

Our resident expert on all things robotic is merely an email away.  
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Tap into the sum of *all human knowledge* and get your questions answered here! From software algorithms to material selection, Mr. Roboto strives to meet you where you are — and what more would you expect from a complex service droid?

by  
**Dennis Clark**

As the summer winds down (sigh), I always start to get more interesting questions. One this month about robot lawn mowers seems more in tune with the summer than the fall, but (in some parts of the USA) I guess stuff grows all year long (not in Colorado I might add, unless you are a pine tree). It appears that some of you like to keep LOTS of data on your robot from one question I got, which is kind of cool — a sort of running diary for your robot, if you are into that kind of thing! I'll say more on these things later.

As hobbyists, we have been doing line followers, wall bumpers, and mini Sumo and their ilk for quite a while now. While they do entertain the myriad gawkers at our shows and demos, they have ceased to entertain us any more. How about folks doing robot "art," like talking heads that track motion, or voice-controlled helper bots carrying your toolbox or ... In other words, are folks out there doing useful things with their robots?

I've wanted to do a robot lawn mower for a while now (one of my questions this month). I did recently get a Roomba to vacuum my lab space for me (I hate to clean) — thank you, Woot! I may not know the answer to every question that I get, but I like to research those questions and hopefully come up with answers, or even options to investigate.

We should step up to the plate as robot hobbyists, and do more than table-top conversation pieces if we want to advance the hobby. So, I challenge folks out there to knuckle their chins, scratch their heads, and generally get creative to come up with more ubiquitous robots to let loose into the wilds of our houses or yards, to actually do something that we find useful or more widely entertaining than say, a remote control mayhem monster or a table-top line follower.

The principles that we learned with our line followers and mini Sumo robots do have a use in this new world of robots. It was not wasted time! The basic idea behind the line follower can be used in our robot lawn mower to have it, for instance, follow a buried cable that it can track. My Roomba vacuum has a wall sensor (maze solver), cliff

detectors (mini Sumo), and a bumper sensor. With these and the IR dome on the top, it does a pretty good job of cleaning a room.

What have you learned that you can build into a larger and more useful robot? Let's see, shall we?

**Q** - I am making an RC project that involves turning a push mower into a mini-zero turn type mower. I would like to know what type of motor to use. I need to know how much torque is needed to push a certain amount of weight. Should I try a high torque, low speed type motor for my project?

— Mark G. Powell, OH

**A** - I have a suggestion for your platform. I've seen the "zero radius" turn mowers that the professionals use; they appear to have differential drive wheels in the back and a pair of large castors on the front of the mowing deck. That seems to be how you should build your mower.

There are some rules of thumb that you can use, or you can use math. Let's start with math. We need to know how heavy your mower platform is to start with, so we know what kind of power we need for the drive motors. I'm going to give you the gist of Chapter 2 of *Building Robot Drive Trains* that I wrote with Michael Owings a few years ago. This is a thumbnail discussion of how you can estimate what you'll need for motors. If you are interested in going into more depth, check this book out of your local library, or, buy a copy of your very own (for which Michael and I will thank you).

Even though this discussion will get into some math, I promise, it won't hurt a bit! First off, we want to estimate what power we'll need in our motors to move the mower the way you want it to move. To move our robot, we'll be working against two basic forces: friction and gravity. Together, we get this:

$$F_{app} = F_f + F_w$$

The force we need to apply ( $F$ ) must be greater than the force of friction plus the force of weight (due to gravity) to move. The force due to gravity is shown as this formula:

$$F_w = mg \sin \theta$$

which means the product of our mass and acceleration due to gravity times the sin of the angle from the perpendicular to the ground is the force due to gravity that needs to be overcome. As obvious as this formula may seem (that was a joke, really), it may need some explanation.

