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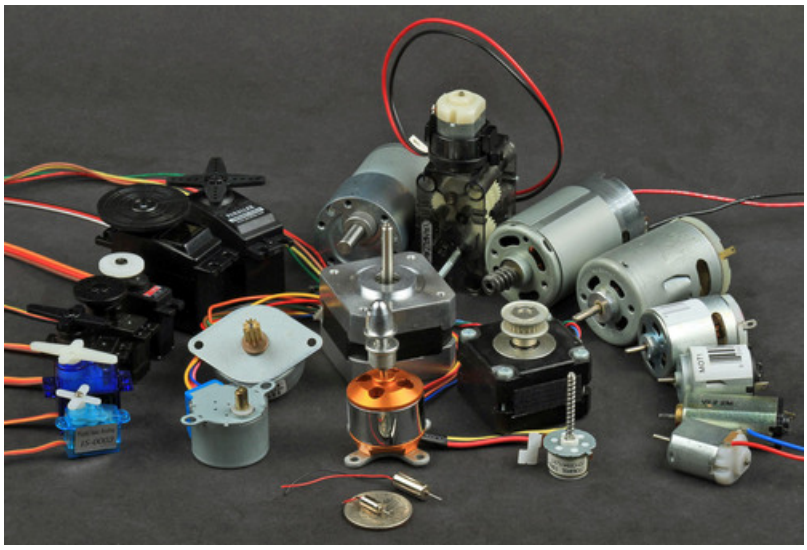
Adafruit Motor Selection Guide

Created by Bill Earl



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If you experiment with motors long enough, you will probably burn out one or two in the process. For smaller motors, this usually just means some very smelly smoke. But larger motors and their associated circuitry and power supplies can become a real hazard if you are not careful. 34
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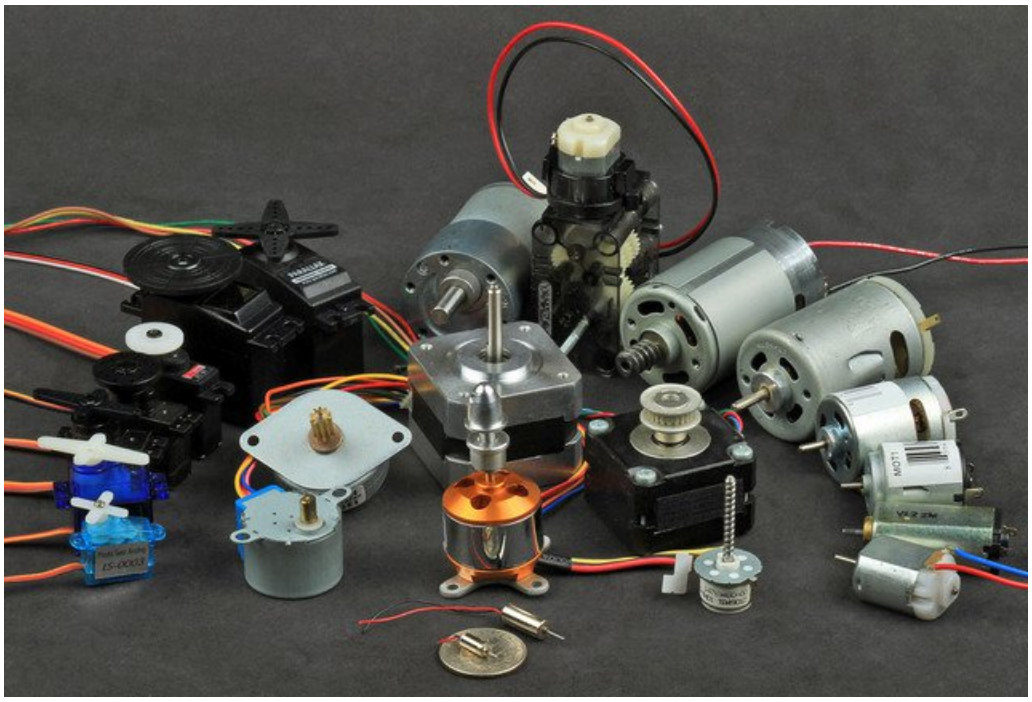
Types of Motors

There are many types of motors. Big ones, small ones, fast ones, strong ones. Whether you need brute strength, blinding speed or delicate precision movement, there is a motor designed for the task. The following pages will help you find to the right motor for your project.



Quick Selection Guide:

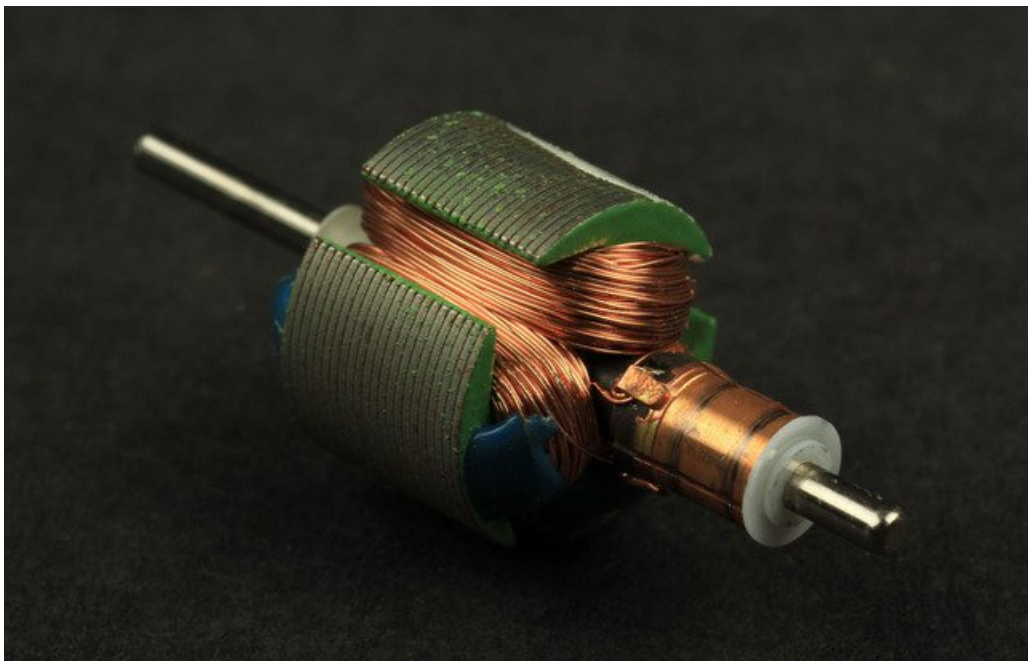
This quick selection guide highlights the strong points of the various types of motors. You can find more detail on each motor type in the pages that follow. This section deals with just the raw motors. No geartrains or controllers. We'll get into those in later sections of the guide.

Basic Raw Motor Types

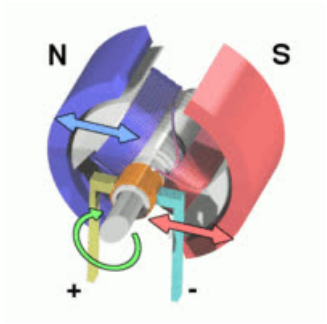
	Brushed	Brushless	Stepper
Speed Control			
Speed Control (w/encoder)			
Position Control			
Position Control (w/encoder)			
Efficiency			
Cost			
Cost (w/encoder)			

Brushed DC Motors

Simple and Economical Motive Power for your Project

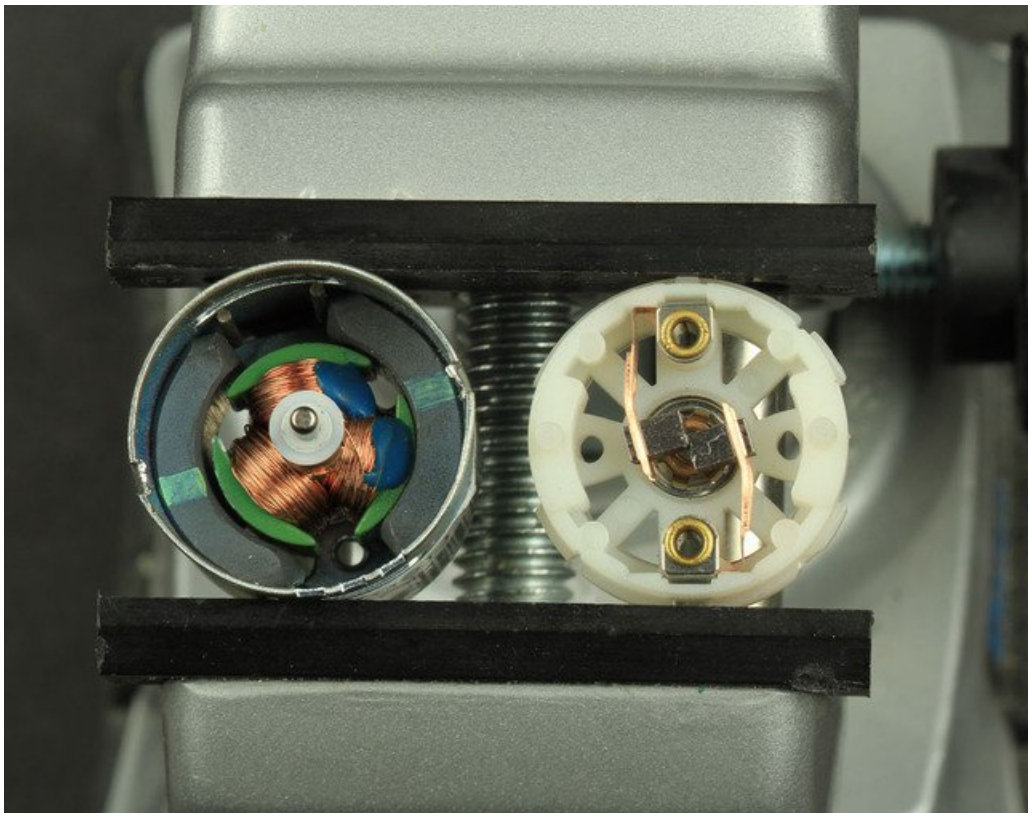


Brushed DC motors are probably the most common type of motor there is. These motors can be found in everything from hand-held fans and cordless drills, to cell phone buzzers and steel mills. These motors are used to power cars and trains, and not just the toy ones!

