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Build a "Hybrid" Outdoor Robotics Power Plant

The era of backyard robots has arrived!

PHOTOS BY KEN GRACEY AND LAUREN DAVIS

Building an outdoor robot presents a whole new set of challenges to think about: navigation, traversing variable terrain, and more substantial power supplies. With this project I focused on the power supply. My goal was to build a supply that would provide plenty of power for an hour-long outdoor navigation excursion.

Converting a gasoline engine's power to proportionally controlled, bidirectional rotation is a challenging task for the hobbyist. The options include: (a) hydraulically, with a pump connected to the engine and two motors on the drive wheels; (b) a clutched direct connection between the engine and drivetrain, using brake steering for either side for forward-only motion; or (c) a hybrid, in which electric power is generated by the engine to drive electric motors. Transmissions are also an option, but they're not readily available for gasoline engines this small.

I reasoned that a hybrid approach would provide the ease of electric motor control, fewer custom parts, and hopefully an abundance of power from a gasoline engine. The battery would only be necessary to provide the voltage the alternator needs to start generating current and to absorb large current surges by acting as a capacitor for peak power demands.

Headlights on the front of the robot provide ample light for nighttime operation.

Electronics are in the front of the robot (that's a Propeller Proto Board on the left). The Ping))) ultrasonic distance sensors are built into six locations around the perimeter of the chassis.

WHAT TO DO WITH ALL THE POWER

Automotive alternators generate at least 25 amps. After my first experiment it was apparent that I had an unlimited power budget. Rather than adding up my power needs and choosing a battery with capacity to run for an hour, I had the luxury of being able to allocate as much power as I wanted to an assortment of accessories! Though it was tempting to load up the robot chassis with broadband, flame throwers and a stereo, my focus was on testing out the hybrid power supply.

I added just enough loads to prove the concept:

Device	Qty/robot	Current draw @ 12V(amperes)
Planetary gear 150 RPM motors	2	7.0
20 watt halogen lights	3	5.1
Propeller P8X32A-Q44 Processor	1	0.1
HB-25 Motor Controllers	2	0.1
Ping))) Ultrasonic Sensors	6	0.1
HS-755 BB Throttle Servo	1	0.5
Total		13 amps

With no load on the motors my power needs were around 13 amps. With load on the motors demands would increase the total budget to around 25 amps.

CHOOSING A FOUR-STROKE ENGINE AND ALTERNATOR

Just a few years ago most of the smaller engines were two-strokes used on garden equipment. Putting such a two-stroke engine on your robot would have been loud and dirty. Furthermore, an alternator doesn't require lots of low-end torque to start spinning.

The new four-stroke engines are quiet and much cleaner. The main manufacturers of small four-stroke engines are Subaru Robin and Honda. The Subaru Robin EH035 1.6 HP engine costs less than $200 and the Honda GX35 1.6 HP engine is about $230. These two engines have identical mounting locations, shaft size, and very similar power bands. The differences are small, but my favorite is the Subaru Robin because it operates more smoothly and it has a built-in power switch. Both engines can easily turn the alternator to around 5,000 rpm with a 1:1 coupling to generate ample power.

Alternators come in a variety of sizes and ratings, but my favorite is the "45A Denso mini 1-wire alternator for race cars." These little alternators provide more than enough power. They are generally available for around $150 on eBay without the exchange of a core.

