PUSHY ROBOTS

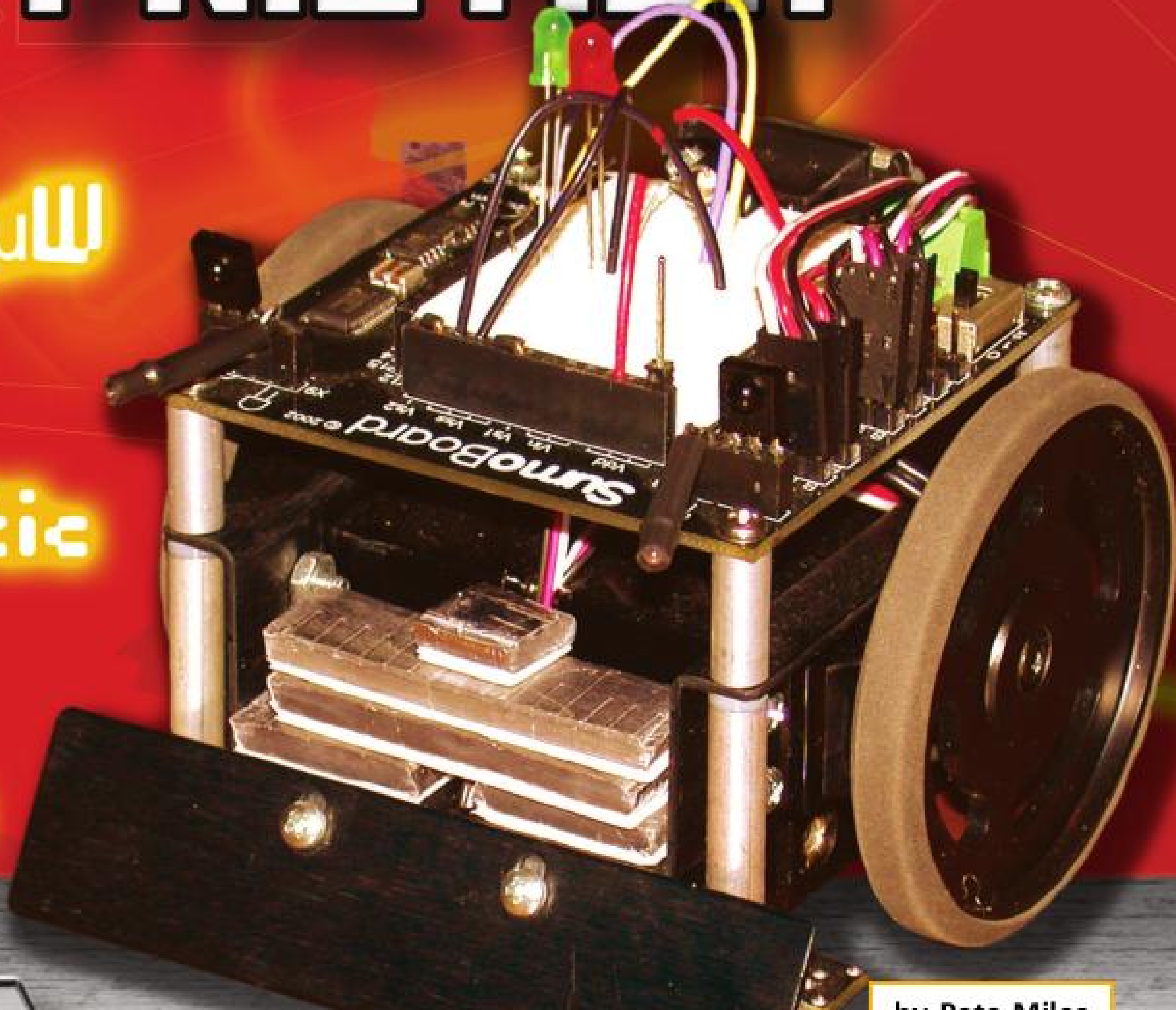
IT'S ALL ABOUT FRICTION

Friction

$F = \mu W$

static

kinetic



by Pete Miles

It is amazing how many people that compete in robot sumo events forget about the main aspect of the game — "pushing" your opponent out of the sumo ring. Most people try to use good software, advanced sensors and electronics, and decoys to win a contest. This does help make the robot look really "smart," but not better at pushing. In the end, they usually lose to a robot that has great pushing capabilities.

This article will explain how to obtain the competitive advantage in the pushing war against other robots. Mini sumo robots will be used as the primary example since there are thousands of them competing across the world.

But all of the information presented here is applicable to all robot sumo weight classes, Antweight (one pound robots) combat robots, or any other type of a robot that needs maximum pushing capabilities.

