Advanced Brushless Power Systems for Small Electric Scooters

by **teamtestbot** on April 24, 2008

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intro: Advanced Brushless Power Systems for Small Electric Scooters

Thesis: It is feasible to construct a very powerful, efficient, and lightweight personal mobility device using hobby-grade equipment for under $400. This amount can be drastically less depending on the individual requirements of the builder. This is possible only through the extremely high power density of modern battery, motor, and controller technologies and the extremely low cost thereof in the radio control model hobbies. The advantages of constructing your own personal electric vehicle include educational experience, the ability to self-service, and the ability to customize to your own preferences at will.

I'm a builder and tinkerer by nature, and am always on the lookout for cool parts, devices which can be made better with cool parts, or some times both. During the summer months of 2007, I happened upon a chance to work with both.

As a bit of backstory, I build and compete fighting robots - as in Battlebots and Robot Wars - and as other builders of robots and non-robots may know, the search for the perfect motor is neverending. In June of 2007, I went on a trip to China to visit my aging grandparents... and hunt for parts. As RC hobbyists may know, China is the prime source of the vast majority of model equipment these days - big-branded or not.

So it was in a small hobby shop in a neighborhood of Beijing that I spotted this large outrunner motor. The only word to describe it was "assnormous" - according to the info card, it was a "7050/6" type motor. Translation: 70mm diameter stator, 50mm stator length, 6 turns per stator pole. Real translation: Massive power. It claimed 6 kilowatts maximum, but as overrrated as many hobby parts tend to be, I didn't trust the rating. Many high-quality BLDC motors of this size range can produce up to 10-11 kilowatts of power. They also cost a cool grand or two, not the $100 I ended up getting this motor for. Here's one example.

However, that didn't prevent me from impulsively buying it, since it's bigger than every other brushless motor I had at the time anyway.

Back in the US, I had to figure out what on earth to do with such a gigantic motor. I had no controller for it, no battery system that could possibly feed it, and no application. My personal hovercraft project was ditched a year before. I could not shove this motor into a 12-pound class combat 'bot.

It took a lucky trip to a local flea market to get this project going. On that day, I passed by the usual vendors selling toys when I noticed one had a small electric scooter, about the size of a large Razor scooter.

And it all went downhill from there.

(Update 15 January 2009) Hey guys, I have 31,000 views and 21 rates? Please rate whether you liked it or not, because that provides me with feedback! As always, comments and questions are welcome. Also, I am preparing a writeup on the wheelmotor scooter, but want to get my motor theory a bit more inline before I finish it.

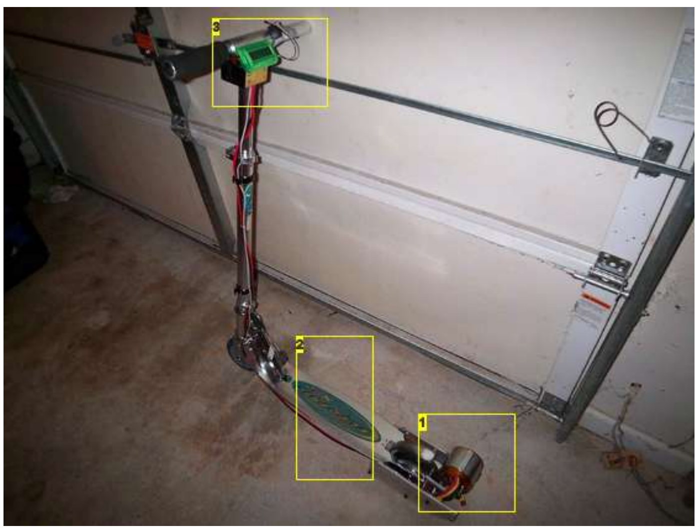


Image Notes
1. 2,100 watts of love!
2. Total weight: 22 pounds
3. R/C meter reads out volts, amps, watts, amp-hours, and that good stuff.

step 1: Select your vehicle

General considerations Just about any wheeled object you pick up these days can be hacked, modded, or boosted to yield a higher power-to-weight ratio. What is particularly exciting about electric vehicles is that this process is comparatively *easy*, part of the reason why I am eagerly awaiting mainstream electric cars, having reached the age of unlimited desire in vehicular performance.

The basic technology of almost all small EVs - scooter, bike, or car - these days is lead-acid batteries and large DC motors. While the heavy build of these parts increases their relative durability compared to a lighter but more powerful part, performance is often left to be desired.

Hence, most small EVs you may find are amenable to power mods. I focused specifically on an electric scooter since.. well, I had one, but also because they tend to be small and extremely portable. One example of a commercial "mini-electric scooter" is the Roth Motorboard 2000XR, which, while extremely compact, has the performance of much larger vehicles.

Larger electric scooters such as the steel tube-framed pneumatic-wheel types can stand a more massive power system than what you can fit on a Razor-size scooter, but weigh comparatively more. Bicycles, electric or not, are another common conversion base. Conversions aside, you can build an electric powertrain into whatever you please.

Conceptually, however different the physical manifestation, the operation of the vehicles are the same, as shown in the diagram. EVs are relatively simple things at their very basic level.

In the end, the kind of power system and performance you will get is a function of how much money you want to spend and what your goal is. Something to move you around campus or town won't cost as much as the next Killacycle.

My personal conversion was an electric scooter whose primary intended application was as a campusmobile for college. It is a Sharper Image Electric X2 model scooter I bought nth-hand for $10, with leaking batteries, no charger, and a slipping belt drive. It was pretty much perfect.

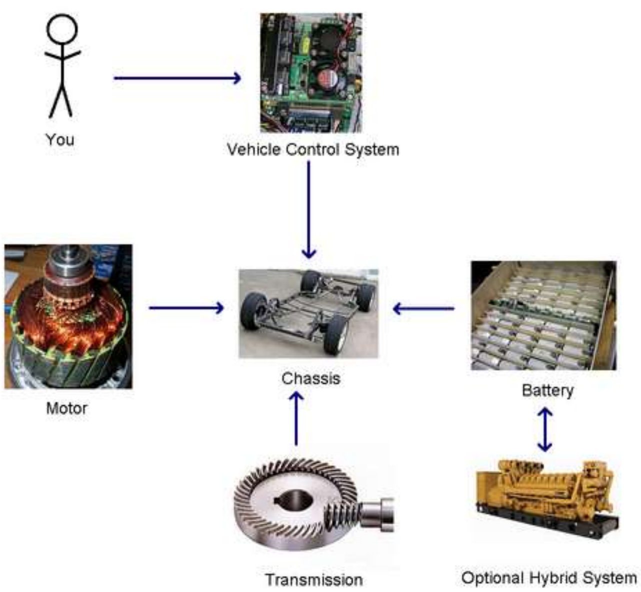


Image Notes
1. Badly failing belt drive
2. Almost all cells corroded
3. Twanged sideways a few degrees

step 2: Mechanical

There are several considerations to be made about the mechanics of your ride.

1. Can the stock power transmission system be used, or, if not, what type will it be replaced with?

Most vehicle systems are specifically designed and calibrated to work well a power level dictated by the manufacturer, and can only handle a certain amount of overhead before something detonates. Depending on how severely you decide to upgrade, you might have to rebuild the power transmission - stronger gears, harder axles, wider belts, etc.

Usually, it is easiest to upgrade in the same family of technologies. For instance, upgrading from #25 chain drive to #35 for more strength, or 5mm HTD timing belt from 3mm timing belt. This is due to the similar form factors for similar technologies - a sprocket has much the same profile as another sprocket, and you can get a new timing pulley in the same width and material as the old, but with bigger teeth. Often, less modification of the structure, wheel hub, etc. is required if the method is kept the same.

However, this all depends on how much you want to change or how much you want to build or buy. A more powerful motor could easily accomplish the same task using a one-stage pulley system in the same space where a previous, weaker motor had to use a large gearbox. Many electric car conversions retain the stock transmission since the electric motor develops similar torque to the engine being replaced, while others using high-torque motors often do away with the transmission and only use the gear reduction of the rear differential.

In the case of this scooter build, the stock 150-200 watt motor was well-suited to the all-plastic powertrain it was attached to. However, I knew that the giant outrunner would shear the tiny belt teeth off instantly.

I went to Stock Drive Products and got myself a set of 5mm HTD timing belts and pulleys in 15mm width, which is both a 5mm upgrade in width and a 2mm upgrade in tooth pitch.