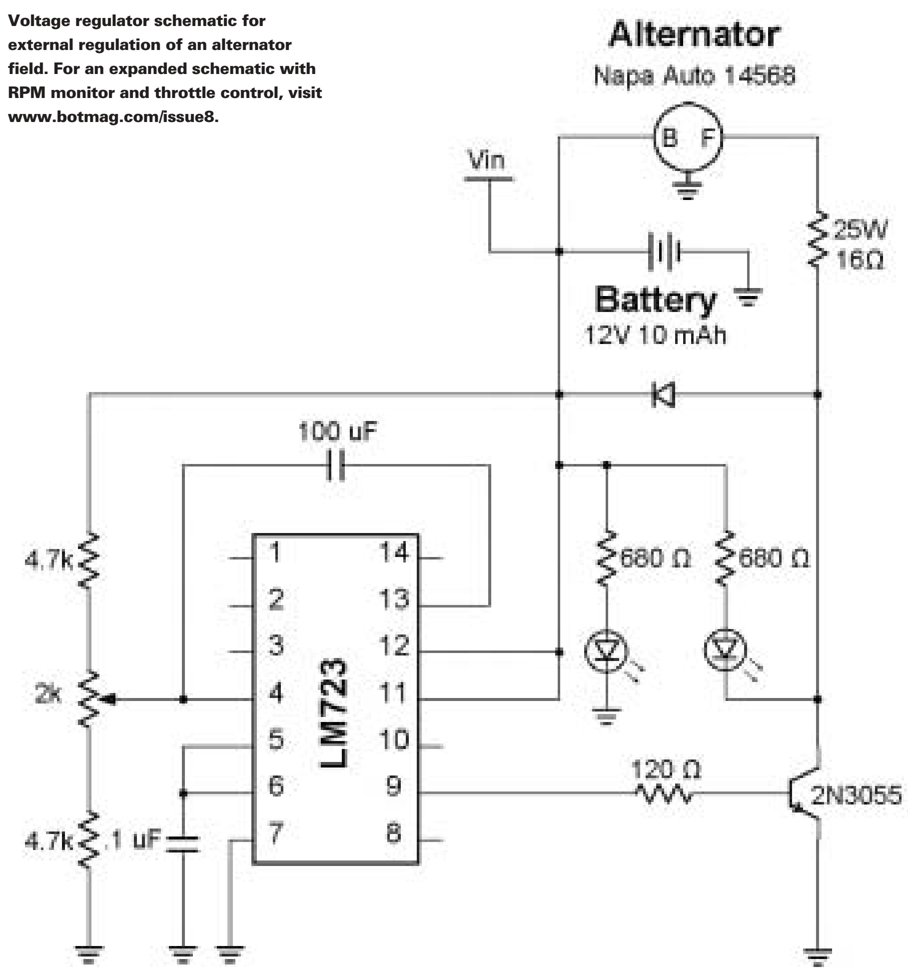
MECHANICAL CONNECTIONS

Every robot project seems to have a set of challenges worth at least several months of effort if pursued individually, but they're all skill builders for future projects. One challenge with this project was the mechanical connection between the engine and the alternator. There are two ways to go about this: a direct coupling, in which the shafts of the engine and alternator are aligned end-to-end and joined with a spider coupling, and a pulley-belt system in which the alternator sits adjacent to the engine. You can choose your connection type based on your tools, skill and perseverance.

I used the direct coupling approach. This uses less space and fewer parts, and is generally safer if you've selected a coupling rated for the torque and rpm. But it still has two challenges, and they're substantial. First, aligning the shafts is quite difficult. Engines include datasheets that show the shaft location relative to mounting holes, but alternators have a mounting system designed for belt tensioning, with two mounting holes that are often not concentric to the shaft. They may even be on different planes. Typically one hole fixes the alternator to a fixed bracket on the engine block and the other side slides along a bracket to tension the belt. To get around using the alternator's mounting holes I milled the face of the alternator and tapped four mounting holes so the alternator could be mounted directly to a plate of aluminum.

I made a similar mounting plate for the Robin Subaru EHO35 engine. The plates were positioned on the chassis so the alternator and engine could slide together and engage the spider coupling. The rubber bushing in the spider absorbs any tiny misalignment that might still exist after assembly.

No machine tools? Use the pulley-belt approach. Alternators come with pulleys and it is easy to find keyed pulleys to slide onto the engine shaft. Now your mechanical hurdles are reduced to mounting the engine and alternator adjacent to one another on a metal plate. Small amounts of misalignment between the engine and alternator are accommodated by the belt, and the only fabrication you will need to do is to make a bracket to mount the alternator to the base plate.