Friction

The key to maximizing the pushing capability of a robot is friction. Equation 1 shows a generalized equation that tells you everything that is important about maximizing pushing capabilities. The frictional reaction force, F, is also the maximum pushing force of the robot.

The coefficient of friction, μ, is the main topic of this article, and W is the weight of the robot. Since the weight of a robot is constant during a match, the only thing that can improve the pushing capability of the robot is to increase the coefficient of friction between the wheels and the sumo ring (arena surface which is formally called a Dohyo). This equation shows that as the coefficient of friction, μ, increases, the robot's maximum pushing force, F, increases (assuming the motors don't stall).

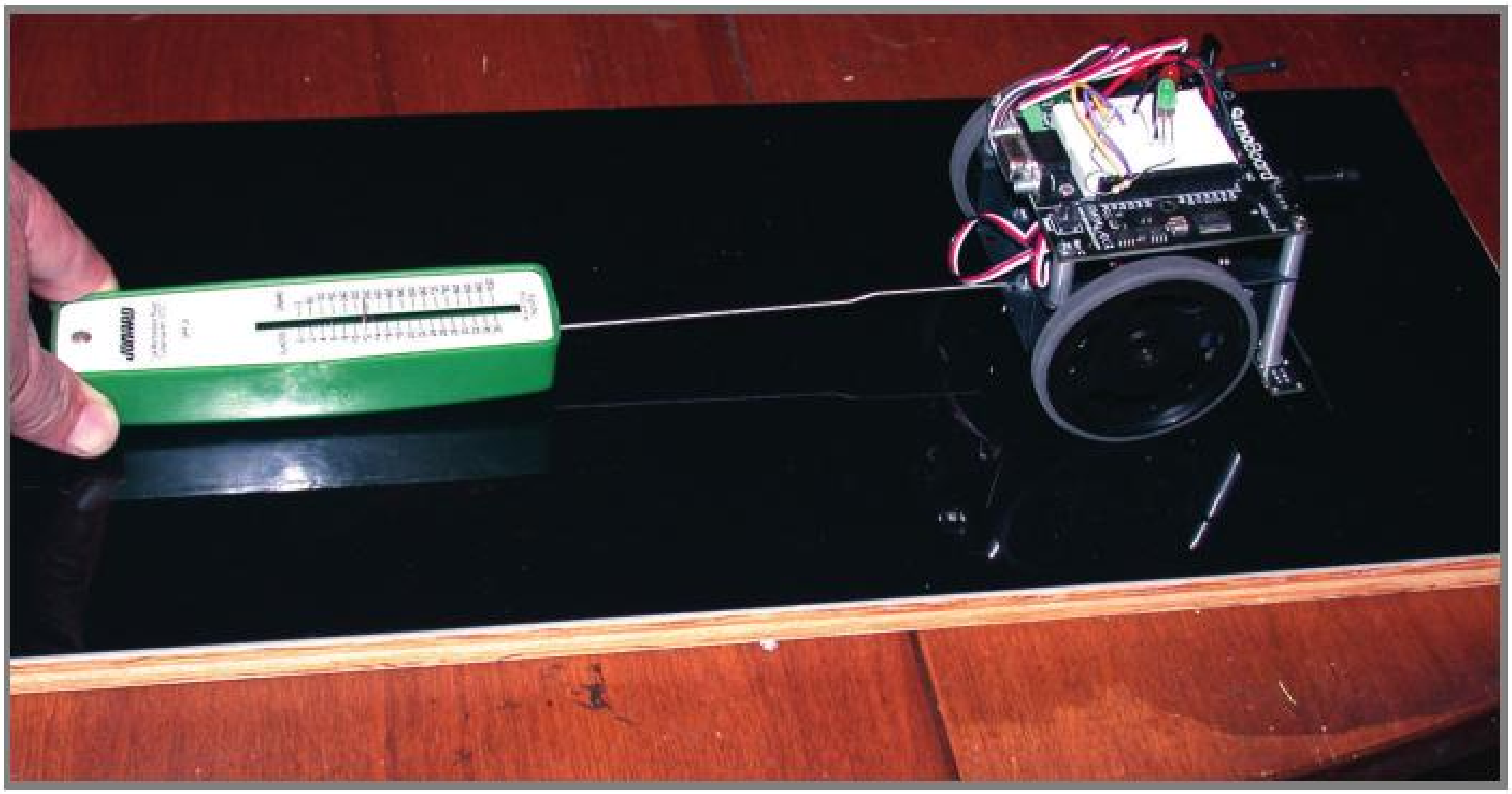
$$F = \mu W$$

The three primary types of friction that have the greatest effect on the overall pushing capability of the robot are: Static, Kinetic, and Molecular/Adhesion. Static friction is what prevents objects from sliding across a surface. Kinetic friction is what resists an object when it is sliding across a surface. For hard, non-deformable objects, the static and kinetic reaction forces are only a function of what the object's materials are

made from and the normal forces pressing the two objects together. In this case, the weight, W, of the robot.