HTD type belts have round teeth which are wide at the base, enabling them to transmit significantly more torque (HTD = High Torque Drive) than a standard timing belt (usually of the "GT" series) of similar pitch.

These pulleys required some creative wrangling to fit into the slightly narrow space, however...

2. Does the chassis require modification in order to fit the upgraded battery, motor, controller, etc.?

There were two problems to be solved. Number one was attaching the big pulley to the wheel, and number two was attaching the new motor pulley to the motor.

In the general case, there is a tradeoff between how well your components would work in an optimal situation and how much machining you're willing to do to reach it. If using your desired motor requires rebuilding the entire back end of your vehicle, it might be wise to consider another vehicle, or to save your motor for another project. If you're going totally balls-out anyways, you're probably not the target audience for this article.

Often, this entails picking components which are either *similar* in size or even *smaller* than stock. Considering the vast increases in power-to-weight ratio of a BLDC motor to a similar ferrite-magnet, standard-issue run-of-the-mill PMDC motor, this is often a viable solution. Again, realize that an equivalent DC motor that can produce 10 kilowatts of power like the Plettenberg Predator is usually about 8 inches in diameter, a foot long, and weighs over 100 pounds. *

In this build, adapting the new pulleys and belts was not too hard, but did require access to a lathe, which a good friend of mine was able to help with. I planned out a stronger hub attachment than the stock double-d mount for the wheel (which would explode instantly on application of power from the new motor). Also, I enlarged the bore of the motor pulley to fit on the motor, and secured it in place with a pin, which both transmits torque and locates the pulley axially so it does not slide around.

A series of holes were drilled at a measured diameter around the large aluminum wheel pulley's hub such that dowel pins, when pressed in these holes, were able to grip the wheel spokes. This greatly increased the strength of the attachment over a plastic double-D shaft. The hub of the wheel pulley was machined to fit snugly into the bore of a 5" scooter wheel, and a bearing cavity was also machined into it at the right location such at the entire new assembly was able to just drop into the space where the previous wheel-pulley assembly was *without* its axle spacer. I took up the space which that spacer used in order to add a larger part.

I did need to cut away a bit of the chassis to clear the new wide pulley, but this was just a few minutes with a file.

Next, I needed to find a way to mount the new motor.

3. What is the most effective way to mount new components if they cannot be simply dropped in?

This sort of goes in concert with question #2. While add-on mounting systems aren't as hard to re-engineer as the entire chassis, you still have to make sure you can actually put your new part on. Usually it's the transition from "small" to "large" which is an issue, and not the reverse, but one thing that smaller parts require is adaptor plates, shaft couplers, bore spacers, etc. in order to interface to the rest of the system.

Many motors are face-mounted, which means they have bolts sticking out of the same side as the output shaft, or perhaps threaded holes. They are intended for use in applications where they're directly stuck into the side of something.

Some other motors have base mounts, which are usually welded steel brackets that have bolt holes, for mounting the motor shaft parallel to a surface. Other motors yet have absolutely no mounts - they're designed to be clamped by a circular ring, such as as a hose clamp, into the frame!

The biggest challenge is usually converting between these types of mounts. Large metal angle brackets, with the bolt circle of the motor drilled on one leg and a mounting pattern on the other, are often used to convert base-mount to face-mount and vice versa. Here's one example, which is also often used in large industrial motors, since they make for versatile mounting arrangements.

Base-mount and clamp-mount conversions are also doable, but usually require some more engineering. They can be as simple as a circular cutout of the motor's diameter in a piece of material and a strap or clamp over the motor that holds it sturdily to that base material. Mounting holes are in turn drilled into the base. To convert clamp-mount to face-mount often entails drilling or machining mounting holes into one end of the motor.

Here's a good example of a clamp mount for a high performance DC motor (which also happens to be a great form of EV motor!)

Luckily, in my case, the bolt circle of the large outrunner was just a hair over that of the stock motor. I did not have to do much machining at all, since I only had to cut a bit of material off one mounting hole which was close to the back end of the mount, as seen in the pictures. Effectively, I have a bolt-and-slot configuration which also allows for convenient belt tension adjustment.

The new motor did not have mounting studs, so I had to simulate it using some long allen-head cap screws, washers, and aluminum spacers. This was handy since I had to increase the mounting offset (from face of motor to face of mount) to clear the wider belt pulley. A gallon of red Loctite later and the assembly was bulletproof.

One thing that you have to remember is that most of the time, electric motors do not directly drive their loads. Prime movers in any situation - internal combustion or otherwise - tend to move too quickly and with too little force to be directly applied to their load efficiently, which is why cars come with a pile of gears attached to the engine. The same is true for electric motors. A high performance brushless DC motor will hit speeds of over 20,000 RPM without incident, and the most extreme ones regularly exceed 60,000 RPM. On an 8 inch pneumatic wheel, that's a little bit over half the speed of sound at mean sea level. Fun, right? But it will never get there, and chances are it will not even start you moving. Even the power required to keep a steady speed against wind resistance will overwhelm it at a certain speed.

Most electric motors have an interesting property that their torque-speed curves are *linear*, with maximum torque at 0RPM and minimum (zero net) torque at maximum rotational speed. The motor will find a happy balancing point somewhere in the middle, the exactly location of which depends on your gearing, wheel size, electrical system capability, transmission efficiency, and a bunch of other stochastic processes. Overall, **power does not automatically mean torque**, which is what actually gets you moving. So that begs one last question to be asked:

4. Does the gearing need to be changed? A motor that runs far faster than stock might warrant additional gearing to operate efficiently. The stock reduction on the 200 watt motor was 4:1. I decided that since the giant outrunner was an order of magnitude more powerful, that a slightly lower reduction was not going to hurt performance. Also, the largest pulley I could fit in the dimensions given and which SDP had in stock was 3.75:1.

*Note that this DC motor is most likely designed to produce 10KW reliably with minimal heating, while the BLDC motor will require active cooling due to its reduced size. This is a rough comparison with maximum power figures.

Image Notes
1. The plastic double-D molding inside the wheel will be totally inadequate if more power is going to be transmitted.

Image Notes
1. To overcome this, the new wheel pulley had a series of pins installed which directly gripped the wheel spokes, requiring the shearing of all twelve of them at once to break the drivetrain.

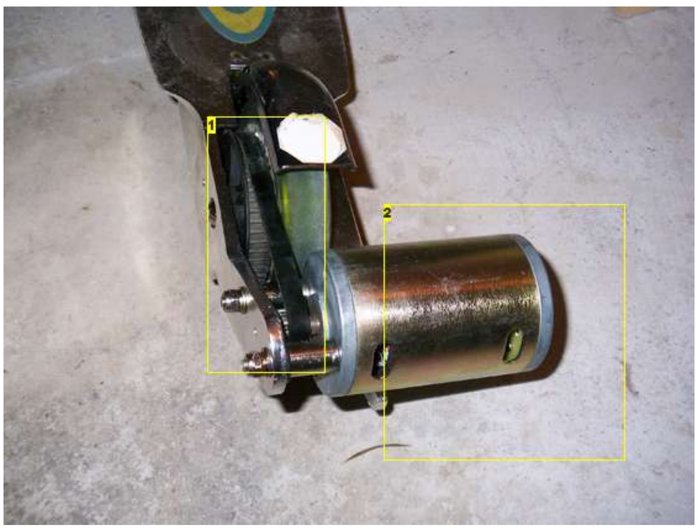


Image Notes
1. Narrow 3mm GT timing belt drive attached to the 200 watt motor
2. This motor has built-in studs for mounting.

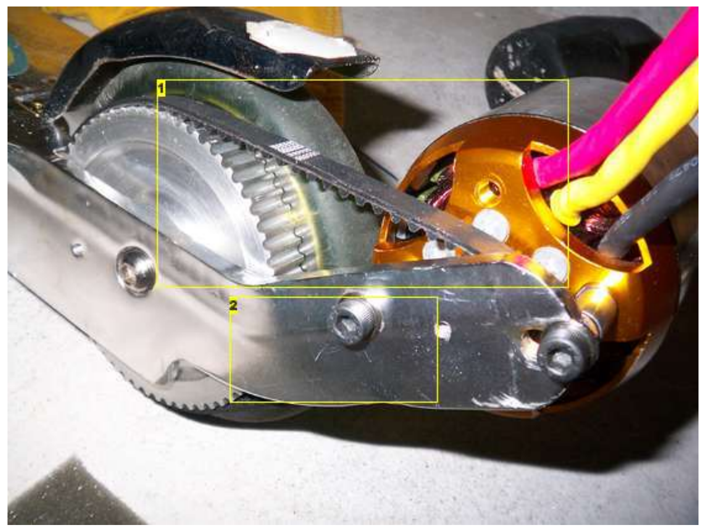


Image Notes
1. 15mm wide 5mm pitch HTD belt and pulley system attached to the new multi-kilowatt drive system!
2. The giant outrunner did not come with mounting studs. Instead, I used their inverse - cap screws threaded through with removable spacers.