Voltage regulator schematic for external regulation of an alternator field. For an expanded schematic with RPM monitor and throttle control, visit www.botmag.com/issue8.

VOLTAGE REGULATION: MEETING THE BATTERY'S EXPECTATIONS

The internet is a great place to research how an alternator works, so I'll describe what you need to know to connect an alternator to something smaller than a car battery. In short, you'll need an external voltage regulator and a way to limit charging current, but first let me explain why.

As an alternator's rotor rotates, a magnetic field is formed through an outer coil to generate alternating current (AC). The frequency is determined by the alternator's rpm. Since the purpose of an alternator is to charge a battery and run 12V direct current (DC) accessories in your car, they have internal diodes to convert the AC voltage to DC.

Most alternators also have internal regulators that limit their output to 14.4-14.8V (normal for charging 12V car batteries). Internally regulated alternators are usually called "1-wire" alternators because they have a single wire for a battery connection. This output voltage is fine for a car battery—they have huge capacity with a 60 amp-hour rating and they're designed to handle 14.4V continuously. These larger batteries can also handle the high output current of an automotive alternator. The alternator I chose can deliver 45 amps, which is fine for a big battery, but would destroy and maybe even explode a smaller battery like the one I'm using. These smaller batteries require an external regulator to protect them from a large alternator.

The wheels were a project by themselves!

PICK THE RIGHT BATTERY

So why not use a car battery? For starters, if your robot carried a car battery, you'd have so much power that you certainly wouldn't need the engine or the alternator to keep it charged, not to mention your robot would be too heavy to be useful. Also, you'd be using excess power just to push the car battery around. It's just not practical. Heavier robots are also more dangerous.

My goal was to minimize robot weight by choosing a smaller battery. The bulk of the robot's power needs are supplied by the alternator so the battery only needs to be big enough to handle current surges. I chose a 12V 12 amp-hour battery from Power-Sonic. This is the sealed lead-acid type for the sake of safety. Like many batteries of this size, the datasheet specifies a 14.5V charging voltage until the battery draws only 20 milliamps when connected to a power supply, after which time it should be reduced to "float" at 13.8V (not 14.5V). Continuing to charge the battery with 14.5V will damage it, eventually causing a leak or perhaps even an explosion. Because the regulator in our alternator would continue to charge at the higher voltage (14.5V) and because it could supply up to 45 amps of current, we had to come up with an external regulator.

EXTERNAL REGULATOR

To use an external regulator, you must first remove the internal regulator from the alternator. To do this you would basically be removing all the electronics in the alternator and bringing the field winding out to an external connector. The specifics of this process will vary with the alternator type, but the procedure is really pretty simple once you get into it. You want to leave the alternator's battery connection alone and remove or disconnect all of the other electronics. Next you locate the wire from the field and bring it out so the external regulator can use it to control the charge rate.

My friend John Olson from Tigerbotics came to the rescue with a voltage regulator design. The regulator circuit is designed to limit the charge to 13.8V. It also incorporates a 25-watt, 16-ohm resistor in the field line to limit the maximum charge current to a safe level. Everything worked perfectly!

THE REST OF THE ROBOT

The robot used in this article is a three-wheeled tail-dragger design. This is an effective steering method at low speed, but becomes a bit unstable at higher speeds as the rear end responds aggressively to any change in drive-wheel velocity. Stability could be improved through a narrower stance on the drive wheels. The robot runs well on pavement and low-cut grass. The drive wheels are about 7.5 inches in diameter, and total weight is around 50 pounds.

If I make another robot like this one, I'll improve it by spacing the drive wheels more closely. Since the width of the robot was determined by the length of the motors, I will either need to find shorter motors or come up with a gear or chain-drive design so I can offset the motors. This would improve performance, but complicate the design considerably. I'll also have a front bumper—it hurts to watch the nicely machined parts run into paved walkways.