Since most tires are made from some type of soft, compliant material, molecular/adhesion friction properties come into play. This is where the material deforms into all of the microscopic nooks and crannies in the surface, and requires more energy to be pulled out of — or pulled across — those tiny surface imperfections. One way to think of it is that it takes more energy to move a wheel over a rock/speed bump than across a flat surface. The molecular/adhesion effects occur at the microscopic level where there are millions of tiny speed bumps trying to resist objects from sliding across the surface. Soft, compliant wheels take advantage of this to improve the overall coefficient of the wheel's friction.

FIGURE 1. Directly measuring the static and kinetic coefficients of friction.



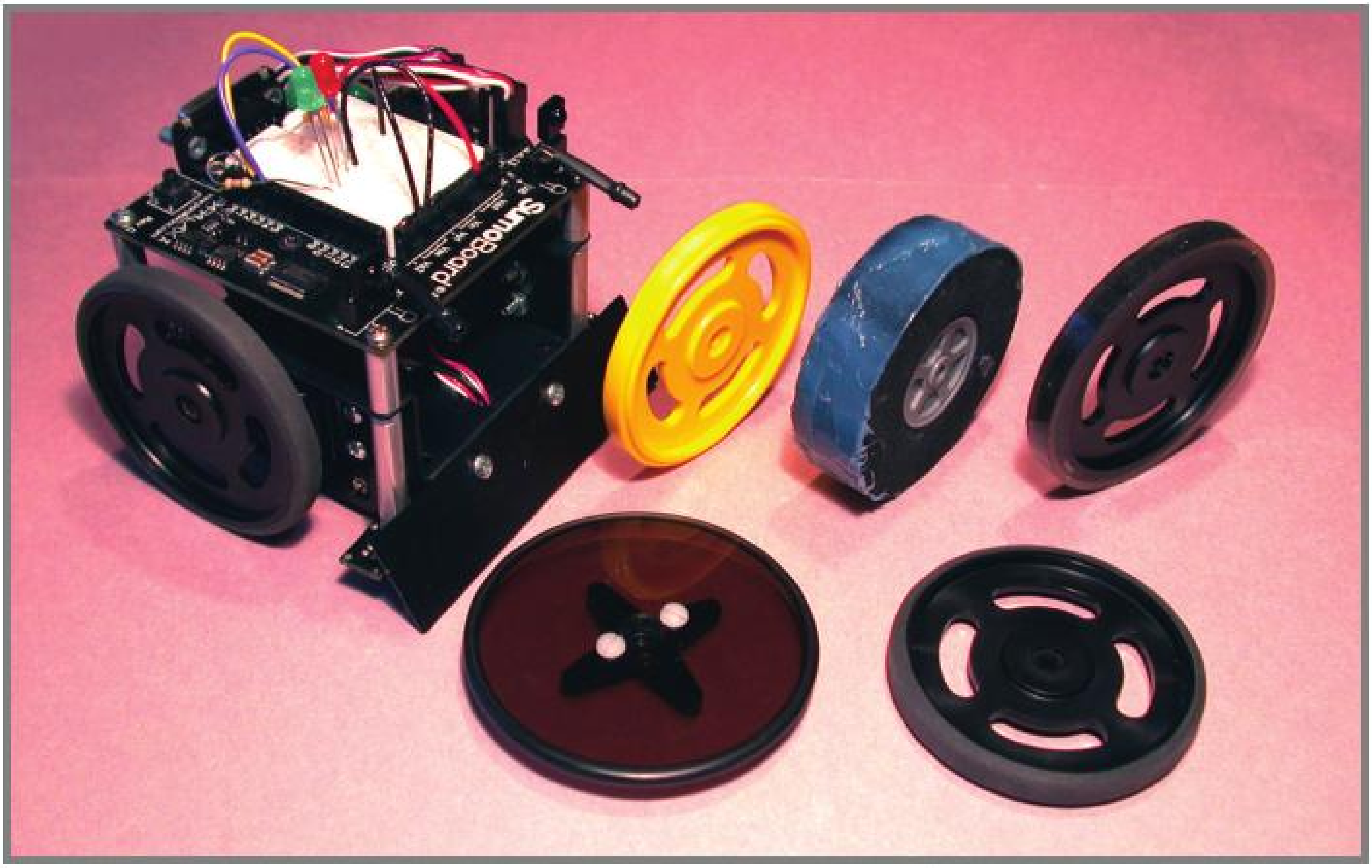


FIGURE 2. SumoBot with various wheels: (top, L to R) solid plastic, silicone coated foam, rubber band, (bottom, L to R) O-ring, polyurethane tire on plastic.