We all get the "heavy things are hard to move" part, but what is that *sin theta* thing all about? It's easy, really. Push something on level ground, grunt a bit, and off it goes, right? Well, now push it up your driveway at a 20 degree angle. Suddenly it isn't so easy to push, right? Now, for the next bit, friction – the other half of our simple equation above. This is the formula for the force to overcome friction:

$$F_f = \mu mg \cos \theta$$

The first term,  $\mu$ , is the coefficient of friction – *static* friction (more on that later.) You have seen "mg" before; it is weight – the cosine is of the angle off of the horizontal plane. What this all comes down to is that friction is highest on flat ground and zero when falling straight down; that makes sense. There are two kinds of friction: static friction, which is the friction to overcome to get moving; and dynamic friction – that which needs to be overcome while you are in motion. The latter is far less than the former. Even a wheel has a surface area in contact with the ground; it isn't just a single point, it has width and length. Until that wheel starts to turn, it is basically just skidding on the ground.

Once the wheel starts turning though, everything changes and the friction goes way down. Push anything with wheels. Did you notice that you really had to heave to get it going? Once it is moving, it is much easier to keep moving. That is partially friction; the other part is Newtonian physics – momentum; objects in motion tend to want to stay in motion.

Back to the point. The coefficient of friction is rarely given, but can be measured. If you are interested, it is the ratio between the *resistive* friction over the *normal* friction. Normal friction is basically the force holding things together,  $mg$ , or weight. To get the resistive friction, get a fish scale and attach it to the object and pull. That force will look like weight since this is a scale; take that value. Simple.

Now, we have the final formula for measuring the force needed to move your robot lawn mower:

$$F_{app} = mg \sin \theta + \mu mg \cos \theta$$

I like to work in metric units, so  $g = 9.8m/s^2$ , therefore, I use mass in kilograms. Finally, we need power. This formula is:

$$P = F_{app} v$$

which means power is force times velocity. For that to be useful, we need this formula for motors:

$$\omega = v / r \Rightarrow v = \omega r$$

Rotational velocity is velocity divided by the radius of the arm from the center of the motor. The second formula just puts it into the form we want for the power formula above.

Now for units. These are the units to work with when using these formulas to get the power you need for your motors:

Term	Unit
Power	Watts (W)
Force	Newton Meters (Nm)
Mass	Kilograms (kg)
Angle	Radians
Rotational Velocity	Radians/Sec

Pick the angle to match the inclines that will most likely be the worst case scenarios in your yard. Pick a coefficient of friction to be something like a car tire, which I've found to be about .9 to 1.0 for a rubber tire on concrete (to be conservative). If you choose 1.0, obviously that term falls out. Just plug in your numbers.

How do you know the power of your motors? Sadly, no one ever gives you that. If you get a motor brand new from a manufacturer, you might be able to get the maximum torque and maximum rotational velocity, which gives you the power by this formula:


$$P_m = T \omega$$

The motor power is the torque times the rotational velocity; this gives you the power at any chosen torque and velocity, but not the maximum power. The maximum torque in a DC motor is at zero rotational velocity, which is no power. The maximum rotational velocity is where the motor torque is at its minimum. To get a motor's maximum power, it needs to be where the torque is at 1/2 and the velocity is at 1/2, which gives this formula:

$$P_{max} = \frac{1}{4} T_{max} \omega_{max}$$

Torque is force and (here) is shown as Nm; rotational velocity is in radians/second. I don't know the English units; I'm more comfortable in metric. Torque is the angular force that a motor can deliver at some distance from the shaft. If your motor could lift 1 kg on a pulley with a one meter radius, that would be one Newton meter. There are  $2\pi$  radians in a full circle.

This suggests a way to get the power of your motor empirically; lift weights using a measured pulley, or pull on



your fish scale if you have a big motor.

That is the math you would use to choose your motors. This will get you close to what you need for success. Gordon McComb (of *Robot Builders Bonanza* fame) shared his secret for success: the heft method. He would look at his robot frame, pick up a motor, and hold it to gauge its *heft* to determine its suitability. I myself do not have Gordon's calibrated arm, so I tend to do a little math.