One additional recommendation I hear from friends is to add a starter motor, or to use a regular DC motor instead of an alternator. Perhaps this motor could do double-duty and start the engine. All of the custom-machined parts were made on a Wabeco FF-F1210 desktop CNC milling machine.

PARALLAX PROPELLER

The Parallax Propeller processor controls the robot. In the trade show environment it runs from the battery alone and the Propeller performs the following functions simultaneously:

- Receiving and mixing of the RC radio signals
- Motor control through two HB-25s
- Triggering and processing the data from the six Ping))) ultrasonic sensors
- Transmission of sensor data over a Parallax RF Module to another Propeller connected to an XGA display, where bar graphs show the data for each of the Ping))) sensors

The Propeller code was written by one of our technicians, David Carrier. David has spent a fair amount of time working with our larger robots, including a full hydraulic model you'll see in the future.

DANGER AHEAD

Working with gasoline, electronics and large robots provide many opportunities to hurt yourself or others. Having worked in our machine shop extensively and sitting through 10 years of safety presentations at

A direct coupling between the engine and alternator requires minimal space and looks really clean. This approach is also safer, since there are no belts to catch your fingers.

Parallax, I take safety seriously. But danger is always seeking a victim, especially when your guard is down and basic safety practices are not being followed.

My first accident with this project happened when the robot caught fire on my desk. I’d start the engine for a few minutes to count the magneto pulses so I could control the engine’s rpm. I opened the front door and slid my desk close to the door so I could direct exhaust outside. While my attention was focused on the oscilloscope display and the microcontroller data on a PC, I throttled the engine to 5,000 rpm and that’s when the explosion occurred. The voltage regulator board caught fire and the LEDs and capacitors exploded. It happened so quickly I didn’t know whether to reach for the fire extinguisher or to throw the flaming project outside. The fire put itself out after the printed circuit board burned out. The cause remains unknown, but I’m fairly certain I had reversed connections on the voltage regulator board.

The second accident occurred while driving the robot around the Parallax building. A co-worker showed interest so I passed him the controls. He drove the robot into a square curb and the battery broke free from the chassis, causing a puncture and leak of sulfuric acid across the power and ground connections. This happened on an early prototype when I was using a regular acid-based battery. Now I’m using gel-cell sealed lead-acid batteries and I mount them low in the chassis and away from power supplies. I also mount the engine so any leaky fuel doesn’t contaminate electronics or batteries.

It’s also possible that spider couplings can break apart at a high rpm. Choose one rated for the project and shield it if possible. If you’re using a belt and pulley mount them in an enclosure. Both of these incidents were a result of my poor judgment, but nobody got hurt in either of them.

CONCLUSION

The hybrid power supply provides lots of power in a compact and lightweight package. As long as you have gasoline you have power, and when the fuel runs out your robot may still run for quite a while off of the battery. This project was rewarding and informative. My next objective with this robot is to navigate around the perimeter of the Parallax building with GPS. I’d like to watch it pass by my office every minute or two while I drink my espresso. I hope to have that part accomplished by the end of summer.

All drawings and technical information about this robot are open-sourced at www.parallax.com/hybrid. There’s also a circuit and Parallax SX code example for counting magneto pulses to control the engine’s rpm. I’d be pleased to answer additional questions about any aspect of the project. If you decide to undertake a project like this you can never have enough helpful friends. Without helpful friends I probably wouldn’t have accomplished this project. Why not build your own backyard robot? If you do, send pictures to editors@botmag.com and we’ll share your project with our readers.

Ken Gracey works for Parallax Inc. in Rocklin, California. His primary robotics interests include educational uses, small walking robots, machining and outdoor robotics. Additional videos and pictures of this robot are available on the Parallax web site at www.parallax.com/hybrid. Ken can be reached by e-mail at kgracey@parallax.com. ◎

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For more information, please see our source guide on pg. 97.