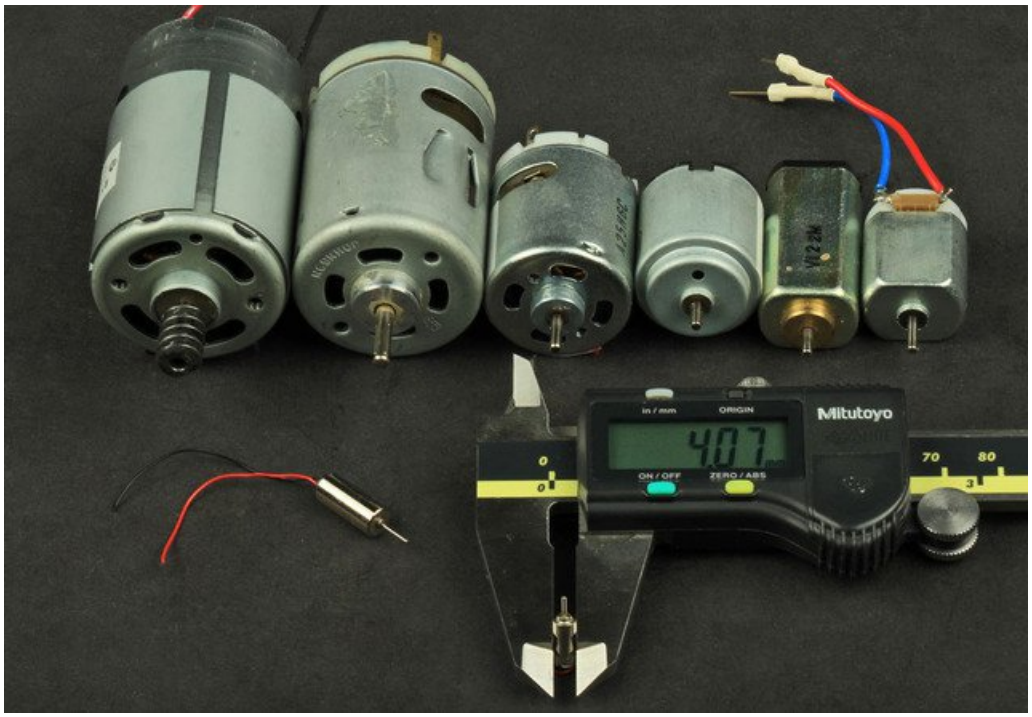


Animated GIF from Wikimedia Commons

These motors use brushes that rub on a segmented copper ring so that the current through the armature coils alternates as the motor spins. We opened one up in the photo below, so you can see the magnets and coils in the left and the spring-loaded brushes on the right.



DC motors are available in a wide variety of sizes, ranging from tiny motors for miniature devices up to and including large industrial motors capable of many horsepower.



Applications:

- **Toys**

- **Cell Phone Buzzers**
- **Cordless Tools**
- **RC Servos**
- **Gear Motors**

Advantages:

- **Inexpensive**
- **Lightweight**
- **Reasonably Efficient**
- **Good low-speed torque**

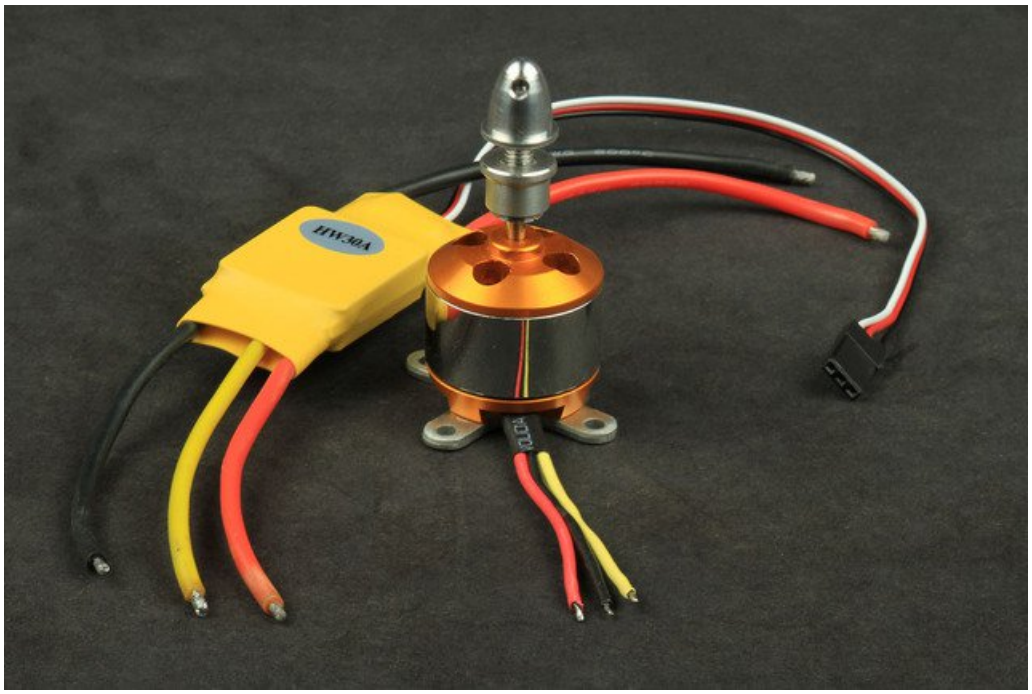
Limitations:

- **Noise** - In addition to the audible whine from the commutator brushes, these motors create a lot of electrical noise which can find its way back into other circuitry and cause problems.

Brushless DC Motors

Quiet Efficiency

Brushless DC (BLDC) Motors are mechanicaly simpler than brushed motors. They replace the brushes and associated sparks and noise with electronic commutation to silently switch the current flow to drive the motor. These quiet motors can be found in computer fans and disk drives, as well as in quadcopters, electric vehicles and high-precision servomechanisms.



Applications:

- **Multicopters**
- **Drones**
- **Radio Control Vehicles**
- **Disk Drives**
- **Fans**
- **Industrial Servos**
- **Hybrid Vehicles**
- **High-End Gearmotors**

Advantages:

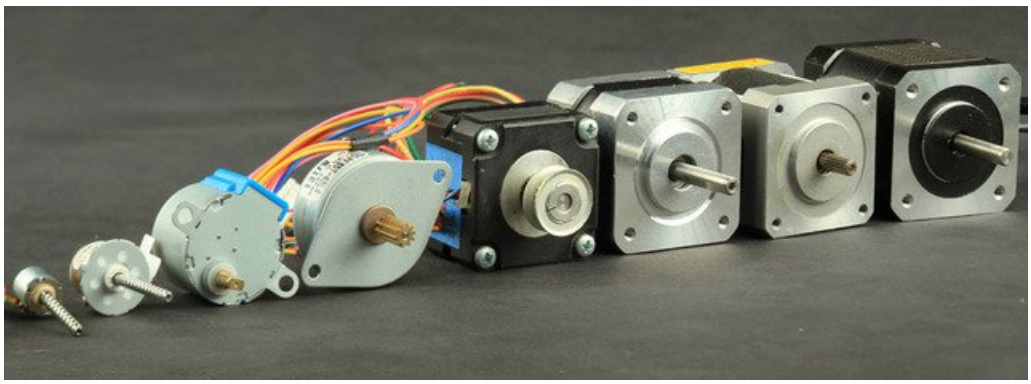
- **Quiet**
- **Efficient**

Limitations:

- **Controller** - Some types of brushless motors require a separate controller for operation.

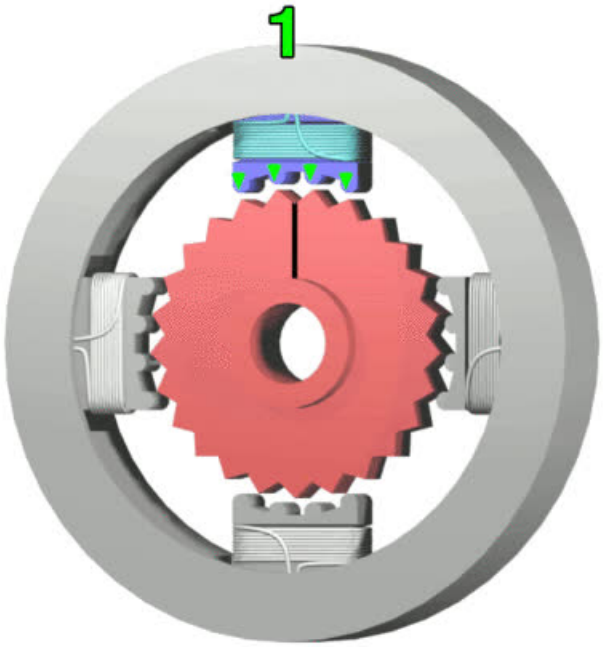
Stepper Motors

Precise and Repeatable Speed and Positioning



Stepper motors are DC motors that move in discrete steps. They are prized for their precise speed control and their repeatable positioning ability. Stepper motors can be found in all sorts of applications ranging from clocks to robots and CNC machines.

Stepper motor come in many different sizes, shapes and electromechanical specifications. For more details on selecting and using stepper motors, see the All About Stepper Motors Guide (https://adafru.it/dtD) in the Learning System.