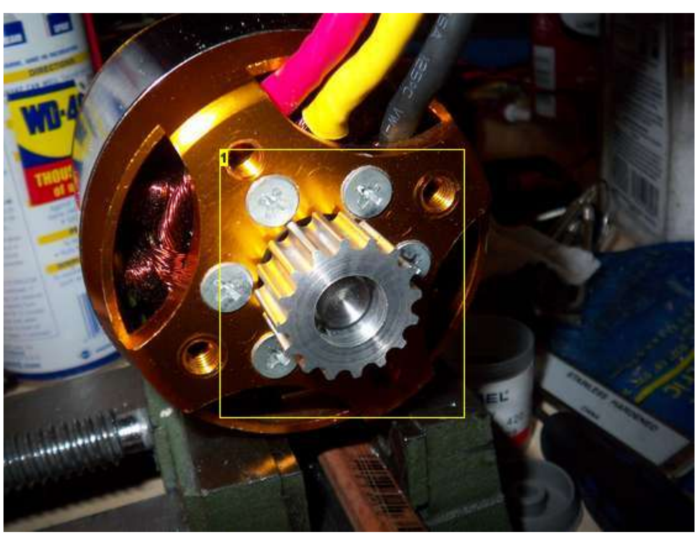


Image Notes
1. A roll pin was used to transmit torque between motor shaft and pulley.

step 3: Electrical

Mechanical bits are no good without the electrical bits to run them. It's a well known fact that **batteries are the biggest limiting factor in an electric vehicle**. Electrochemical technology alone cannot even begin to compete with the raw chemical energy stored in liquid and solid fuels at this time. Often, a good percentage of the weight of an EV is made of batteries, so if you're converting from scratch, make sure to take this into account. For a small vehicle like a scooter or bike, it's easy to tack on 30% or more of the original vehicle weight just for batteries.

Chances are, you will have to either upgrade or replace any existing electrical system. You've heard the whole talk about batteries - lead acid is cheap and heavy, lithium ion is expensive but awesome, and nickel chemistries float somewhere in between. The usual suspects in electric scooters and bikes these days are still lead-acid - usually the big 7-20AH types, and not particular high-amperage types (Just how many amps can you pull through a little 1/4" tab?).

When upgrading to a BLDC system, it's sort of counterproductive to keep the old, heavy batteries. Although this is easy to say, a good equivalent lithium polymer battery pack to a 12v, 7AH SLA battery (roughly 3 Li cells in series) will still run over $150-200. However, I think the expense is warranted. A high-discharge rated LiPo battery will supply *more* of its rated capacity at sustained high current draw than an equivalent SLA - the chemistry itself is simply more efficient. You will get vastly improved battery life for an equivalent capacity simply by switching to a chemistry that can stand the discharge characteristics of an EV (heavy burst, moderate continuous current).

At the very least, I would either start with or upgrade to nickel-cadmium cells, of which there is a wide selection. The Sanyo N3000CR cells I used on this build are a classic, and can dump 80 amps continuously. If you want more energy density, look for nickel metal hydride cells. If you want ultimate performance, check out a set of lithium polymer or lithium iron phosphate, which, although even more expensive, won't run the risk of catching on fire.

Not to fear-hype, of course, since LiPos are good at being stable if you charge them correctly. That's a good side-note actually. **Buy a good charger** if you're switching chemistries! Here's a site that has a slew of single-duty dedichargers. Many of those are OEM for companies like Razor or Currie, and while they don't have all the bells and whistles, tend to be plug-in-and-leave.

Here's a neat section of the RobotMarketPlace that lets you design and order your own battery pack.

Pictured below is the stock 2.8AH, 24v sub-C pack that came with the Electric X2. As you can probably tell, it's neither 24 volts nor 2.8AH any more, as almost all the cells have corroded in some way.

If you resize, you have to resize according to the predicted increase in power. This should pretty much be common sense. If you can afford the space or cost, it might be better to go for something with more overhead so you have space to grow for future upgrades.

For this project, I splurged on a 100 amp, 44v brushless ESC with a programming card. This was a full 100% nameplate rating over anything the rest of my electrical system could support at the time, but with the cost of large lithium batteries falling, I decided to give myself that room to expand.

I investigated several alternatives. One of them cost only $70, but was limited to 10S (about 37 volts), and came without mounting tabs. The rest were limited to 6 lithium cells. There was a decision to make - go with the 6S, inexpensive controllers and save on controller costs and battery charger costs, or go all-out with the 12S controller and as many cells as I could fit into the scooter.

I heeded the old adage "buy right or buy twice" and went with the latter option. Electronics are some of the most important parts of any project, and you should never skimp on them. The worst thing that can happen is to have an overloaded part fail while you're on the vehicle, because unless you have a good contingency plan, Really Bad Things will happen. Especially with R/C hobby equipment, which is often of dubious quality and stretched capacities and ratings, you want to give yourself some space, and never run components at their "maximum" power. Thus is the tradeoff between industrial and hobby parts.

Make sure your new stuff can talk to your old stuff. One of the biggest challenges with upgrading anything is backward compatibility (you software guys ought to know this well). If you are only upgrading one or two parts, for instance, the motor or controller, you will probably need to modify something unless it's a factory OEM part (then what's the fun in that?!). The biggest challenge by far is not interfacing physically, as wires can be swapped and connectors switched, but signalling.

Many stock DC motor controllers on bikes and scooters tend to be very simple devices. They are controlled by a 1 to 4 volt analog voltage, from any source. They often have no microprocessor in them at all, only a series of op-amps which are attached to a PWM generator that directly translates the analog voltage to an output. This 1-4v analog control is a standard in industry, and even large (and smarter) golf kart and forklift controllers use them (see 4QD controllers, famous for driving many Robot Wars and Battlebots entries to victory). With that said, most of the throttles that interface you to said controllers output a plain 1-4v analog voltage, and is usually a big potentiometer with a spring loaded grip, pedal, handle, or whatnot. Simple, rugged, and proven.

When using an R/C controller, the signalling is very different. R/C servo control uses "pulse width modulation", which means the controller is driven by a series of digital pulses. The industry standard is 1.5ms (millisecond) long pulse for neutral, 1.0ms for full reverse, and 2.0ms for full forward, with pulses every 20 milliseconds or so. This is vastly different from what alot of electronics engineers think when they hear "PWM", which can also refer to a *fixed frequency with variable duty cycle* whose intent is to generate an analog voltage out, after being filtered.

So chances are you have to upgrade your bike or scooter throttle so it can put out a servo pulse. Problem? I have **never** seen one like that commercially! You will most likely have to rig your own signal interpreter, and there are numerous ways to do it.

1. **Microcontroller**. If you're down with programmable controllers, you can whip up a very quick servo signal generator using an ADC. The upside to this is that you can also include a slew of other features along with it - variable acceleration curves, battery monitoring, built-in datalogging, whatever. The most flexible option. Take a reading, scale it, and spit out a 1.5-2.0 (or 1.0-2.0, depending on your motor controller's tastes!) millisecond pulse every 20 milliseconds.

2. **Commercial servo tester**. These usually appear as boxes with buttons and knobs. If you want to operate an EV with it, you want the most drop-dead simplest type - a box with a knob that outputs a 1.0-2.0ms signal. You can then rig this to your own array of levers, springs, and whatnot to make a trottle. Most of these are even 5K potentiometer based, and so you can even rig your old bike / scooter throttle into the circuit.
Here's one example of an ultra-premium one for ultra-premium luxury servos with Corinthian leather. You do not want this.

This is a bone-stock basic one very much suited for throttle conversion.

The downside? Fixed, linear throttle curves and the requirement of mechanical trims. If your throttle neutral isn't the controller's neutral, you're out of luck unless you can physically adjust the throttle's travel limits! If you're a good e-hacker, you could twiddle some components and allow for adjustment, but if you're going that far, might as well go with option 1.