One of the things that makes molecular/adhesion friction different from classical static and kinetic friction is that it is very dependent on the surface areas that are in contact with each other. The larger the contact surface area, the greater the coefficient of friction. The molecular/adhesion coefficients of friction are extremely difficult to calculate, so they are often found by experiments and presented as a range of values.

One of the easiest ways to measure the static coefficient of friction (including molecular effects) is to use a scale (such as a fishing scale) to pull/push the robot across a horizontal surface (see Figure 1). The highest observed force — at the point when the robot first starts to move — is used to calculate the static coefficient of friction. From Equation 1, the static coefficient of friction can be determined by dividing the measured force by the weight of the robot.

The kinetic coefficient of friction is found in a similar manner. For sumo robots, there are actually two different types of kinetic friction. One is found by measuring the force required to

TABLE 1. Coefficients of friction of various mini sumo wheels on a vinyl sumo surface.

Material	Static Friction	Kinetic Friction
Hard plastic (SumoBot wheel w/o rubber band)	0.39	0.11 — 0.17
Buna-N rubber (O-ring style wheel)	0.44	0.52 — 0.62
Rubber band on SumoBot wheel	0.73	0.51 — 0.85
Silicone rubber coated foam wheel	1.39	1.26 — 1.44
Cast polyurethane tire on SumoBot wheel	1.53	0.67 — 1.67

slide the robot across a surface at a slow constant speed. The other is to hold the robot stationary, let the wheels spin on the surface, and measure the robot's pulling force. The second one actually gives more useful information, since the robot will be spinning its wheels during a contest.

When including the molecular effects in the kinetic coefficient of friction, there is usually a fairly large range of values that are measured for a particular type of material. This is due to the vibrating nature of soft materials sliding across a surface. The vibration is due to the materials biting into each other, then releasing, then biting, and then releasing, and so on.

The release results in the tire bouncing up in the air. The greater the bounce height or vibration frequency, the greater the drop in the pushing force (i.e., kinetic friction) that is measured. When a wheel is spinning on a surface, it will experience the full range of different kinetic friction values at any given moment. This is one of the reasons why a robot that is pushing well is suddenly pushed backwards, and then regains the pushing advantage.

Table 1 shows a list of measured static and kinetic coefficients of friction for different types of mini sumo tires on an official vinyl mini sumo ring surface. The kinetic friction values were measured from pulling force when the tires were spinning on the Dohyo. For pushing purposes, the larger the friction coefficient, the greater the pushing capability of the robot. This table shows that solid plastic tires are the worst tires to use, and the best to use are the cast polyurethane tires. Though the polyurethane wheels had the highest static coefficient of friction, they also had the greatest range in the kinetic friction coefficients. This shows that this material could see large momentary reductions in pushing capabilities when the wheels are chattering across the surface of the Dohyo.

The silicone rubber coated and cast polyurethane wheels are generally the best wheels to have on a sumo robot, since they offer the best traction over the other types of wheels. The following sections will describe how to make silicone and polyurethane wheels.

FIGURE 3. Coating a wheel with silicone, commonly used to make automotive gasket seals.

Silicone Coated Wheels

The easiest method to modify an

FIGURE 4. Diagram for SumoBot tire mold.