Applications:

- **3D Printers**
- **CNC Machines**
- **Camera rigs**
- **Robotics**

- Printers
- Precision Gearmotors

Advantages:

- Precise repeatable positioning
- Precise speed control
- Excellent low-speed torque
- Excellent 'holding torque' to maintain position

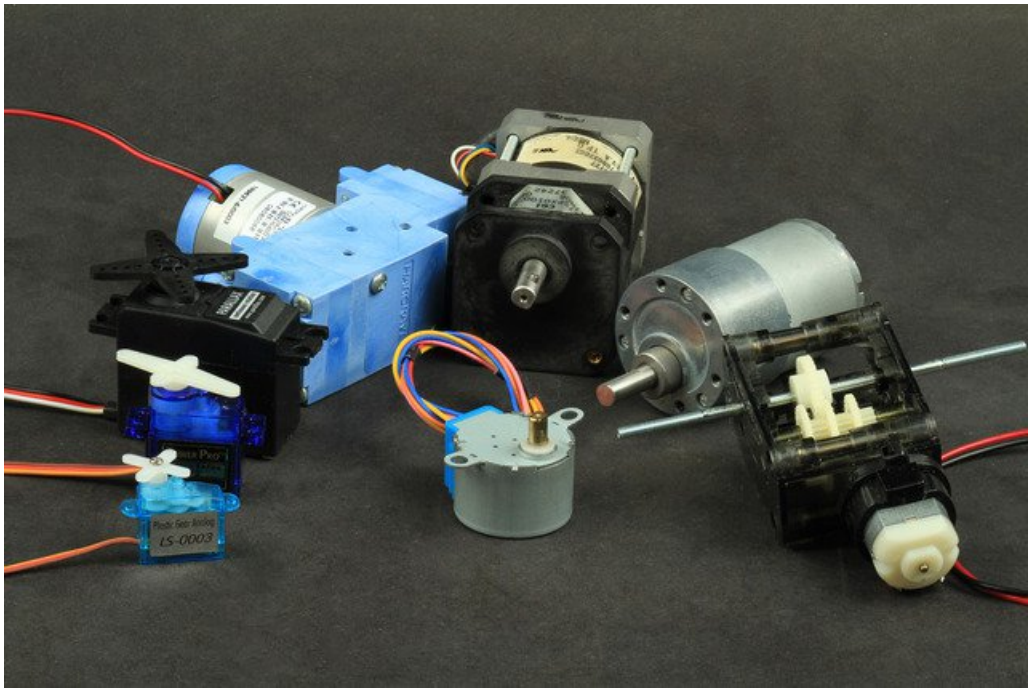
Limitations:

- Low efficiency
- May need encoder or limit switch to establish a reference position
- Subject to missed steps if overloaded

Motor Assemblies

Harness That Power!

Motors in their elemental form are not always easy to work with. How do you turn 5,000 RPM of raw power into smooth controlled motion? Designing and building your own gear-reduction and/or control system is a lot of work.



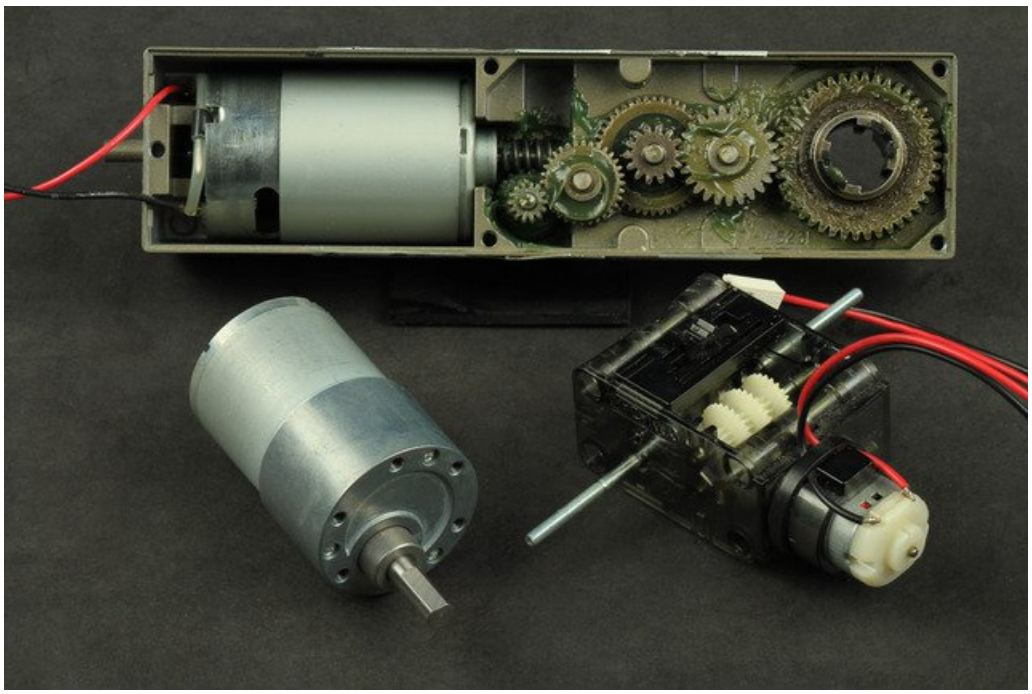
Motor assemblies help to harness the raw power of motors and package them into a form that can be easily integrated into your project. The Quick Selection Guide describes the basic features of some of the more commonly use motor assemblies. The following pages provide more detail on each type.

Motor Assembly Quick Selection Guide

	Brushed and Brushles Gearmotors	Stepper Gearmotors	RC Servos	Continuous Rotation Servos
Continuous Rotation				
Speed Control				
Speed Control (w/encoder)				
Position Control				
Position Control (w/encoder)				

Geared Motors

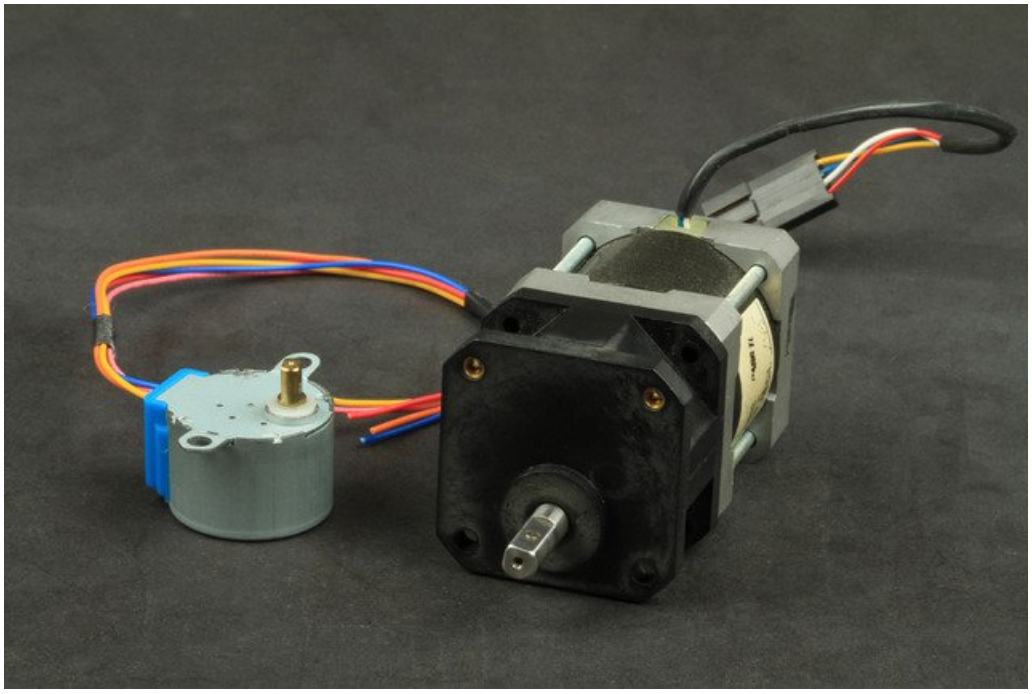
When the going gets tough, the tough get gearmotors!



Adding a gear-train to the output of any motor will reduce the speed, while simultaneously increasing torque. Gearing can be added to any type of motor. There is no need to waste time designing a geartrain and sourcing all the parts. Chances are, there is a gearmotor solution that you can drop right into your design.

Gear train construction ranges from simple plastic drive-trains for toys to beefy metal gear-trains for extra-high-torque applications.

Gear trains can be mated to brushed or brushless DC motors as well as steppers. Gear-train modules in a variety of gear ratios are available to fit standard NEMA sized steppers.



Applications:

- **Robot Drive Trains**
- **Radio Control Vehicles**
- **Cordless Tools**

Advantages:

- **Speed Reduction - Many DC motors simply run too fast to be useful in direct-drive applications.**
- **Increased Torque - A lot of work can be coaxed from a relatively small motor if fitted with a suitable gear train.**

Limitations:

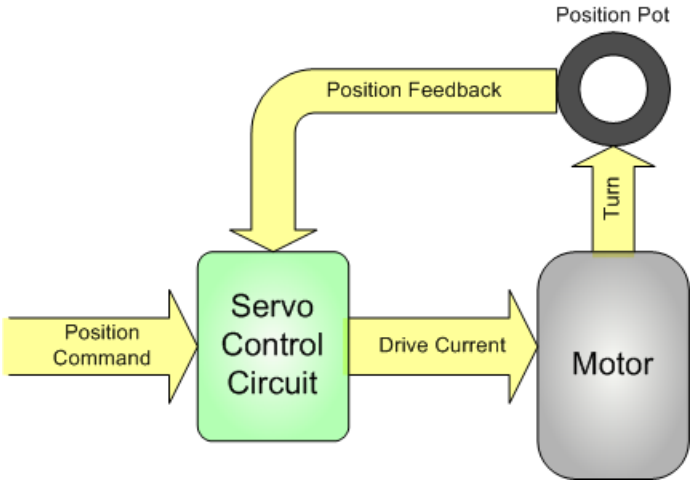
The potential downsides of adding a gear train to a motor include:

- **Friction** - This is especially a problem with low-cost plastic gear trains used with low-voltage motors. The extra resistance can make these gear-trains balky at low speeds.
- **Inertia** - This is more of a problem with metal gear-trains. All that additional rotating mass can inhibit rapid acceleration.
- **Backlash** - Any sloppiness in the gear-train tolerances create slack that must be taken up whenever the direction reverses. This can be a problem in precision motion control applications.

High-end precision gear-trains can be optimized to minimize any or all of these disadvantages. But be prepared to pay a premium price for them!