3. **Brute-force DIY servo pulse generator circuit** out of discrete components. This is the route I took, and I will never do it again.

At the time, I had no programming facilities, but did have piles and piles of components. So I decided to just get some perfboard and make a pulse generator from a 555 timer, which is pretty much the most common IC around.

There are many circuits online for simple servo pulse generators using a 555. Some use two (or one 556) to get a more stable signal. The simplest I found (and the one I ended up using) is here. 7 parts. You could probably make it hard-connection-to-hard-connection and wrap it up in a ball of duct tape.

I got a little more fancy, however, and laid all the parts out on two square perfboards (I didn't have one big one!) and also dropped in a 12 volt DC-DC regulator for future expansion accessories. You could mount this regulator elsewhere or not even use one at all, but I put one on just in case (And to run the underglows which never materialized)

Downsides? Although it's electronically trimmable (by putting a small trimpot on one leg of the main throttle pot), the components will be subject to temperature drift. Neutral in my room wasn't neutral outside, nor neutral in Boston. This is especially true if you are not using precision components. It's complicated, there's more parts to fail and solder joints to mess up. Don't do it (Unless you love putting yourself through pain).

I would really love to see an R/C type controller that can take a straight 1-4v input beucase the their power densities greatly exceed industrial controllers of the same type. How complicated can it be? Most of the airplane controllers I see have fat Atmel ATMEGA32 chips running them, which have onboard ADCs!

Someone want to hack one?

Image Notes
1. That looks real healthy.

Image Notes
1. If you're good, you can run it off one of these!
2. Sanyo N3000CR cells provide high discharge.

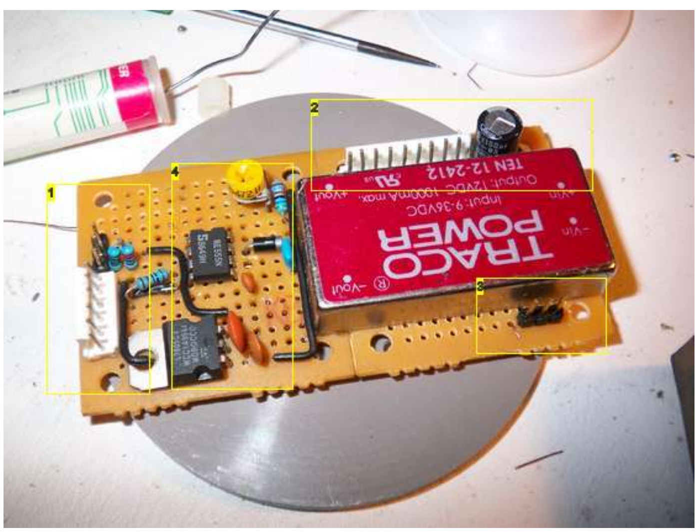


Image Notes
1. 5 volts out, potentiometer in, controller signal out
2. 12 volts out for accessories!
3. 36 volt battery input
4. Brute-force discrete servo signal generator

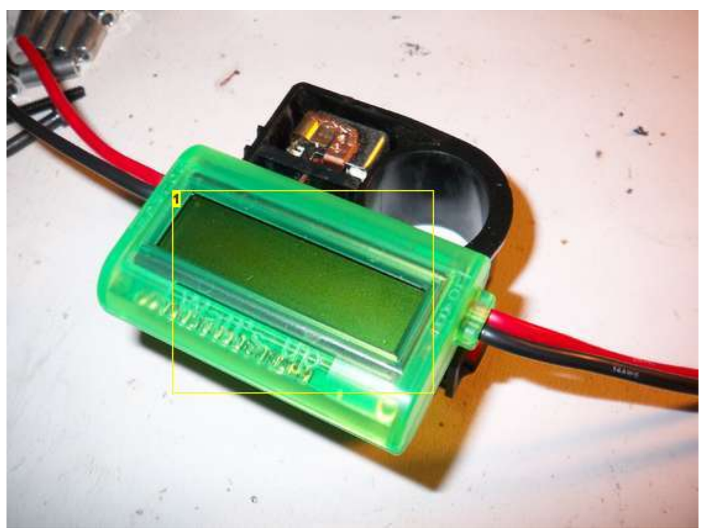


Image Notes
1. Common R/C model diagnostic tool being used as a dashboard

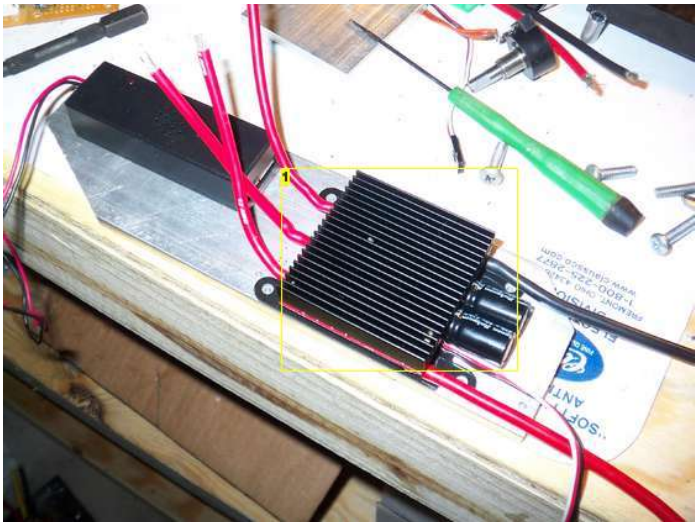


Image Notes
1. High-powered brushless controllers are very inexpensive these days. This 100 amp, 44 volt model cost only $100.

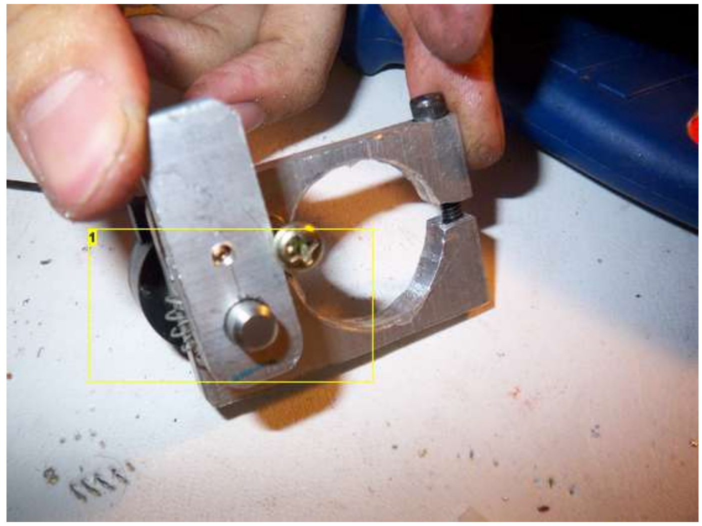


Image Notes
1. A 5K potentiometer hooked to a spring-return lever makes a convenient ghettothrottle.

step 4: Integration

Great, now you have a pile of parts and a vehicle sitting on top of it. Things won't happen unless you put it together, since unlike Transformers, our real-world objcts don't build themselves. Yet.

In terms of tools and equipment, you should have at least some basic EE tools - wiring tools, multimeter, etc. Because much of this is snap-together and COTS, you shouldn't have to do much custom electronics except if you are making a custom throttle interface, in which case things like an oscilloscope (to check for signal quality!), a good soldering station, etc. will be indispensible.

You should also have some shop tools. I've made many things in my garage, whose major tools are a small drill press, 10" compound miter saw, and Dremel. Not even a real Dremel, mind you. Hand tools included a power drill, jigsaw, and circular saw. Basically, you want to be able to put holes in metal and plastic.

(Ask me later about how you can mill with a miter saw and use a drill press as a lathe.)

For precision machine work, you want access to some kind of machine shop. "Precision" in this case means round things or things which need to be very straight - including axles, bolt circles, spacers, gearboxen, etc. The worst sticklers about tolerances are gears, and plain old belts are the best about it, so keep this in mind when you're designing. I had access to a lathe for turning the pulleys. That's pretty much all the machine work this project entailed.

I assume that you carefully planned out your build and didn't go about impulsively buying things that looked shiny, and have a plan for how things will go together. There are really too many ways of building these things that I can't really do a "general theory and guidelines" writeup, so I will just tell my tale.