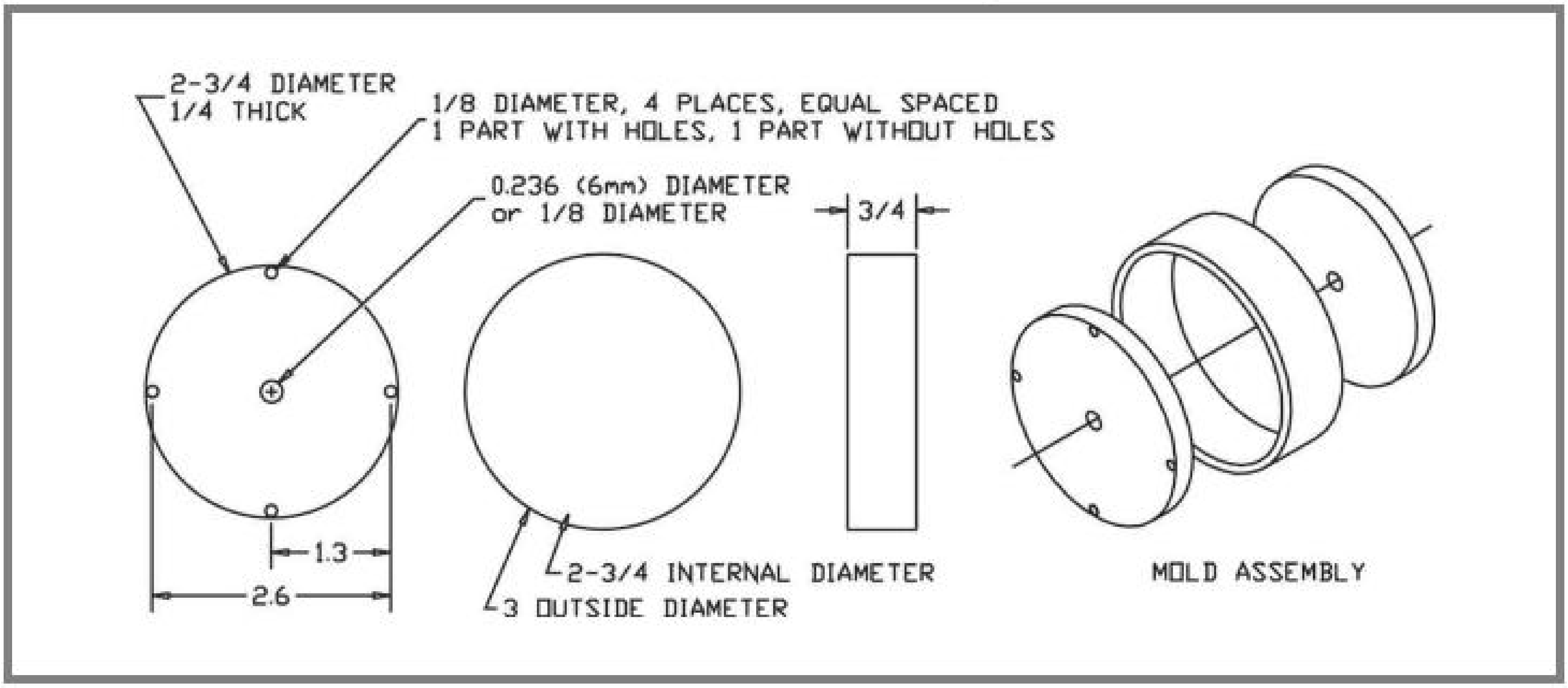


FIGURE 5. The completed mold, without wheel (L) and with the wheel inside (R).

existing wheel into a high traction wheel is to coat the wheel surface with silicone rubber. All that is required is a tube of silicone rubber, such as the RTV (Room Temperature Vulcanizing) silicone rubber that is used to make gasket seals for automotive engines. They can be found at any store selling automotive parts. Spread a small amount of the silicone on a small flat stick such as a popsicle stick, and then spread the silicone on the surface of the wheel. Only a thin coating is needed. Do this in a well-ventilated area since fresh silicone odor is noxious and wear rubber gloves, since this can be very messy. When the wheel is coated, place the wheel on its flat side on an elevated surface to dry. The elevated surface is used to keep the fresh silicone from touching another surface when drying. Allow a minimum of 12 hours to dry.

Past experience has shown that a mini sumo with silicone coated wheels will out-push any mini sumo that is not using any silicone or urethane enhanced wheels. This is one of the easiest things that you can do to enhance your robot's pushing capability. The finished wheels are generally not pretty to look at, but when you are winning, who cares.

Casting Urethane Tires

Casting your own tires is often a challenging process, mainly because there is very little information available on how to do it. Table 1 showed that tires made with a soft polyurethane material yielded the highest coefficients of friction. Because of this, it is the material of choice for the serious competitor. Mold fabrication is one of the trickiest parts of the tire casting process. The shape of the tire is solely dependent on the shape of the mold. The mold needs to consist of several parts, such as an internal wheel geometry and external tire geometry. The mold must be designed for easy disassembly so that the completed tire can be removed without being damaged. The mold must also have injecting ports to allow the liquid casting material to be poured/injected in, and have exhaust ports to allow the air inside the mold to escape as it is being filled. Getting the air out of the mold is often the hardest part of the casting process. Any air left inside the mold results in air bubbles in the final tire.

There are many different ways to make a mold and it's difficult to say which way is the best. Figure 4 shows an example of how to make a mold for casting tires on the Parallax SumoBot wheels. This is a four-part mold. Three of the parts are shown in Figure 4, and the fourth part is the actual SumoBot wheel (with the rubber bands removed, of course).

The best material for this mold is clear so that you can see if there are any bubbles inside the mold. The four 1/8 inch diameter holes near the outside diameter of the 2-3/4 inch diameter disk are only placed on one of the two disks. These holes are for filling and allowing air to escape as the mold

FIGURE 6. Mixing the two compounds together on a scale — ratios are by weight, not volume.