Servo Motors

When a little Negative Feedback is a Good Thing



The technical definition of a "Servo Motor" is a motor which employs negative feedback to control motor speed and/or position. Servo feedback senses the difference between the actual and desired speed or position so that the controller can adjust the output to correct the 'error'. Servo control systems are capable of very precise motion control. They are used in everything from high-speed CNC machines to positioning motors for telescope mirrors.

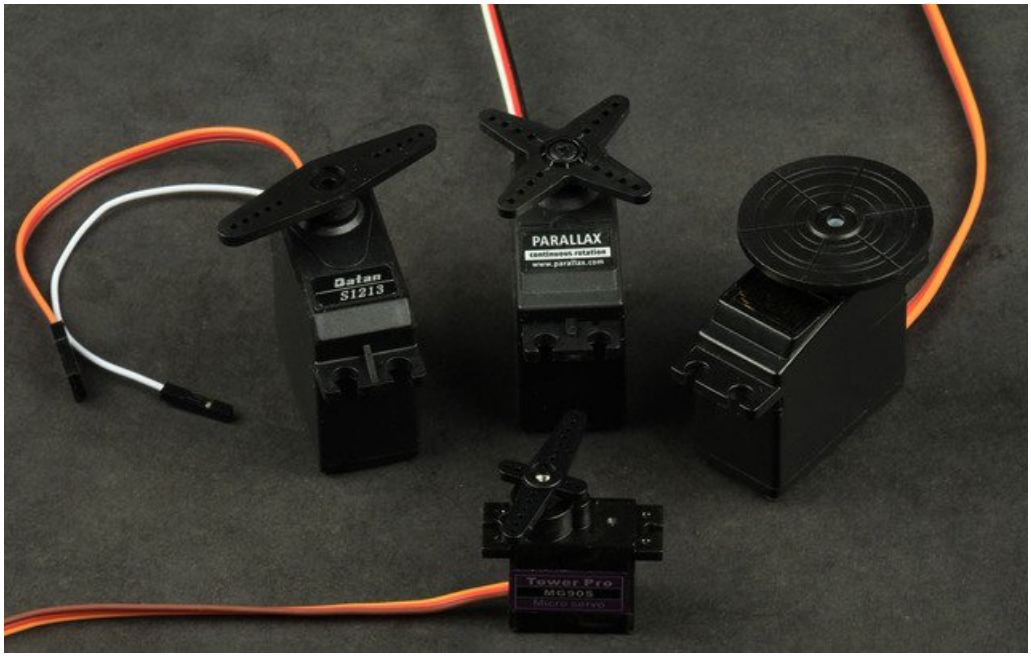
RC Servos:

The most common and economical type of servo motor in the hobbyist world is the RC Servo. These were originally designed for hobbyist Radio Control systems. But these days they are widely used for all sorts of small-scale projects where moderately precise positioning is required.

Most RC servos provide position control over an approximately 180 degree range. They do not provide speed control or continuous rotation. Inside, an RC servo typically consists of a brushed DC motor with a gear train and a built-in H-Bridge motor driver. A potentiometer attached to the shaft provides position feedback to the control circuit.

RC Servos are available in a wide variety of sizes, torque and speed ratings. Case dimensions and control interfaces are mostly standardized. RC servo case sizes are generally categorized as 1/4 scale, Standard, Mini and Micro.

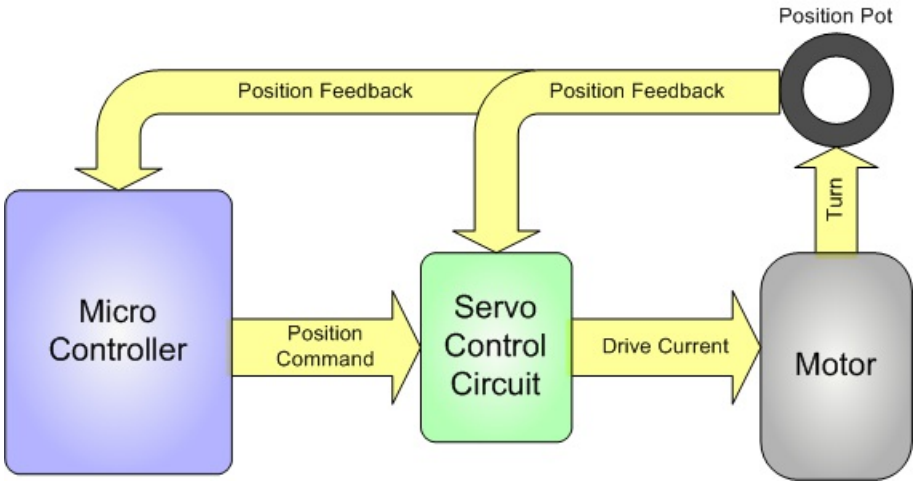
These motors are simple and economical to drive, either with dedicated servo controllers or with a GPIO pin from a microcontroller.



Analog Feedback Servos

One problem with RC servos is that there is only feedback to the internal controller. There is no feedback to your program, so you can't be sure that it is performing as expected. Analog feedback servos solve this problem with an extra feedback wire that you can connect to an analog input pin.

For more details on these specialized servos and how they work, see Analog Feedback Servos Guide (https://adafru.it/dtE) in the learning system!



The following summary applies to RC Servo Motors suitable for hobbyist use. Industrial servo motors are far more capable - but at a much higher cost!

Applications of RC Servo Motors:

- **Robotics**
- **Animatronics**
- **Radio Control Cars/Boats/Planes**

Advantages:

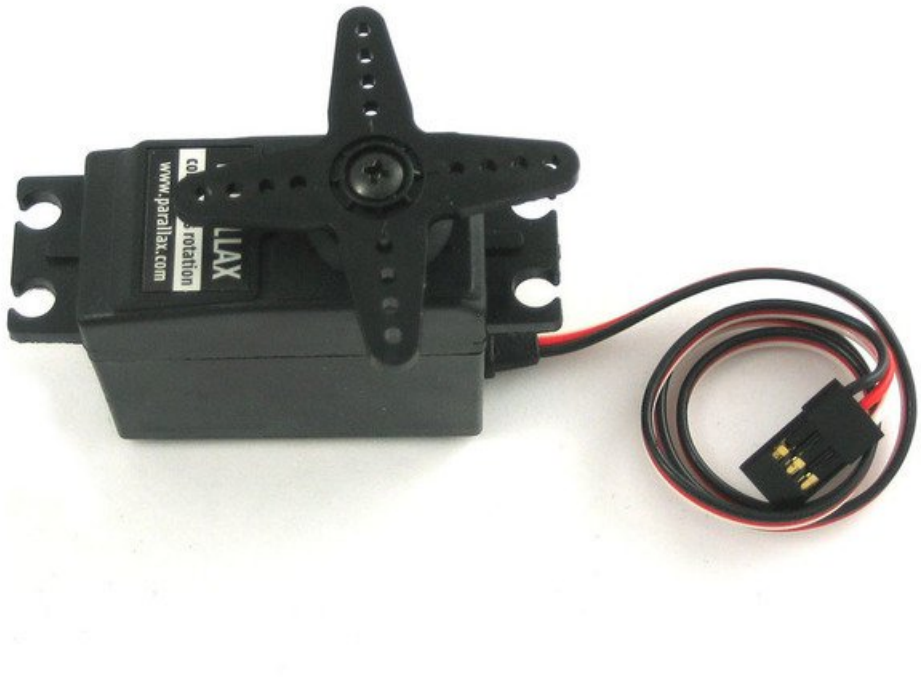
- **Low cost** - (RC Servos) Smaller sized servos can be purchased for just a few dollars.
- **Variety** - There is a wide range of sizes and torque ratings
- **Simple to control** - using logic level pulses from a microcontroller or a dedicated servo controller

Limitations:

- **Limited range of motion** - Most RC servos are limited to 180 degrees of motion.
- **Moderate precision** - Positioning accuracy and repeatability of +/- 1 degree is typical.
- **Jitter** - The feedback mechanism in the servo will actively try to correct any drift from the target position. This constant adjustment can create annoying twitches while trying to hold a steady position. If this is a problem for your application, consider a stepper motor instead.

Continuous Rotation Servos

When is a Servo not a Servo?



Continuous Rotation 'Servo' is somewhat of a misnomer. By definition these motors are not servos anymore because the feedback has been disabled.

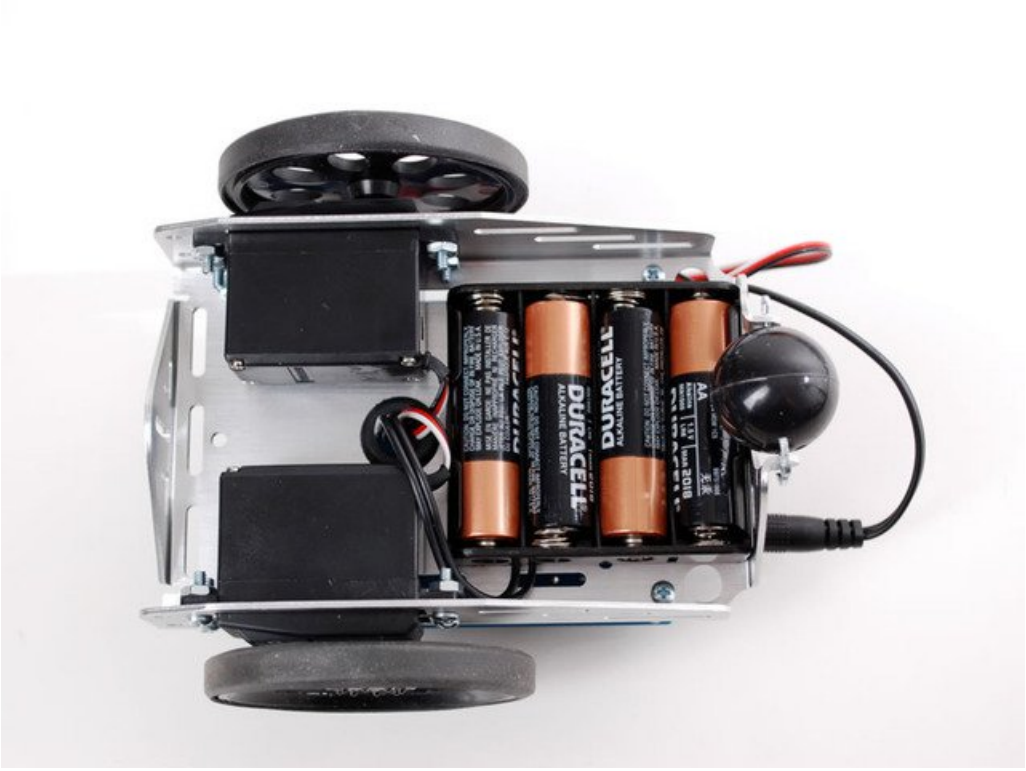
The first continuous rotation servos were simply hacked RC servos. Enterprising hobbyists removed the physical hard-stops and hard-wired the controller feedback to think it was always at the middle position. Since the controllers are 'proportional', the motor speed and direction is proportional to the difference between the command position and the measured position. This simple hack results in a **miniature self-contained reversible, speed controlled gear-motor!**

This modification became so popular, that manufacturers recognized the demand and started offering them too. Since they are based on the ubiquitous RC Servo motor case, the name "Continuous Rotation Servo" stuck.