Installing the batteries was a surprisingly easy task. The ElectricX2 housed its battery pack inside its channel-shaped chassis, and all it took was swapping my pack for the stocker. I found out that given my cell arrangement I could fit a maximum of 27 cells in the channel before hitting the rear brake stop and interfering with folding at the front.

So I did just that. The pack was made in a peak-and-valley config with an odd cell out to fit under the brake stop, giving me space for that last 27th cell. It's an odd number of cells for sure.

Two bits of aluminum angle were bolted into the side of the chassis, with the legs facing inwards, to retain the battery pack from underneath. Conveniently, the peak-and-valley arragement of C cells made for a pack just high enough to allow for some compression fitting with the retaining brackets such that it didn't go anywhere.

I ran the power leads out towards the back where the electricals were.

Bringing the R/C power meter into the mix required running one very long 10 gauge wire to the top of the handlebars and back. The meter took a direct reading from the large wire and didn't use some sort of remote sensing such as a hall-effect sensor, so I had to deal with it if I wanted it up top. This is one thing I'd change in the design - get a real datalogger or one with some remote sensors! 10 extra feet of wire adds system resistance which decreases overall efficiency.

The whole thing was mounted inside the little box that used to house the original power electronics

All other electronics were mounted on two aluminum side plates that were mounted to the left and right of the back end. There wasn't any space left for electronics inside, so they had to be moved outboard! Not exactly weather or bulletproof, but it got by.

Some last-mile things included a spring-loaded belt tensioner to take up some slack (Belts stretch!). I also replaced a missing suspension guide bolt

And violin, instant kilowatt electric scooter.

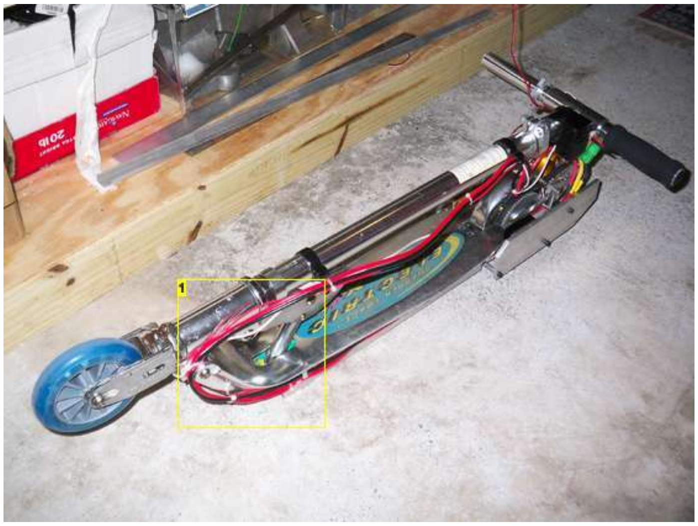


Image Notes
1. Convenient stow-and-go position!

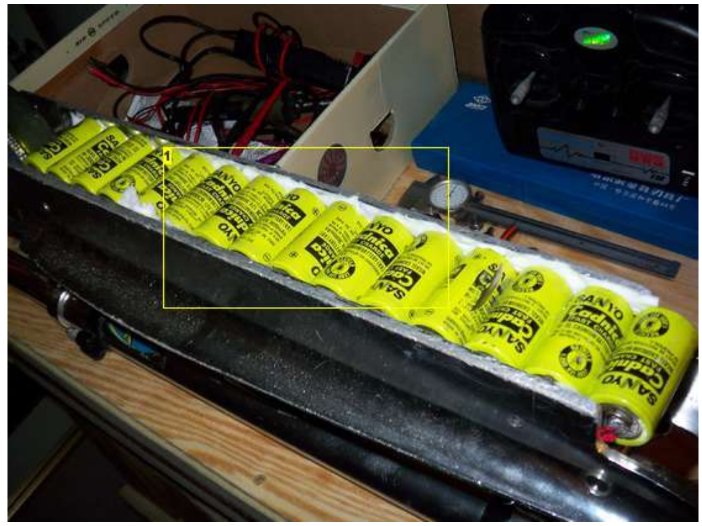


Image Notes
1. Just wide enough and just high enough!

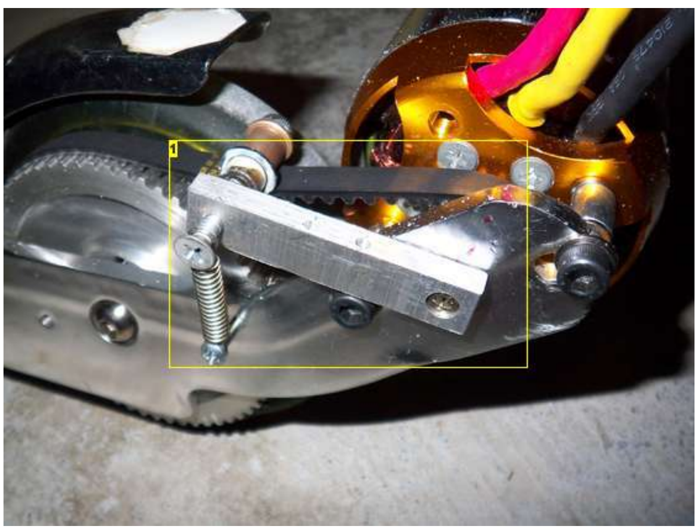


Image Notes
1. A quick belt tensioner with guide flanges stopped the belt from wandering on the flangeless pulleys.

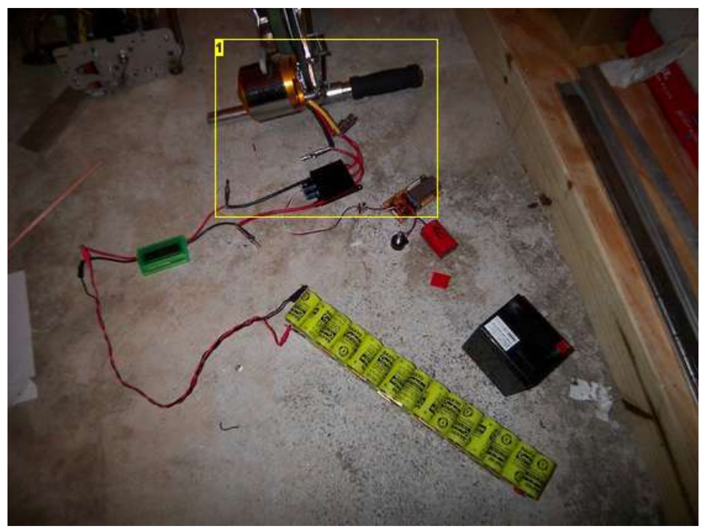


Image Notes
1. Dry run of the whole system on the floor for debugging.

Image Notes
1. When a 1/3AP AC motor just isn't enough to get through a piece....

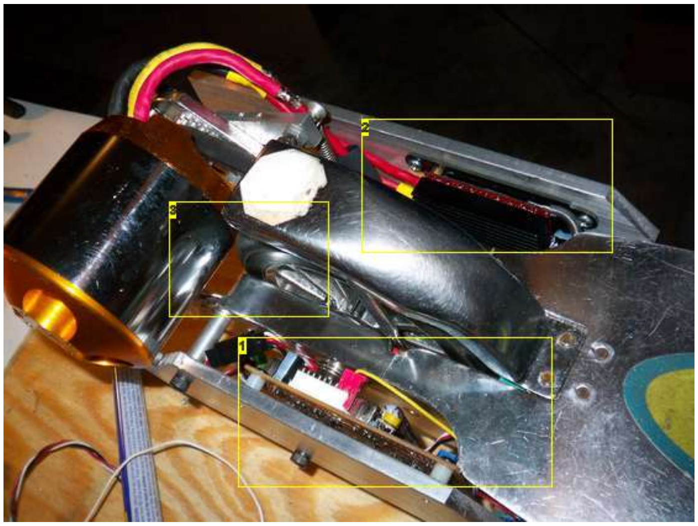


Image Notes
1. Signal generator and DC power board
2. Motor controller and main power distribution
3. A bunch of wires run under the vehicle here. This is bad, since the wires could get damaged by any number of things.

Image Notes
1. Battery retainment angles installed.

step 5: Closing Thoughts

There were a few problems, and alongside them, some more questions.

1. **DO YOU NEED THAT MUCH HORSEPOWER?!** The new scooter was almost *impossible* to control. This was due to several reasons.