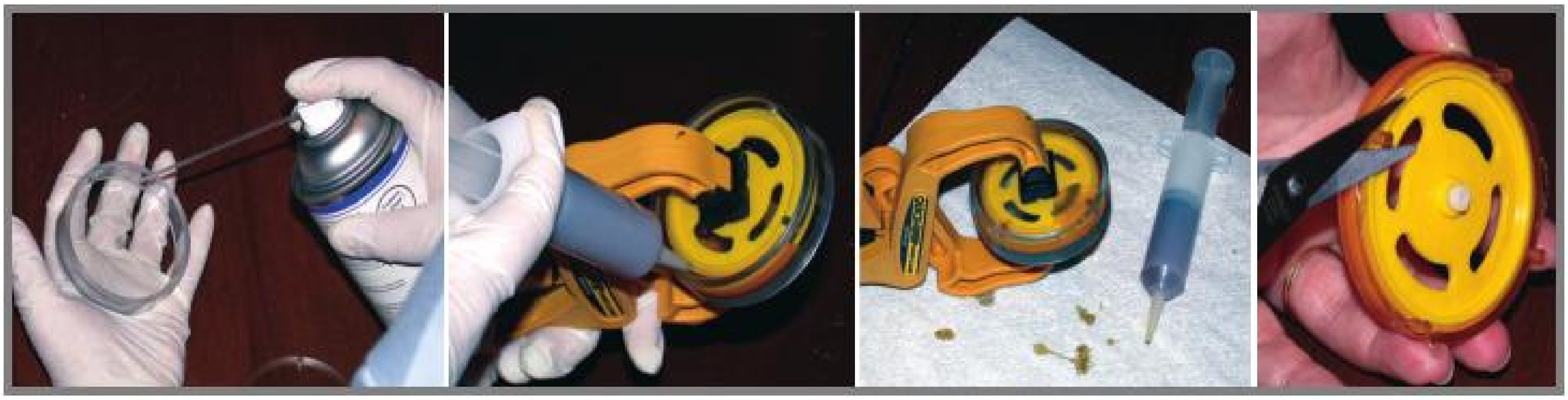


FIGURE 7. Applying mold release (left), injecting the mold with polyurethane, filled mold, and trimming excess flashing and mold spurs (right).

is being filled.

Prior to making the mold, you need to decide how you want to center the wheel inside the mold. This affects the decision on whether to use a 0.236 inch diameter or an 1/8 inch diameter hole in the center of the front mold disk. I like to use the shaft from an old servo to center the SumoBot wheel.

The spline end of the shaft is pressed into the wheel, and the other end fits inside the 0.236 inch diameter hole. The other option is the use a 1/8 inch diameter hole instead of the 0.236 inch hole. Then a one inch long 4-40 screw is used to center the SumoBot wheel inside the mold.

One advantage is that a nut can be used to clamp the entire mold together. Otherwise, an external clamp is required to squeeze the entire mold together. The two 2-3/4 inch diameter disks should fit snugly inside the tube section, but loose enough to be easily pushed out of the disk with the fingers. The looser the fit, the greater the amount of leakage that will occur when the mold is filled. Figure 5 shows a photo of a completed mold with a yellow wheel from Acroname.

The most popular type of casting material for the tires is the two-part liquid (known as Part A and Part B) polyurethane that is used for making molds. There are many different types that are designed to produce a certain Shore A hardness rating in the final product. (Shore A is an industry standard for measuring the hardness of rubber materials.) The different polyurethane materials can have hardness ranges from 10 to 80.

The smaller the number, the softer the material. A Shore A hardness of 80 is similar to a bowling ball, and a Shore A of 10 is a soft, flexible gummy material. The softer the polyurethane becomes, the higher the coefficient of friction becomes, but it becomes easier to stretch and tear. For mini sumo wheels, a Shore A in the range of 20 to

FIGURE 8. Polyurethane tires on three different colored mini sumo wheels.