We have a tutorial on how to 'DIY' a continuous rotation servo here (https://adafru.it/dtF)

Continuous rotation servos are handy wherever you need a compact DC gearmotor with a built-in H-Bridge driver. Like their RC (true) Servo brethren, the continuous rotation servos are simple to control. Since they have a built-in H-bridge controller, you just need to supply them with power and a pulsed signal. The pulses are easily generated from most any microcontroller GPIO pin.

Continuous rotation servos can be found in countless small robot chassis, such as the BoeBot.



Applications:

- **Robot Drive Trains**

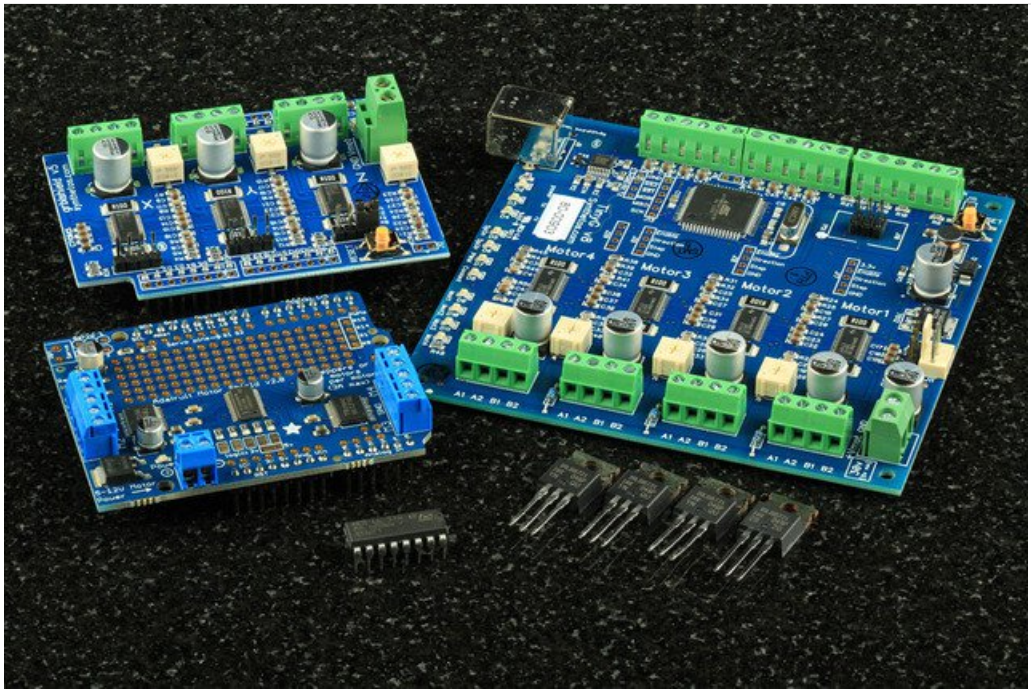
Advantages:

- **Inexpensive**
- **Compact**
- **Simple to control**

Limitations:

- **Bearings** - The shaft bearings on most CR servos are not designed for heavy loads. So these are best suited to smaller robot platforms.
- **Neutral Point** - Due to variations in the analog circuitry, it can be tricky to find the precise 'neutral' point in the control signal where the motor stops moving. Usually there's a little trim potentiometer you can hand-adjust

Motor Controllers



Anyone that has worked with motors long enough has smelled the acrid smoke of burning electronics. Finding an appropriate match between motor and controller can help avoid a date with the Blue Smoke Monster.

The following pages will help you select a controller that can safely drive your motor.

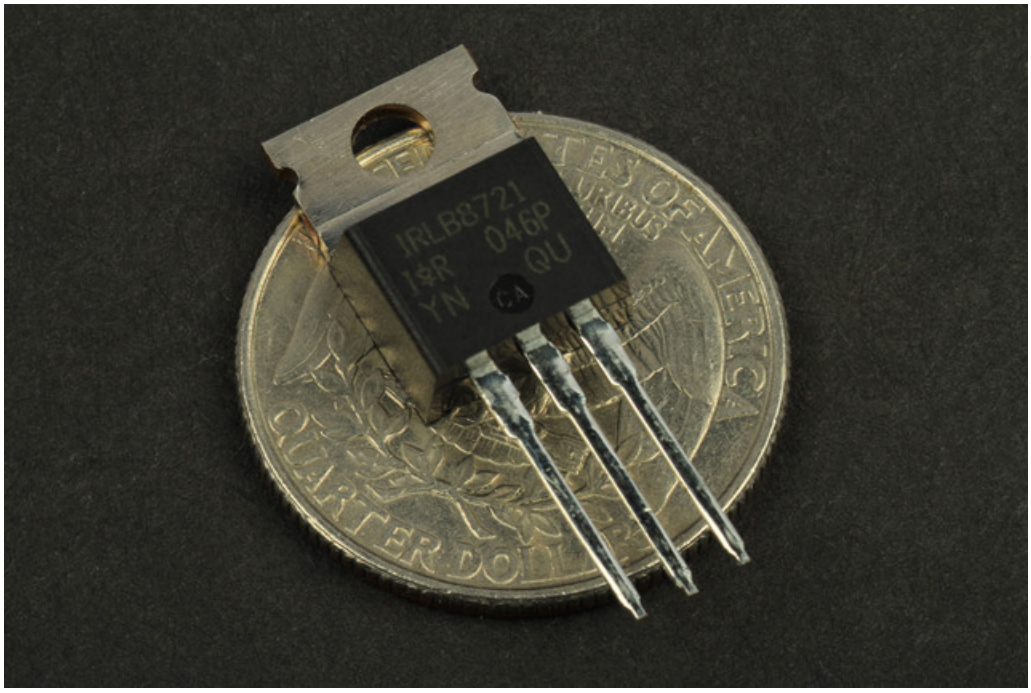
Brushed DC Motor Control

Brushed DC motors are simple to drive. Just give them a voltage and they go. Lower the voltage and they slow down. Reverse the voltage and they go backwards.

Simple Speed Control

If all you need is speed control, you can drive a motor with a PWM pin and a simple transistor circuit. The PWM pin controls the transistor which switches the current to the motor. The higher the PWM duty cycle, the faster the motor will go.

Learn how to build one in Arduino Lesson 13 (https://adafru.it/dtG) from the Learning System:

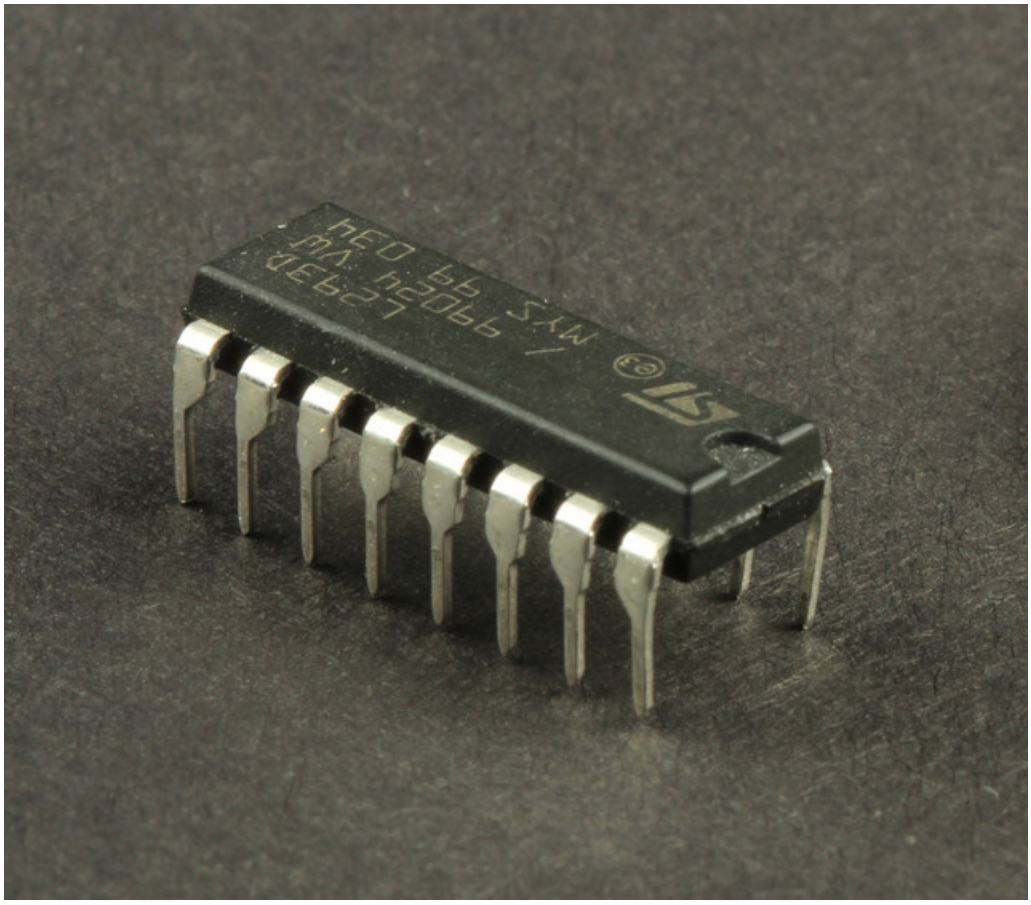


Basic Speed and Direction Control

Need to reverse direction too? That requires some more circuitry. The H-Bridge is a 4-transistor circuit that allows you to reverse the current flow to the motor. With an H-Bridge and a PWM pin, you can control both the speed and direction of the motor.