First and most obvious is that I have a 6KW motor hanging off the thing. It's huge, it's awkward, and it's *monsterously torquey*, being run near its rated voltage, with batteries that can burst-dump 150+ amps.

Second, the controller does not have a soft-start option. Actually, it does, but only for a split second - before it lays as much current as it possibly can into it.

Third, the wheelbase is small, I'm up high, and so the center of gravity is 3 feet in the air and almost over the rear wheels.

All this combines to give absolutely nightmarish handling - especially when trying to start. I found that the acceleration is so forceful from a standstill that it threw me off almost all the time. The only way I could stay on was to give it a good kick-start, then *slowly* ease in the throttle. If I did it too fast, I would fly off. Any time I punched the throttle too hard, I would fly off. It's a drag racer, and little more.

Clearly, the motor, even running at 2100 watts (the peak reading on my R/C meter on a good launch when I was actually able to hang on) was *much* too powerful.

So what should you do? Well, this is one data point. Unless you want a wheelie bar, a 7050 type motor is too huge. I'd say even one of the 63xx series or even a 50xx would do just fine moving this sized scooter with ~5:1 gearing. This 7050 motor is much more suited to a full-blown electric *bike*.

Alternatively, you could just run a lower voltage, say, 22.2 volts, and be able to run a less expensive electrical system alongside it. AlternativeÃ?Â?Ã?Â?Ã?Â?Ã?Â²ly, you have a 44.4v lithium pack with a switch that could rearrange the cells in parallel or series - 22.2v paralleled for cruising, and 44.4v for drag racing. I'm not that ambitious.

Besides that, there was also the issue of...

2. **How durable can you make it?**

I didn't make it durable enough. It did great on smooth suburban Atlantan sidewalks and on my driveway. That environment went completely away as soon as I arrived at MIT in fall '07. The sidewalks were rough, most of the paving was done with cobblestones and tile, and there were more sidewalk ledges to jump.

All this completely destroyed my signal board within the first few days, splitting it into four pieces from the shocks! The scooter has no rear suspension and hard wheels, so each vibration and shock went straight to the components. Loctite was holding half the back end together within a week.

I noticed this first as a weird random resetting every fre dozen feet of riding. Of course, each reset means the ESC would brake the motor hard, and I occasionally had to avoid impending faceplants. On one occasion, it occured over the Harvard Bridge, and I almost flew over the guardrail and into the river below. That would have been really funny....not.

If I were to rebuild it, the signal board would be smaller, microcontroller based, and the DC-DC converter mounted elsewhere. It would reside on rubber shock mounts and be totally potted.

Last but not least...

3. **Is it legal?** Who cares?! Well, if you're going to be running a turbo-electric vehicle around town, you should note the local electric bike and scooter laws. Most jurisdictions classify these things as "electrically assisted mobility devices" or "mopeds", and have light or helmet laws. Electric scooters especially are in a strange gray-area of the law, since they are small enough to traverse sidewalks but are often blocked from doing so by electrically powered non-medical device laws. I have found that nobody really cares around here, and probably will not care unless I flout it in front of them.

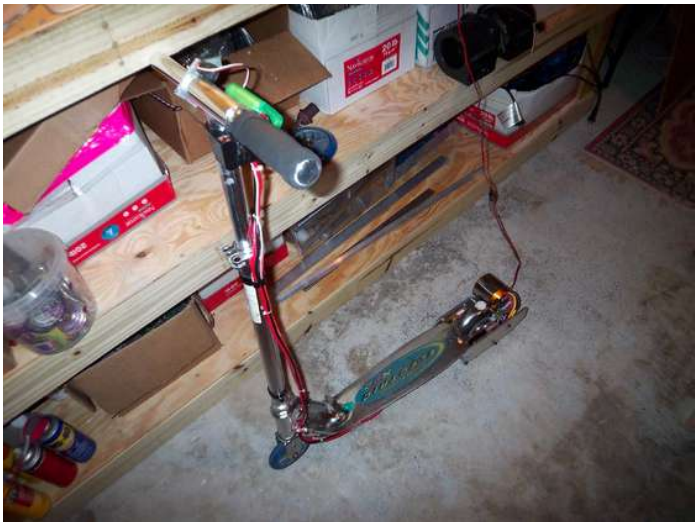
It will depend on how much ass your local law enforcement is, how nanny-like your local government is,and how many old people there are to yell at you to get off their lawn.

This is one more area which I think small but power electric scooters have an advantage in. *Stealth*. From afar, it would be hard to tell whether or not your vehicle is electrically powered, and if you give it the occasional kick (to save batteries!), nobody will notice either.

Unfortunately, I wasn't able to collect running video of this version. Disappointing, since when I was actually able to hang on for full cruising speed, it was blazingly fast. The calculated top speed was about 25MPH, and I probably managed at least 20. This is absolutely heart-stopping on tiny 5" urethane wheels, as one sidewalk seam can kill you.

So that's it. After arriving in Boston, I decommissioned this version of the scooter, and it currently resides in my closet. I'm working on a new version, however, which tries to incorporate everything I wanted to upgrade. Durability, simplicity, stealth, and compact....ness. It will have a large outrunner motor hiding inside the rear wheel (a hub motor) and use lithium ion batteries.

You may read the progress reports at my website under the Snuffles project"" pages, where "Snuffles" is the codename given to this scooter by a female friend of mine. All nasty, powerful machines must have cute, fluffy names, of course!



step 6: Resources and Links

All in all, I spent probably $400 on this build in total.

$100 of it was for the motor controller
$100 for the motor itself
about $80 for drive components - pulleys, belts, and new wheels.
$30 on a battery charger
At least $50 on random-ass hardware!
$50 on the R/C meter.

I, of course, went as far as my finances then would allow. You can do one better, no doubt!

Here are some resources I found useful.

1. The self-explanatory Electric Scooter Parts. One guess as to what you might find here. Good source of drive components and some electronics, such as throttles.

2. United Hobbies / Hobbycity is a Hong Kong based distributor of hobby equipment. The site is vast and the selection is enormous. The prices are also excellent, and the quality is consistent. They also make *absolutely no attempt* to hide the fact that their stuff is Chinese in origin, unlike many shameless 'manufacturers'.

Check out their selection of high-discharge lithium batteries and assnormous outrunners!

3. The RobotMarketPlace is a one-stop-shop for more than just robot parts. Their selection of brushed DC equipment is very expansive, and they also have wheels, axles, pulleys, etc, including 5" polyurethane mountainboard wheels and giant pneumatic tires with built-in sprockets (Handy!)

4. McMaster-Carr Supply. Seriously, if you don't know who these guys are, I'll buy a crane from them to lift up the rock you're under. Any and all forms of hardware, drive parts, mechanical bits, and goodies for electrical wiring (Cheap prices on dual-pole Anderson-type connectors!), among 465,000 other things.

5. Stock Drive Products sells stock drive products, among them pulleys, belts, chains, gears, axles, bearings... you name it. SDP caters more towards the precision crowd while McMaster is more big-iron industrial, though their selection overlaps in those departments.

6. EBAY! You can find great junker chasses to start your build here.

7. Your local hardware store or hobby shop! Don't leave these guys out. I was at my local HobbyTown USA in Duluth, GA about every weekend of the build.

8. The EV Album is a database & photo collection of many, many EV conversions, including yours truly. Harvest ideas, anyone?

9. RCGroups has a great section in their forums about *Electric Motor Design and Construction* if you're into that stuff. I've moved on to building custom motors since they're relatively simple things. The *Power Systems* forum is great for asking questions about your whole wiring rig.

More to come as I think of it! Have fun, and I look forward to drag racing one of you guys soon.

A picture of the rebuild is below.

Image Notes
1. Razor A3 scooter with 125mm wheels
2. Custom direct-drive motor module with a 1KW brushless motor built into the rim.
3. All the squishy bits are inside the tube chassis with additional batteries in a belly pack.