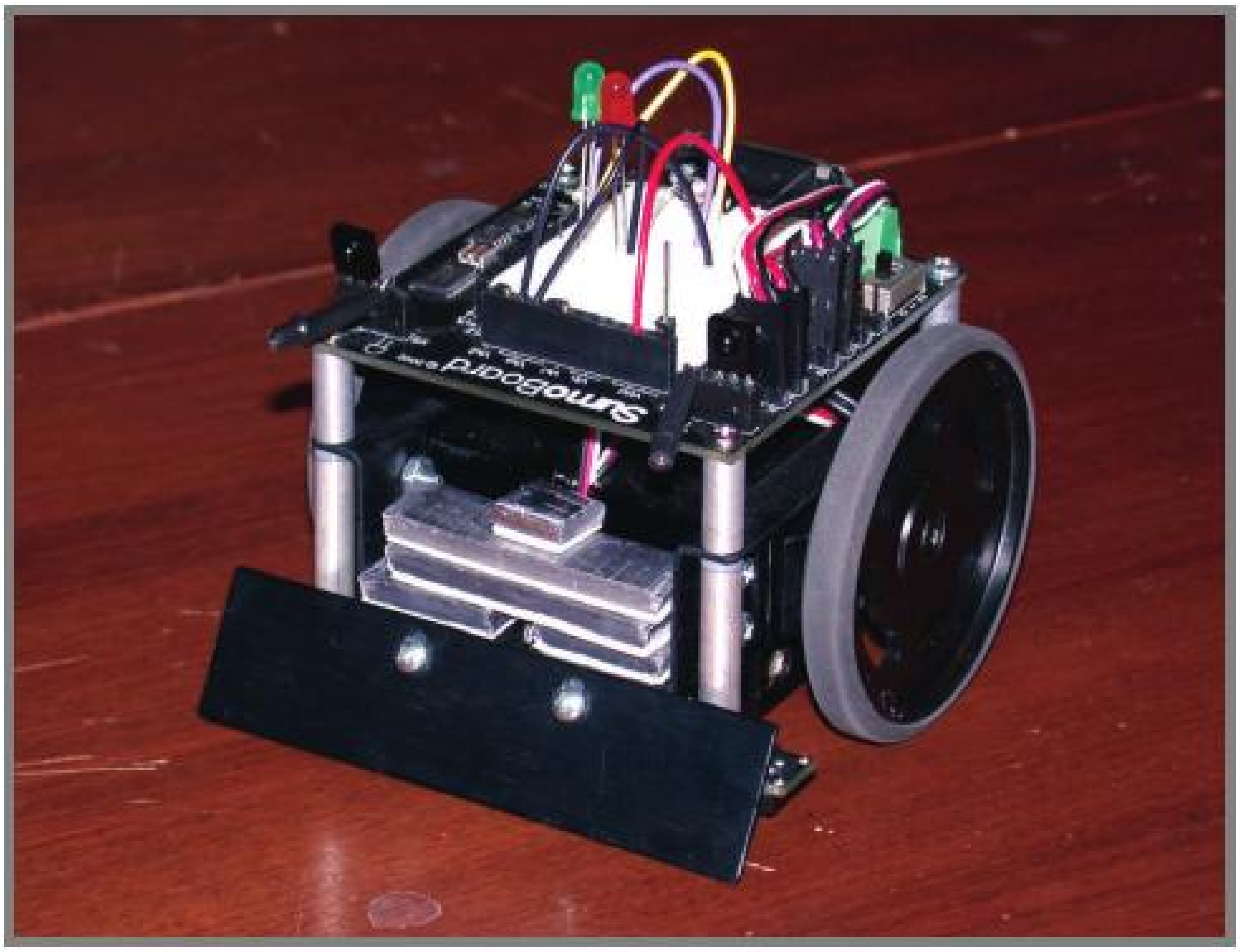


FIGURE 9. Adding lead weights to the front of a Parallax SumoBot robot.

30 should be sufficient. Tires with hardness values less than 20 may be difficult to keep on the wheel because they will be very flexible.

The two compounds are mixed together by weight, not by volume, and they are very sensitive to the exact mixing ratios. (Different products have different mixing ratios that range from 1:1 up to 4:1.) One of the best methods for mixing the two compounds is to use three disposable cups and a scale. Pour a small amount of each compound in two of the cups. Place the third cup on the scale and then zero the scale. Pour a certain amount of one of the Parts in the cup on the scale, say 25 grams if you are making two of the wheels described here. Make sure the volume is more than half the volume you are going to need to make the tire.

Calculate how much of the second compound that will be needed, and then pour it into the cup on the scale until the total weight is achieved. The Urethane RTV Mold Making System, Shore A-30, from Tap Plastics was used in this example. This product is easy to work with, and uses a 1:1 mixing ratio. Slowly mix the two compounds together to prevent bubbles from forming in the mixture.

Before assembling the mold, spray all of the mold surfaces with a mold release compound, such as Polytek POL-EASE 2300, so that the tire will easily release from the mold, otherwise the tire will be damaged when disassembling the mold. If you want the tire to stick to the wheel, then do not spray any mold release on the wheel's surface. Place the wheel in the mold after the mold release has been sprayed in the mold. Then clamp the two surfaces tightly together so that no casting material can leak towards the center of the wheel.

One of the best ways to fill this mold is to use a bulk syringe to inject the polyurethane into the mold. Hold the mold vertical then inject the polyurethane at the bottom of the mold. Slowly fill the mold until the polyurethane leaks out of all of the air holes (see Figure 7). Then rotate the mold so that all of the air holes are pointed vertically.