You can learn how to build an H-Bridge circuit using an L293D chip in these Learning System Guides:

Arduino Lesson 15 - DC Motor Reversing (https://adafru.it/dtH).
Raspberry Pi Lesson 9 - Controlling a DC Motor (https://adafru.it/dtI).

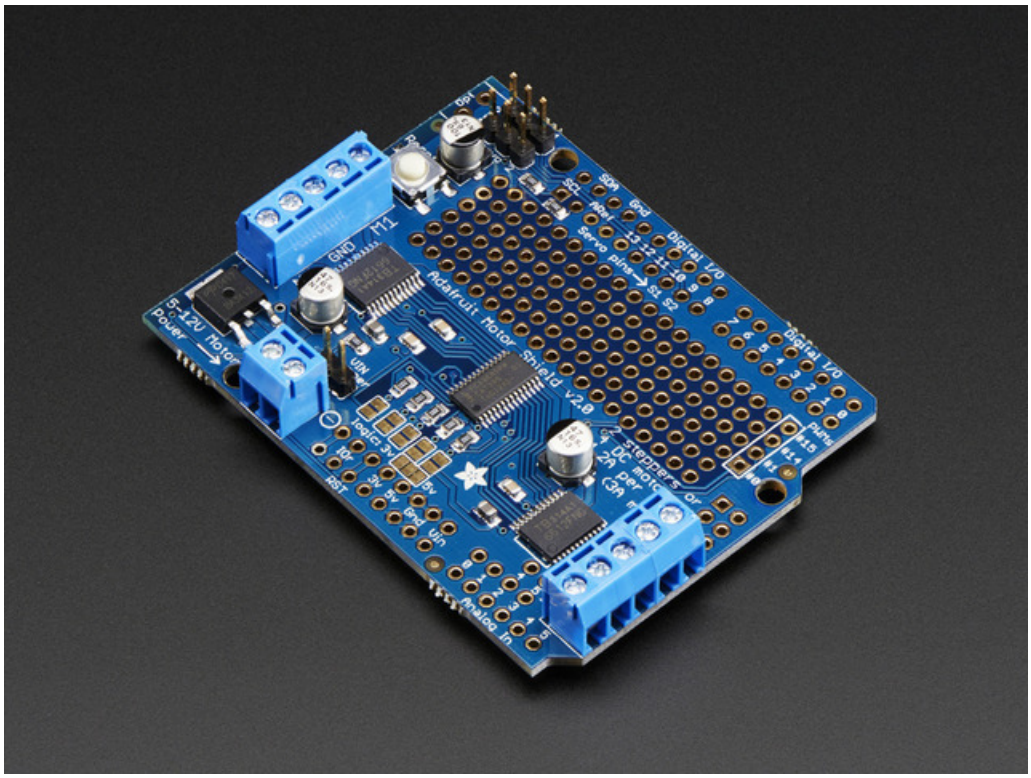


Motor Control Boards

The **Adafruit Motor Shield V2** is an off-the-shelf solution capable of powering brushed DC motors up to 1.2A continuous (3A peak) at up to 12v.

Learn how to use this shield for DC motors in the Adafruit Motor Shield V2 Guide (https://adafru.it/doc) in the Learning System Guide

The nice thing about the shield is it handles all the PWM speed control on its own, and uses only the two shared I2C pins to control motors. It's also stackable so you can add more shields as desired to control more motors without taking up any more pins.


Adafruit Motor Shield v2.0
5-12V Motor Power
Digital I/O
Servo pins
Analog In

Brushless DC Motor Control

Brushless DC motor control is not quite as simple as the regular brushed type. Brushless motors require a controller that can sense the proper time to reverse the voltage to the coils.

Sensor or Sensorless?

Some motors have built-in hall-effect sensors that can detect the orientation of the rotor. Controllers for this type of motor require sensor inputs to read these hall sensors.

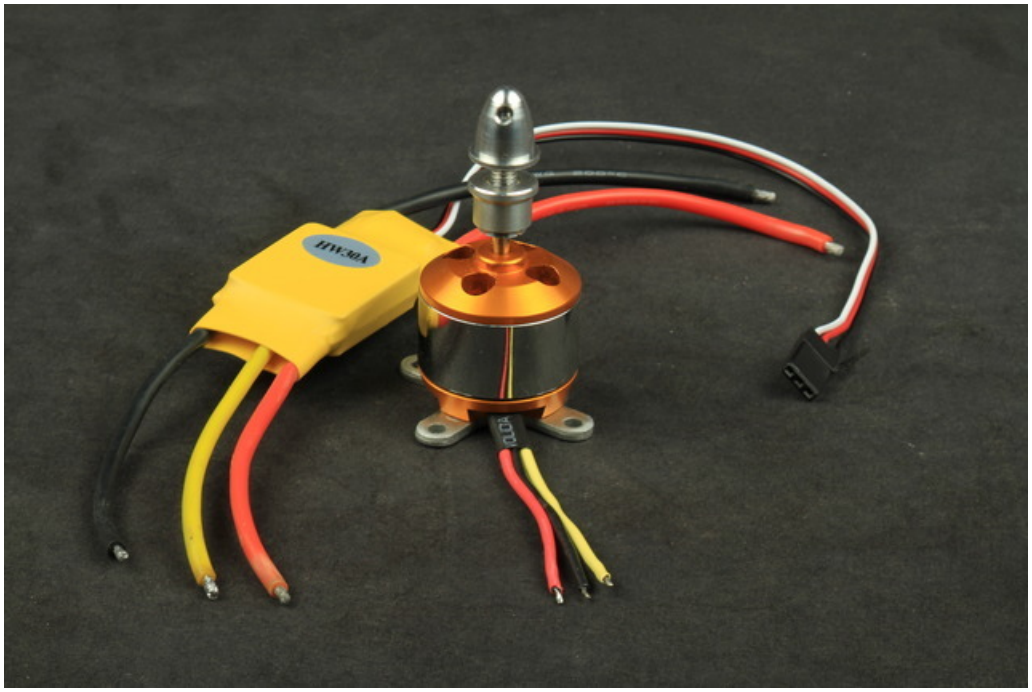
Other 'sensorless' motor controllers sense the back EMF in the motor coils themselves to detect the rotor position. Most ESC (Electronic Speed Controls) for brushless RC motors use this technique.

Integral or Separate?

Many BLDC motors have integral controllers. Computer fans are one example. These may or may not have PWM inputs or tachometer outputs. If speed control is one of your goals, be sure that you understand the capabilites of the controller.

Brushless motors designed for autonomous and remote control aircraft and vehicles typically require a separate controller. These are typically of the sensorless type and use standard servo type pulsed signals for speed control.

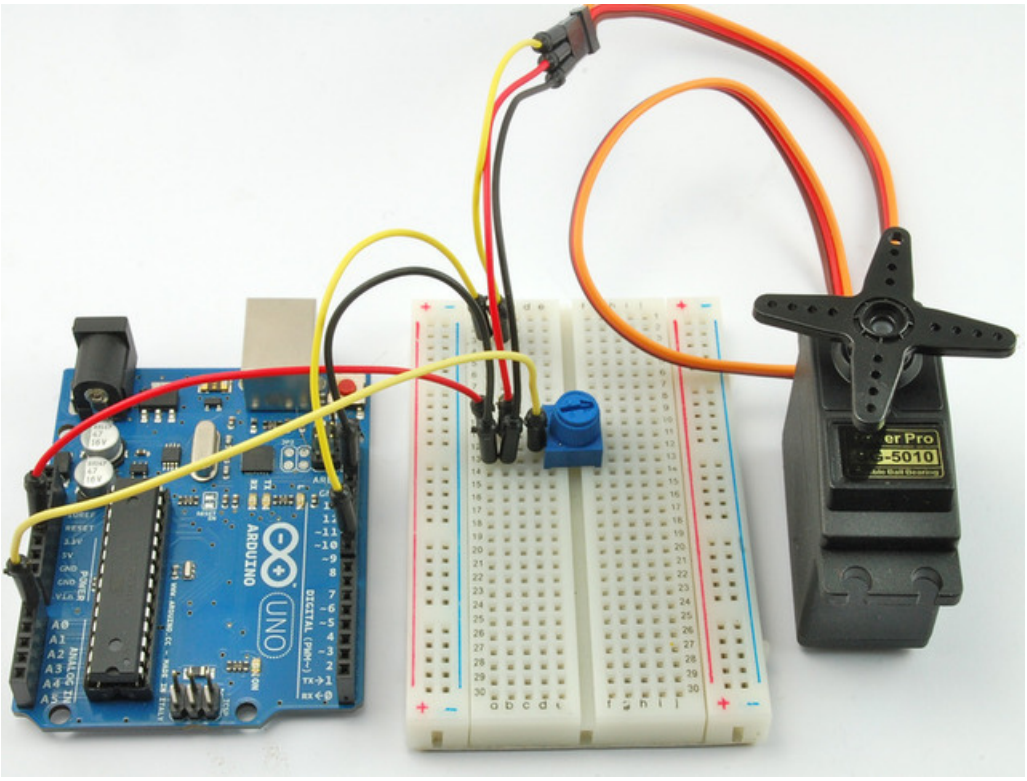
ESCs for brushless motors are rated by amps. Select an ESC rated for at least as many amps as your motor. If you will be driving the motor hard, a 10-20% safety factor in the ESC rating is a good idea.