Related Instructables


Get Out And Get Biking (or Scootering, etc.)... An Experiment In Alternative Transportation by Gjdj3


Solar Powered Trike by dpearce1


Electric Vehicles (guide) by PKM


An Electric Trike with a leaning wooden frame by Garreth


Electric Mountain Board by Vurp


Steampunk Razor Scooter (slideshow) by gimmelotsarobots


48V Electric Flat Tracker by Radioactive_Legos


STOP-LED by Dipankar

Comments

50 comments Add Comment view all 137 comments

cool! says: Jan 5, 2009. 6:05 PM REPLY

For something larger, maybe a scooter with a seat, try:
http://64.33.154.92/blackdogrc/BIGbrushless.jsp#CX63P-L-200
Black dog rc is great, that motor (bottom) is 4,5 to 5.3 hp

HADJISTYLLIS says: Dec 25, 2008. 9:26 AM REPLY

Can i use 12Volt motor?

teamtestbot says: Dec 26, 2008. 3:29 PM REPLY

You could indeed. In fact, low-voltage is usually the cheapest to run. Obviously your power will be limited, but hey.

bob the builder #1 says: Jul 26, 2008. 4:18 PM

(removed by community request)

nicholast says: Nov 1, 2008. 2:31 AM REPLY

You don't get to build it and have fun :D

bob the builder #1 says: Dec 2, 2008. 2:50 PM REPLY

good point! sorry to be negative, I was just pissed when I posted that

teamtestbot says: Jul 26, 2008. 7:39 PM REPLY

Nobody sells one that does what I want.

swbluto says: Nov 26, 2008. 10:27 PM REPLY

Thanks for the comment! I now have a drill spot in the shaft and it seems able to handle the torque. But the grub screw doesn't seem tight against the shaft as it was initially after usage, although the timing pulley is still secure.

My scooter has ascended to operational status and here's my build in more detail.

Every 5 seconds to upwards of a minute, I noticed that something(I presumed the motor) started rumbling and I suddenly slowed down and this seemed to last upwards of 3 seconds(I didn't hold down the throttle long enough to know the maximum extent) and this seemed to happen regardless of my speed. I don't know the cause and I'll be investigating more fully, but I suspect that vibrations from mini-impacts(micro-cracks, bumps, etc.) might be causing irregular back-EMF that might be confusing the controller. I've heard the Plettenburg has a "bell skirt" that minimizes this bell vibration and I seem to have interpreted that the Castle Creations controllers keep sync well enough that this problem doesn't occur. Do you have any ideas on what the possible problem might be? The belt seemed secure, the phase lines seemed connected, throttle's connected, battery's connected, the timing pulley seemed secure, no motor magnets came loose, in essence, nothing was visibly wrong.

teamtestbot says: Nov 27, 2008. 9:14 AM REPLY

The less expensive outrunners like the Turnigy series do suffer from bell resonance at certain speeds. Having a can bearing (a large bearing that supports the open end of the can - a bell skirt, I suppose) will help immensely with cutting down the vibrations. This is why I'm a bit cautious with high-speed outrunners, because the motor can easily build up vibrations on the open, unsupported end of the can.

All outrunners like that have a certain speed where the imbalance of the can is magnified by the rotation. Well-built ones can dampen it even at those speeds, but not the cheapies.

swbluto says: Nov 24, 2008. 6:09 PM REPLY

"Also, I enlarged the bore of the motor pulley to fit on the motor, and secured it in place with a pin, which both transmits torque and locates the pulley axially so it does not slide around."

When you secured it in place with a pin, what type of pin did you use? Also, did the motor's shaft already have a hole for the pin to fit through or did you have to machine/drill it in? My build currently is set-up such that the grub-screw is holding the timing pulley to the motor's shaft for all its worth but I have a feeling that's not going to withstand the ~2000 newtons it's going to experience.(The grub screw/set-screw is pressed against the motor's shaft as tightly as possible. Would drilling a small depress/hole-wannabe and then screwing the grub screw in as tightly as possible work just as effectively as a pin?)

teamtestbot says: Nov 24, 2008. 9:52 PM **REPLY**

Absolutely. Set screws need to be used with a spot drill in the shaft or a flat. Otherwise they are extremely ineffective at transmitting anything except the lightest torque (And if they slip, they make a nice round gouge around the OD of your shaft, making it impossible to remove anything ever again.

I used a spring (roll) pin, and drilled through both the motor shaft and the pulley.

---

swbluto says: Nov 13, 2008. 12:10 PM **REPLY**

I've been doing a bit of adding onto the original single Permanent Magnet motor vehicle simulator: The current development thread is at http://www.endless-sphere.com/forums/viewtopic.php?f=2&t=6892&start=75 .

Anyways, I'm currently converting a small, light Viza Volt electric scooter to run off a large brushless outrunner motor(It's a 200Kv motor with a 3kW input rating) and am running into... technical questions. Using the above simulator, it seems a gear ratio close to 7-9 would be best for 7% hills(the higher up, the better for less heat dissipation) but my current scooter's gearing is ~4. There also seems to be concern at the forums for axial load coming from the belt/chain. So, I'm thinking about adding a 2:1 converter with the 2 being a gear that runs from a gear attached to the outrunner and the 1 being a timing pulley that's apart of the scooter's original drive system(It's a 15:5 500mm belt with "rounded" teeth, so I guess it's HTD? Can you get these belts in any length?), which would address the gearing issue but... also... I think it'd help with the axial("sideways") load on the shaft but I don't know. What do you think? I'm curious, do you know what the Kv and gear ratio of your set-up is? It looks like a ~5-6:1 set-up with a ~150Kv which sounds pretty optimal.

I'm also thinking about the "rod" I'd use to suspend the 2:1 converter: do you know how/where I could find out about what bearings I should use for this rod? Also, I was thinking about using a sealed bearing for supporting the motor's output shaft.

Also, how did you attach the timing pulley to the motor's shaft? Did it require any modification? The outrunner I ordered(http://www.hobbycity.com/hobbycity/store/uh_viewItem.asp?idProduct=3890&Product_Name=HXT_63-74_200kv_Brushless_Outrunner_(Eq:5240)) appears to have a 10mm round-shaft which doesn't seem to correspond to the inner diameter of too many gears.

My mechanical experience is kind of limited to my erector set that I used when I was 12, so I apologize if my questions appear too n00bish.

---

roccopeterbilt says: Oct 27, 2008. 3:46 PM **REPLY**

I read, either here or on your blog, that you are making your own motors and saw some of these steps on your blog. I am curious if there are any good permanent-magnet motor-building sites, tutorials, or Instructables. I am vary interested in trying this out myself, but have no clue where to start. Where do you get your stator (rotor?) center pieces? How do you calculate the number of wraps appropriate and how to orient them? A shove in the right direction would be nice, another instructable on it would be great :D

Thanks

---

teamtestbot says: Nov 1, 2008. 6:13 AM **REPLY**

Yup, I've been messing around with making my own motors. Not having a professional level in-depth knowledge of electric machinery makes little brushless DC motors rather simple things to build if you have access to machine tools. I would recommend against trying to carve your own stator plates (core) because the material used is very specialized. Generic sheet steel doesn't have the same electrical properties.

I haven't seen a big repository of knowledge in one place, but you'd be pretty set if you visit the RCGroups forum on electric motor building. They're friendly folks over there, so ask questions.
rcgroups.com -> Electric Motor Design and Construction

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vr38dett_fast says: Nov 7, 2008. 9:23 PM **REPLY**

how about awd(*2wd*) F+R?

---

teamtestbot says: Nov 7, 2008. 10:47 PM **REPLY**

When I get the wheelmotor'd version running, definitely a possibility...

---

trumpkin says: Jul 16, 2008. 7:53 AM **REPLY**

do you have any motor and battery recomendations?

---

nicholast says: Nov 1, 2008. 2:33 AM **REPLY**

If at all possible use brushless motors, they are much more efficient than brushed motors.

And if you can afford it the best choice for battery's is Li-Ion, they have the best energy density for weight, they do however have a rather low power density. That shouldn't be an issue on a scooter

---

teamtestbot says: Nov 1, 2008. 6:01 AM **REPLY**

The best choice currently is not the usual "lithium ion", which is lithium cobalt or lithium manganese (the latter half referring to the battery's cathode chemistry), but lithium iron phopsphate, also known as "A123" cells after the company that made them popular. Your average laptop battery is still LiCo/LiMn, and they are indeed not suitable for high current discharge.

LiFePO4 has a slightly lower energy density, but extremely high power density, which you'd want for high performance.

---

nicholast says: Nov 1, 2008. 4:18 PM **REPLY**

A123's are usually double the weight and size of a Li-Ion battery. On a scooter this can sacrifice half of your range for power density you don't need.