This is a very messy process, and there is a good chance that the mold will leak during the filling process. You may have to continually add more polyurethane to the mold until the polyurethane sets up (starts to harden) if the mold leaks. You have about 15 minutes to fill the mold from the time the compounds are mixed. Otherwise, the polyure-thane becomes too thick to be useful.

After the mold is filled, then let it harden for at least 24 hours before removing the tire from the mold. If done properly, the tire should slip out of the mold without any effort. It takes about a week for polyurethane to fully cure.

A successful casting process is a tire that has no bubbles in it, which is very difficult to achieve. But some small bubbles in the tires are okay to have. The last step is to trim off any excess flashing and the spurs from the air and fill holes. Figure 8 shows polyurethane tires mounted on three different colored mini sumo wheels available from Acroname.

Casting should be done in a well-ventilated area, and you should wear gloves since the liquid compounds are respiratory and skin irritants. The liquids smell bad during the mixing process, but the final dry casting has very little odor. Though the casting process can be complicated, it will be well worth the effort when you have a superior pushing robot at your next competition.

One last comment on silicone coated and polyurethane tires — in order for them to work at their maximum capability, they need to be clean. These wheels will pick up every dust particle in the world, and this will significantly reduce the effectiveness of these wheels. It's best to bring cleaning material to a contest, such as baby wipes or facial wipes you get at barbecue restaurants, to clean the tires immediately prior to a match.

Maximizing Weight

The one thing that everyone should do with their mini sumo robots is to make sure that they are at the maximum weight of 500 grams. Equation 1 showed a generalized equation that told you everything that is important about traction. The equation also shows that as the weight of the robot increases, the greater the pushing force becomes.

Maximizing the weight of a mini sumo robot is probably the easiest thing you can do to improve your robot's pushing capability. The SumoBot kit from Parallax only weighs 360 grams right after assembly (with batteries), which is 140 grams less than the maximum competition weight. A lot of people build these kits and add some really great software where it can dance circles around opponents on the sumo ring, but end up losing to a brainless bot all because the other robot weighed 50 grams more. This is one of the most frustrating things many new mini sumo competitors experience.

The easiest way to solve a weight shortage is to add some lead weights. Lead is very dense, so it won't take up a lot of space on your robot. Lead weights can be obtained from lead fishing weights found at your local sporting goods store, or from an auto tire store. Another good source is your local hobby store. There they have strips of lead with an adhesive backing that is helpful for sticking on the bottom of your robot.

When your robot is completed, place the robot on a scale, and add the lead weights to the scale until you reach 500 grams. Then all you have to do is find open places to place this lead on your robot. The best place for the lead is at the bottom of the robot and more towards the front scoop of the mini sumo robot (see Figure 9). You want to keep the weight as close to the ground as possible, to minimize the chances of getting tipped over.

Bring a pair of wire cutters with you when you go to weigh-in at a tournament. Many times, the scales at the tournament will read a different weight than what you have at home. If your robot is a little over weight, then you can use the wire cutters to trim off a little bit of the lead weight to reduce the overall weight of the robot.

By applying everything you learned in this article to your mini sumo robot, 3 kg sumo robot, and just about any smaller combat robot, you will have a robot that should have the competitive pushing edge during any contest over robots that are not using these techniques. **SV**

ABOUT THE AUTHOR

Pete Miles is a senior research engineer that develops advanced abrasive water-jet machining technologies and hardware. He is a long time competitor in robot sumo, heavily involved with the Seattle Robotics Society, and he organizes one of the largest amateur robotics events in the US — the Robothon. He is also the author of ***Build Your Own Combat Robot*** and ***Robot Sumo: The Official Guide.***

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Recommended Casting Material

Synair, Inc., **www.synair.com**
Por-A-Mold 2020
Shore A-20

Tap Plastics, **www.tapplastics.com**
Urethane RTV Mold Making System
Shore A-30

Polytek Development Corp., **www.polytek.com**
Poly 74-30 Clear, Shore A-30
POL-EASE 2300 Mold Release

Plastic Mold Materials:
McMaster Carr, **www.mcmaster.com**
12" x 12" x 1/4" Polycarbonate sheet, P/N 8574K28
3" O.D. x 2-3/4" I.D. Polycarbonate tube, P/N 8585K21
30 cc regular tapered syringes, P/N 7510A655

Mini Sumo Kit
Parallax, Inc., **www.parallax.com**

Alternative Mini Sumo Wheels
Acroname, Inc., **www.acroname.com**

Robot Sumo Rules
Northwest Robot Sumo Tournament
www.nwrst.com