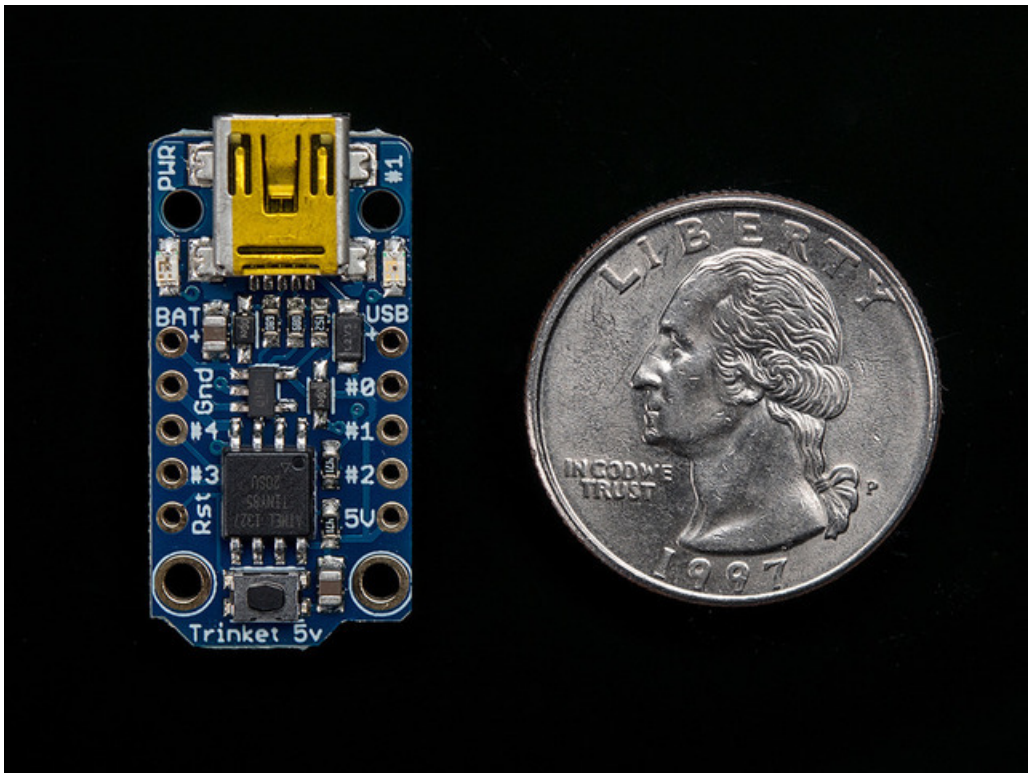
RC Servo Control

RC Servo control requires no special high-current capacity. These servos are controlled with logic-level pulses, so all you need is a GPIO pin and the ability to produce consistently timed pulses

This is pretty simple to do using the Arduino Servo Library. Learn how in Arduino Lesson 14 (https://adafru.it/dtJ) in the Learning System.

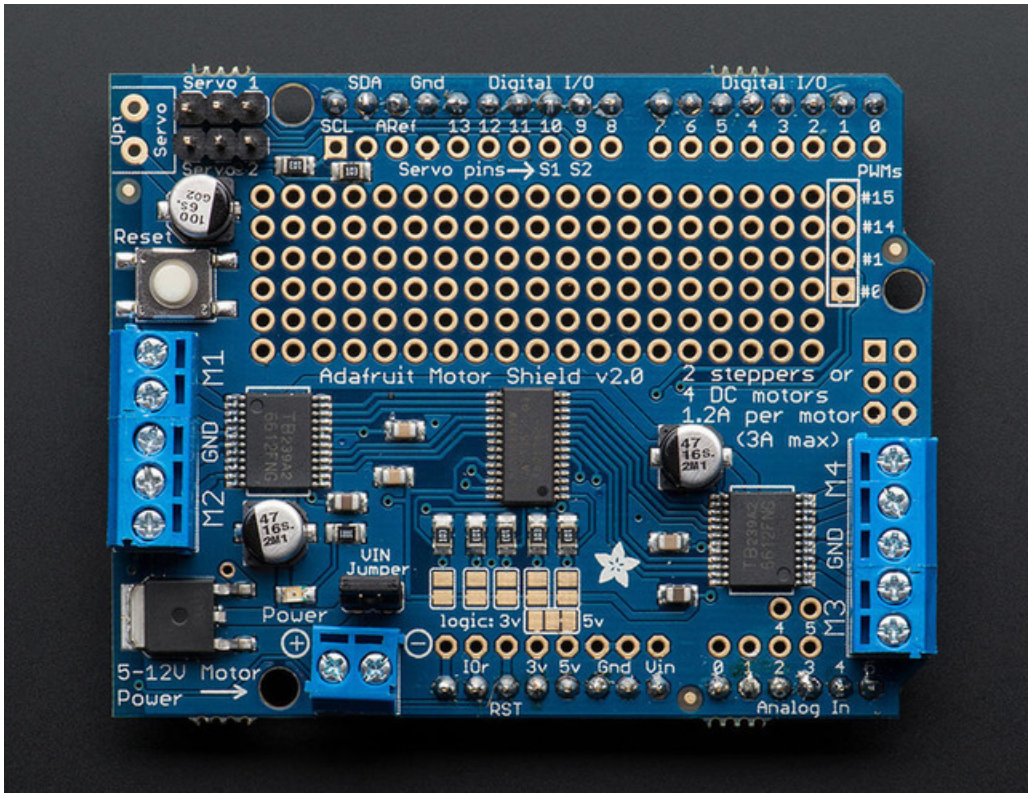


Even tiny processors are capable of servo control! Check out **Trinket and Gemma** Servo Guide (https://adafru.it/dtK) in the Learning System too.

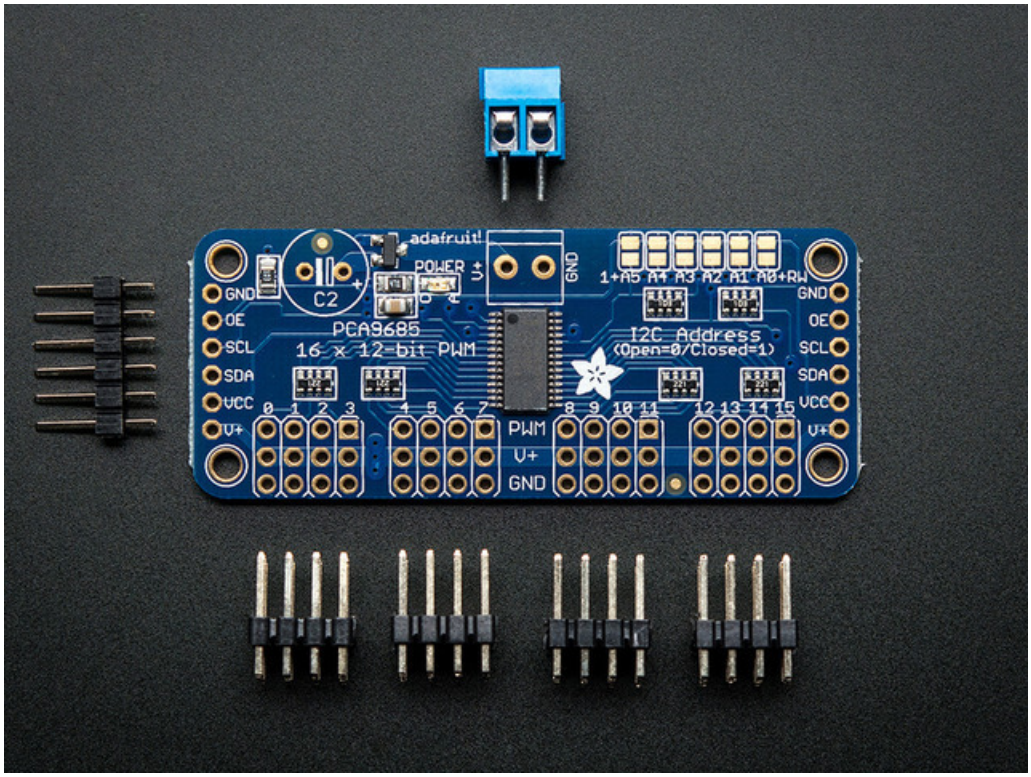


The versatile **Adafruit Motor Shield V2** is another option for servo control. It too uses the Arduino Servo Library, but provides 2 convenient pin headers so you can just plug right in.