An 18650 Li-ion cell is 2300mah/3.7volts, they can sustain 5c (6.6AH * 5 = 33 amps continuous) discharge rates with some air cooling. If you have a 12s/2p (44.4 volts/6.6 AH) pack it would be about the same size as 28 Sub-C cells but at about 1/2 the weight. And would give you triple the range.

---

teamtestbot says: Nov 1, 2008. 5:50 PM **REPLY**

A good LiFe cell will easily discharge at 20C and can burst-discharge 40C for short periods of time. It's important to also consider the implications that C rating has for the internal resistance of the battery - as you're aware, the more C, the lower the IR has to be, which is directly linked to how much usable power you can extract from the battery. There are subtle differences in the internal construction of cells within the same chemistry that make some suitable for high discharge and others not so much. It essentially boils down to less IR = more efficient battery pack.

It also depends on what you're going for... A pack made of 18650s will give you further range provided you can keep the current draw very low. But they will not be able to give you as much kick when you want to accelerate.

---

nicholast says: Nov 1, 2008. 9:13 PM **REPLY**

Heres the other thing too, you shouldn't have to use more than 5c, you get longer run times and such.

A smart controller that can limit the current after a period would be good too, that way when you accelerate it would boost it a bit and then turn it down for longer run time.

---

teamtestbot says: Nov 1, 2008. 5:53 PM **REPLY**

But perhaps a less twitchy accel is better anyway.

I cracked open a BionX e-bike kit and found that it uses a massive glob of 18650s - at least 6 cells in parallel and 10 in series. At that level, it's advantageous to use them because you can have many in parallel to boost the dischrage characteristics.

---

teamtestbot says: Jul 21, 2008. 11:53 PM **REPLY**

Depends, what kind of vehicle are you running?

HADJISTYLLIS says: Aug 18, 2008. 2:20 AM **REPLY**

How many volts is your motor?

---

teamtestbot says: Aug 18, 2008. 4:12 AM **REPLY**

That's kind of hard to answer. Electric motors have an interesting characteristic in that as long as you keep everything cool, you can pump as much power as you can manage through it. This continues right up until the magnetic parts of the motor saturate, then any more power applied goes only to heating. At that point you've reached the *physical* limit of the motor. This characteristic is different depending on the motor design and materials, as well as the temperature... the lower the better.

I'm running that large outrunner on 36 volts, but its manufacturer rated it for 10 lithium cells, or about 40-45 volts. I don't trust its structural integrity enough to run for long at that voltage, but it will definitely do so if I rebuild the thing physically.

This is part of the reason why I'm a fan of electric vehicles. You can, for short periods of time, easily extract 10 times as much power as you use for normal running from a good motor.

---

nicholast says: Nov 1, 2008. 2:30 AM **REPLY**

10 Lithium cells is 37 volts/42 volts full charge, with the voltage drop of a 2100 watt motor you get about 30 volts into the motor.

Don't the magnets saturate with too much current and weaken?

---

teamtestbot says: Nov 1, 2008. 6:06 AM **REPLY**

The motor itself will see whatever the controller passes to it. The voltage drop you're referring to would actually occur in the controller, and a good controller at this power level should drop less than a volt.. but mind you it's still going to be passing a hundred amps or more, and since P = VI, that's why your controller gets hot.

And yes, you can demag your permanent magnets if the current level is too high. Rare earth magnets are pretty good about it today, and the current that would cause this condition is far higher than what you'll probably see in operation on something of this scale...

---

nicholast says: Nov 1, 2008. 4:14 PM **REPLY**

I'm referring to the battery's internal resistance causing voltage drop, not the controller.

A typical Sub-C NiMH has 5-12 Milliohms of internal resistance, you have 28 cells in series from what I can see, thats about ~250 Milliohms of resistance in your battery pack..

Which means that under full load (assuming 60 amps) your motor is only getting about ~15 volts.

The controller and wires have some resistance also, but its usually not an issue.

Another thing to consider is that the lower your throttle the lower the efficiency of the motor. This is because is you look at both the battery (you already are) and motor (hard with brushless) current, at 50% throttle the battery current would be 30 amps but the motor current would be 60 amps but at half the voltage of the battery pack.

The problem with this is that at lower throttle settings the motor gets hotter then at full throttle (this is assuming that the motor is at full load, on flat ground you don't need to worry about it)

Awesome project though! I've been thinking about a brushless scooter for a while now.

---

teamtestbot says: Nov 1, 2008. 5:44 PM **REPLY**

You're basically correct on the motor, but a few additional details. The motor current wouldn't be 60 amps. DC (and BLDC) motors aren't constant power devices - if you drive them with effectively half the voltage, they will draw half the current, because the winding resistance is constant.

Running 50% throttle would give you about 1/4 the power at full throttle/full load.

It will, however, be less efficient due not only to additional switching losses in the controller, but also the inductive effects of the motor windings. Depending on how fast your ESC switches, you could see current spikes, which would lead to increased heating.

---

ichiwazaryu says: Jul 25, 2008. 11:54 AM **REPLY**

The real question is; Range?

---

teamtestbot says: Jul 26, 2008. 7:49 PM **REPLY**

For this thing, about 5 or 6 miles. It could improve, but hey, it wasn't optimized in any way.

---

nicholast says: Nov 1, 2008. 2:31 AM **REPLY**

Is that at full throttle? what speed?

---

teamtestbot says: Nov 1, 2008. 6:06 AM **REPLY**

I don't think I've actually touched full throttle with this thing because it's just that nuts.

That was probably more 10-15% duty cycle accelerate-cruise.

---

nicholast says: Nov 1, 2008. 4:20 PM **REPLY**

I can imagine it gets scary haha

---

nicholast says: Nov 1, 2008. 2:27 AM **REPLY**

Do the 3000mah NiMH cells get warm after running? If your taking 65 amps it seems like they should get quite warm, although it depends on the continuous current your running at.

also whats the max current and average current?

---

teamtestbot says: Nov 1, 2008. 5:57 AM **REPLY**

The average cruising current was closer to 10-15 amps. I've metered momentary current draws of 80 amps on good launches. Note that I have never done a full throttle launch - it's physically impossible to stay on the thing like that.

---

legoman1922 says: Oct 7, 2008. 1:37 PM **REPLY**

cool scooter!

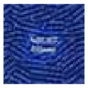
Ko0LaiD says: Oct 4, 2008. 5:29 PM **REPLY**

get a bigger scooter and put all this on it, one of those kind with small bike tires, this stupid kid is outside my dad's girlfriends house with his little 12mph electric scooter and its driving me nuts, someone needs to show him who's boss.

---

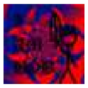
teamtestbot says: Oct 4, 2008. 8:30 PM **REPLY**

Then do it.



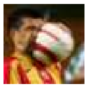
Ko0LaiD says: Oct 5, 2008. 1:44 PM **REPLY**

I use pedals.



BobicusIX says: Aug 23, 2008. 5:58 PM **REPLY**

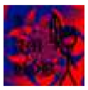
Wouldnt just buying a normal electric scooter be cheaper? i mean dont the costs add up to what? $410? plus the scooter if you dont have one $500? and the electric scooter itself costs $200? but, i would build this. its great.



kicker109 says: Sep 29, 2008. 1:32 AM **REPLY**

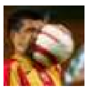
yeah you cant say that you built it all by yourself if you buy it

but you can if you buy all the pieces and actually build it yourself
who cares about the cost
JUST BRAG A LOT



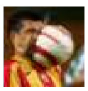
BobicusIX says: Sep 29, 2008. 6:15 AM **REPLY**

i like that...... looks like you could be good in debating, but youll probably need more reasons... good defense though...



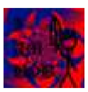
kicker109 says: Oct 2, 2008. 11:07 PM **REPLY**

Cheers, i was in the debating team once



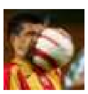
kicker109 says: Sep 29, 2008. 4:20 PM

(removed by community request)



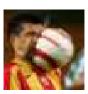
BobicusIX says: Oct 1, 2008. 10:20 AM **REPLY**

wait a minuet debating team? im in a math team but ive never heard of a debating team. is there a special competition for debating?



kicker109 says: Oct 2, 2008. 11:06 PM **REPLY**

no it isnt it is like a thing i do at school



kicker109 says: Oct 2, 2008. 5:40 PM

(removed by community request)

teamtestbot says: Oct 2, 2008. 6:06 PM **REPLY**

We can also talk about electric vehicles.

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