affect walking performance. Carpet will be too bushy for Nybble's short legs. It can only crawl (command **kcr**) over this kind of tough terrain.
- You can pull the battery pack down and slide along the longer direction of the belly. That will tune the center of mass, which is very important for walking performance. Otherwise it may keep falling down.
- When Nybble is walking, you can let it climb up/down a small slope (<10 degrees)
- Whatever Nybble is doing, you can lift it vertically, and it will stop moving, just like a cat scruffed on the neck.

- The servos are designed to be driven by internal gears. Avoid rotating the servos too fast from outside.

- Don't keep Nybble walking for too long. That will overheat the electronics and reduce the servos' life span. It's possible to [reconfigure NyBoard V0_1] to make Nybble run longer.
- Sometimes the program may halt due to voltage fluctuation. Check if the battery is running low (< 3.5V each or <7.0V in series). Press the reset button on NyBoard to restart the program.
- Be kind as if you were playing with a real kitten. (^=◕□◕=^)

8. Teach Nybble new skills (advanced)

8.1. Understand skills in **Instinct.h**.



One frame of joint angles defines a static posture, while a series of frames defines a periodic motion, usually a gait.

EEPROM has limited (1,000,000) write cycles. So I want to minimize write operations on it.

There are two kinds of skills: **Instincts** and **Newbility**. The addresses of both are written to the onboard EEPROM(1KB) as a lookup table, but the actual data is stored at different memory locations:

- I²C EEPROM (8KB) stores **Instincts**.

The Instincts are already fine-tuned/fixed skills. You can compare them to "muscle memory". Multiple Instincts are linearly written to the I²C EEPROM only once with WriteInstinct.ino. Their addresses are generated and saved to the lookup table in onboard EEPROM during the runtime of WriteInstinct.ino.

- PROGMEM (sharing the 32KB flash with the sketch) stores **Newbility**.

A Newbility is any new experimental skill that requires a lot of tests. It's not written to the I²C nor onboard EEPROM, but the flash memory in the format of PROGMEM. It has to be uploaded as one part of Arduino sketch. Its address is also assigned during the runtime of the code, though the value rarely changes if the total number of skills (including all Instincts and Newbilities) is unchanged.

8.2. Example **Instinct.h**

```
#define WalkingDOF 8
#define NUM_SKILLS 6
#define I2C_EEPROM

const char cr[] PROGMEM = {
26, 0, -5,
 35, 37,-46,-53,-23,-32, -3, 12,
 40, 28,-42,-59,-24,-28, -4, 12,
 ...
 33, 39,-47,-51,-22,-32, -3, 11,
};
const char stair[] PROGMEM = {
54, 0, 30,
 44, 90,-39,-38, 10,-32,-10, 32,
 45, 90,-32,-46, 16,-38,-16, 38,
 ...
 43, 90,-44,-32,  6,-26, -6, 26,
};
const char pu1[] PROGMEM = {
1, 0, 0,
  0,-30,  0,  0,  0,  0,  0,  0, 20, 20, 60, 60, 60, 60,-55,-55,};
const char pu2[] PROGMEM = {
1, 0, 0,
  0, 10,  0,  0,  0,  0,  0,  0, 60, 60, 40, 40,-45,-45,-55,-55,};
const char rest[] PROGMEM = {
```

```
1, 0, 0,
-30,-80,-45,  0, -3, -3,  3,  3, 60, 60,-60,-60,-45,-45, 45, 45,};
const char zero[] PROGMEM = {
1, 0, 0,
  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,};

#if !defined(MAIN_SKETCH) || !defined(I2C_EEPROM)
        const char* skillNameWithType[] =
                {"crI", "stairN", "pu1I", "pu2I", "restI", "zeroN",};
        const char* progmemPointer[] =
                {cr, stair, pu1, pu2, rest, zero, };
#else
        const char* progmemPointer[] = {stair, zero};
#endif
```

8.2.1. Defined constants

```
#define WalkingDOF 8
```

Means the number of DoF for walking is 8 on Nybble.

```
#define NUM_SKILLS 6
```

Means the total number of skills is 6. It should be the same as the number of items in list `const char* skillNameWithType[]`.

```
#define I2C_EEPROM
```

Means there's an I²C EEPROM on NyBoard to save Instincts. If you are building your own circuit board that doesn't have it, comment out this line. Then both kinds of skills will be saved to the flash as PROGMEM.

8.2.2. Data structure of skill array

Observe the following two skills:

```
const char rest[] PROGMEM = {
1, 0, 0,
-30,-80,-45,  0, -3, -3,  3,  3, 60, 60,-60,-60,-45,-45, 45, 45,};

const char cr[] PROGMEM = {
26, 0, -5,
 35, 37,-46,-53,-23,-32, -3, 12,
 40, 28,-42,-59,-24,-28, -4, 12,
...
```

```
33, 39,-47,-51,-22,-32, -3, 11,
};
```

They are formatted as:

<table>
<tr><td rowspan="2"></td><td rowspan="2">Total # of Frames</td><td colspan="2">Expected Body Orientation</td><td colspan="16">Indexed Joint Angles</td></tr>
<tr><td>Roll</td><td>Pitch</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td></tr>
<tr><td>Posture</td><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Gait</td><td rowspan="2">>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="8">#define WalkingDOF 8</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="12">#define WalkingDOF 12</td></tr>
</table>

8.2.3. Suffix for indicating Instinct and Newbility

You must upload **WriteConst.ino** to have the skills written to EEPROM for the first time. The following information will be used:

```
const char* skillNameWithType[] =
        {"crI", "stairN", "pu1I", "pu2I", "restI", "zeroN",};
const char* progmemPointer[] =
        {cr, stair, pu1, pu2, rest, zero, };
```

Notice the suffix **I** or **N** in the skill name strings. They tell the program where to store skill data and when to assign their addresses.

Later, if the uploaded sketch is main sketch **Nybble.ino**, and if you are using NyBoard that has an I^2C EEPROM, the program will only need the pointer to Newbility list `const char* progmemPointer[] = {stair, zero};` to extract the full knowledge of pre-defined skills.

8.3. Define new skills

There's already a skill named "zeroN" in Instinct.h. It's a posture at zero state waiting for your new definition.

You can first use command `mIndex Offset` to move individual joint to your target position, then replace the joint angles (bold fonts) in array at once:

```
const char zero[] PROGMEM = {
1, 0, 0,
 0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,  0,};
```

Because it's declared as a Newbility and doesn't require writing to I^2C EEPROM, you can simply upload **Nybble.ino** everytime you change the array (without uploading **WriteInstinct.ino**). You can trigger the new posture by pressing **7** on the IR remote, or type `kzero` in the serial monitor.

You can rename this skill, but remember to update the keymap of IR remote. You can also write short programs to perform multiple skills sequentially, like the push up behavior in Nybble.ino. By integrating sensory data, you can even define behaviors that’s triggered by certain interactions!

9. Understand parameters in **OpenCat.h** (research)

10. Mess up with the code and hardware.

To be written by **YOU**!

Share your knowledge and creativity with the community at https://www.petoi.com/forum.

Appendix I: Parts