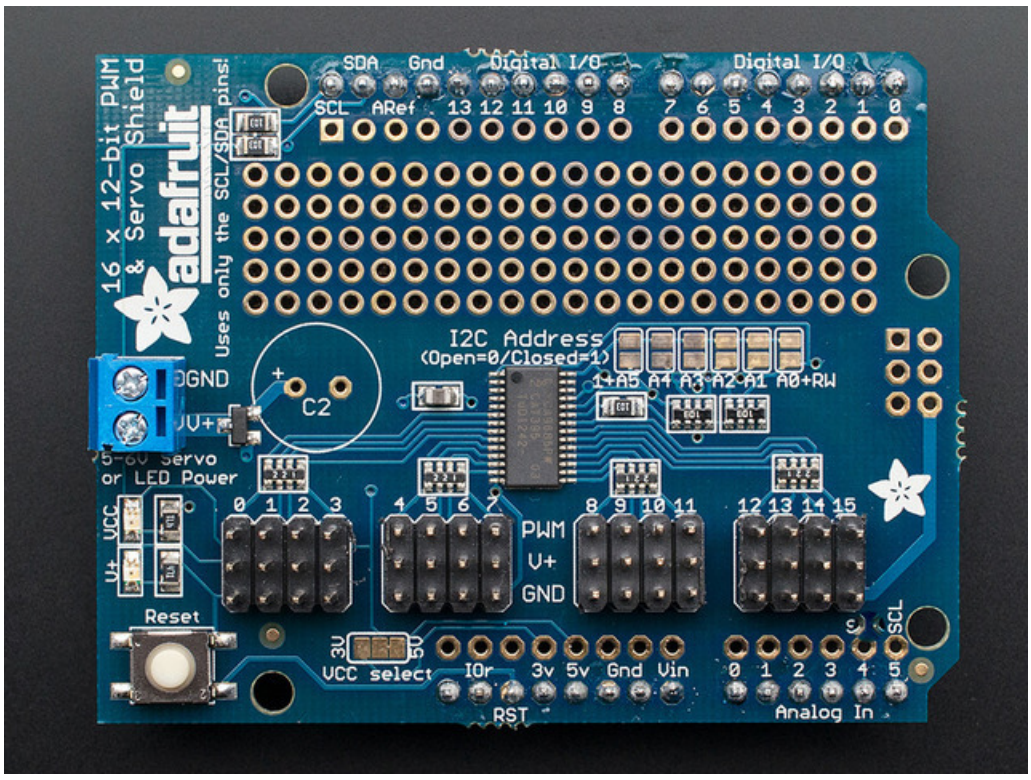
The Motor Shield Guide has a page devoted to Servo Control here: (https://adafru.it/dtL)



If you need to control more servos and/or free up some Arduino resources, you can use a dedicated servo controller, such as the Adafruit 16 channel/12 bit PWM Servo Breakout (https://adafru.it/dtM). These are addressable, so you can control hundreds of servos from a single processor.



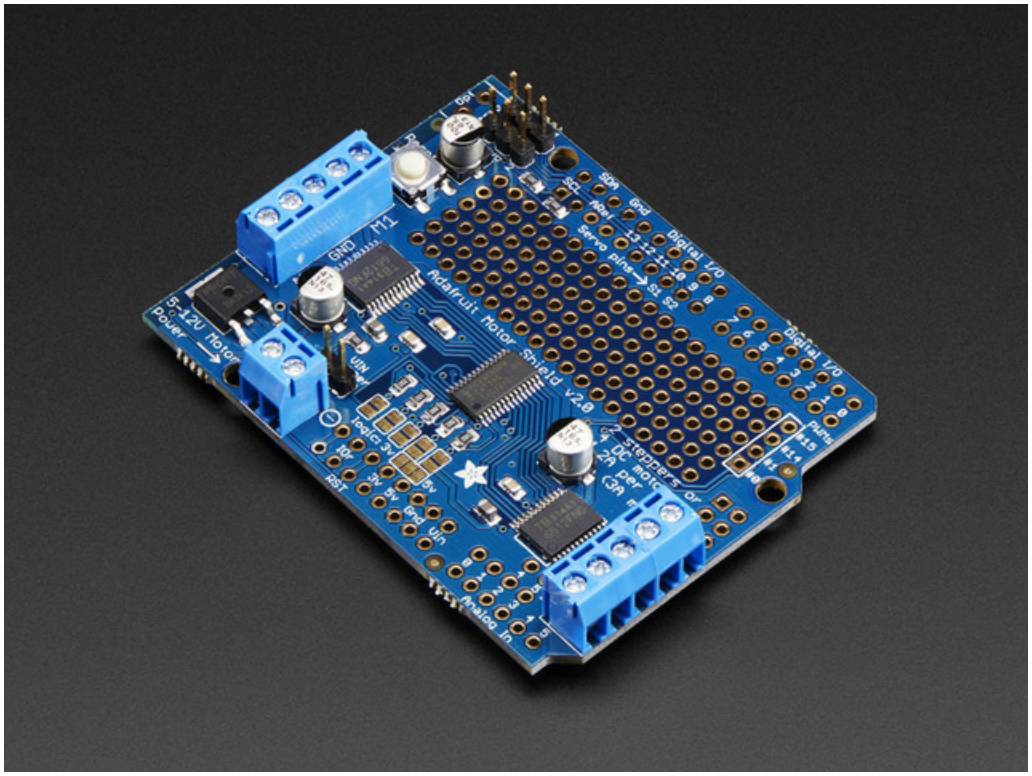
Or the Shield Version (https://adafru.it/dtN)of this contoller. It uses the same PWM chip and is addressable and stackable to control hundreds of servos.



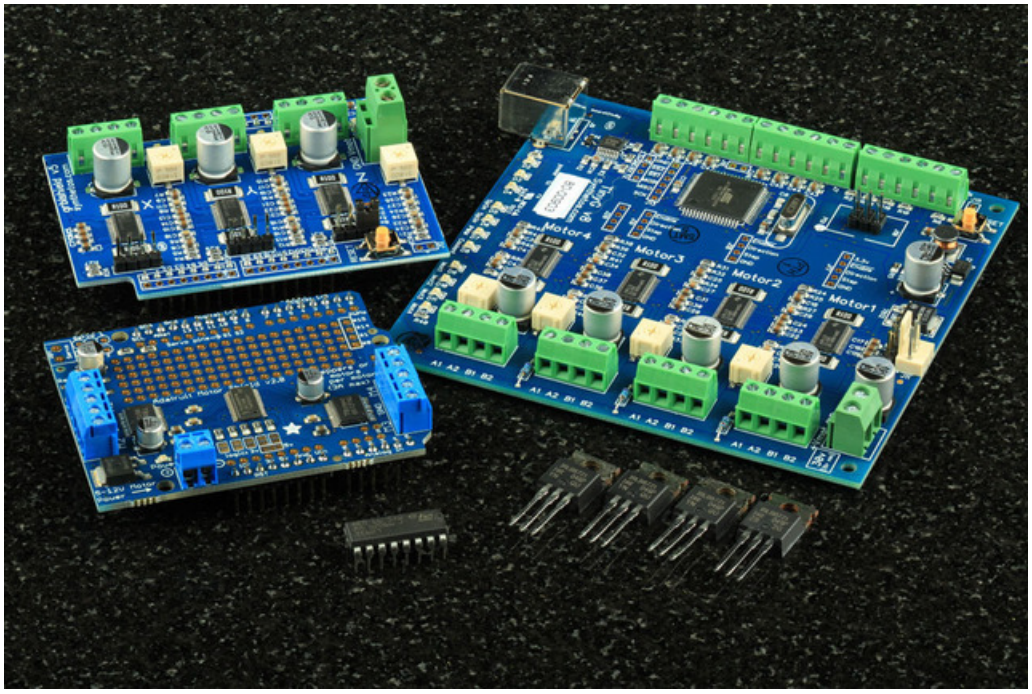
Stepper Motor Control

Stepper motor controllers are more complex than DC motor controllers. Driving a bipolar motor with microstepping requires 2 complete H-bridges and 2 channels of PWM.

The versatile **Adafruit Motor Shield V2** has 4 H-bridges and can drive as many as 2 steppers. What's more, it is stackable to control dozens of motors.



For more stepper motor control options, see the "Driving a Stepper (https://adafru.it/dtO)" page of our "All About Stepper Motors (https://adafru.it/dtD)" guide.


Motor4
Motor3
Motor2
Motor1
A1 A2 B1 B2

Powering your Motors

Motors are power hungry devices. They are also not very well behaved loads and can cause supply fluctuations that disrupt other devices powered from the same supply. Many difficulties with motorized projects stem from power supply problems.

Voltage

It is important to choose the right voltage for your power supply. Too low will result in reduced performance. **Too high will cause damage to the motor and/or the controller.**

- Make sure that your power supply voltage does not exceed the rated voltage for your controller.
- Unless you have a current limiting controller, make sure that the voltage does not exceed the voltage rating of your motor.

Too high a voltage can damage your controller and/or your motor

Current

Current draw is determined by the motor. As long as you stay within the voltage rating for the motor, the motor will only draw a safe amount of current. To protect the power supply from overload:

- Make sure that the current rating for the power supply is at least as high as the motor.
- Keep in mind that stepper motors are rated 'per phase'. To calculate the current demands of a stepper motor, multiply the current per phase number by 2.

Understand the current ratings of both motor and controller

Safety

"The greater the power, the more dangerous the abuse."

I don't think Edmund Burke was referring to motors when he said that. (In fact, they hadn't even been invented yet!) But his wise words are still applicable.

If you experiment with motors long enough, you will probably burn out one or two in the process. For smaller motors, this usually just means some very smelly smoke. But larger motors and their associated circuitry and power supplies can become a real hazard if you are not careful.

Be careful around live circuits and moving machinery

Protect yourself

Use caution when handing high current power sources, circuitry and attached machinery.

- Avoid skin contact with live circuits. You can get a pretty nasty shock from a 12v circuit!
- Short circuits in batteries and power supplies can result in fire and/or explosion. Always double-check polarity and use caution when making connections.
- Beware of loose wires and stray tools that can cause short circuits or get caught in moving machinery.
- Wear eye protection.
- Stand clear of moving parts such as robot arms and other machinery when applying power. Unexpected rapid

movement can cause injury.

Check that your power supply, controller and motor are compatible before applying power to the system

Protect the Electronics

Understand the capabilities of the components you are using and use care when connecting them:

- Make sure that the motor is matched well to the controller. If you try to pull 3A from a controller rated for 2A, you will likely end up with a burnt controller.
- Make sure the power supply is a safe voltage for the controller. Feeding 24v to a controller rated for 12v will kill the controller.
- Make sure that the power supply is the right voltage for the motor. Unless you have a constant-current controller, doubling the voltage will double the current to the motor, risking damage to both motor and controller.
- Don't make connections to live circuits. Make all connections first before powering up the system.

Overloaded circuits can be a fire hazard

Protect the Wiring

Overloaded wiring can quickly turn red-hot and burn through insulation and whatever else is nearby.

- Always use a wire gauge large enough to handle the expected current. This chart (https://adafru.it/dtP) from Georgia State University is a handy reference.
- If your power supply is rated for more current than the wire, add a fuse to protect against short circuits.
- If you are powering several circuits from one large supply, fuse each one separately to protect the wiring.