Chapter

9

Combot Events

This chapter presents several tips related to combat robot events, and how to get ready for them.

9.1. Before the Event

The first step is to find out an event. In the www.buildersdb.com website you'll find all the information on most of the incoming as well as past events. There you'll also be able to register your team, builders and robots, as well as search for other teams and robots. In addition, the Robot Fighting League events can also be checked at http://botleague.net. Don't forget about the registration deadlines, the organizers need to know as soon as possible how many teams will attend to plan accordingly. It's important to register in advance for the events, because there might be a limited number of robots in each weight class. Read carefully all the event rules, to make sure that there are no problems with your robot.

9.1.1. Test and Drive Your Robot

Finish your robot before you travel to the event. There's nothing more stressful than going for an all-nighter on the eve of the event. Especially if you'll be waking up all other hotel guests with grinding noises and the smell of burnt rubber mixed with Dremel disks, as we unfortunately did during our first event back in 2003. Guarantee that your robot will pass safety inspection.

Train driving your robot. A lot. Several matches are won or lost because of the driver's ability. Train slalom using traffic cones. Wendy Maxham suggests a practice technique from Grant Imahara's book [10], in which you mark out a square on the floor and then drive the robot as close to the edges as possible. You'll learn how to drive straight, and how to make sharp turns. Start out slow, then go faster and faster until you reach full speed. Don't forget to train in both directions, to practice both left and right sharp turns.

Another great practice move, suggested by Matt Maxham, is the "James Bond turn." While driving forward on a straight line, quickly spin your bot 180^o and reverse the wheels to keep driving in the same sense (you'll be driving backwards, but in the same original sense). Then spin again, to make the bot face forward, always moving in the same sense. It is a good maneuver to make your weapon face the opponent while you're escaping from it. It is also a great maneuver to shoot your pursuer during a car chase, if you're James Bond.

During a combat, you can't waste time thinking about which way to steer, left or right, which can be tricky if your robot is moving towards you. As Matt Maxham says, you (the driver) need to imagine that you're sitting on top of the bot, then you'll naturally steer in the correct direction.

Buy a cheap remote control car to play cat and mouse. Actually, buy more than one, they usually don’t survive when you catch them. In early 2003 we created a toy overhead thwackbot out of a plastic remote control car (pictured to the right). The robot itself, while driven, was useful to improve our skills controlling overhead thwackbots in general, which are very tricky to handle. And this toy robot also doubled as a very fast and efficient “mouse” when chased by our first middleweight combot *Lacrainha*.

Always test your robot. Test it under real conditions, drive it against a wall, several times. Use its weapon (if any) to hit on junk parts with up to the same weight as your robot. Try to hit solid one-piece blocks, to avoid having small parts flying all over. A low hardness sparring is a good idea to avoid blunting your weapon, such as the 7” diameter solid aluminum block that our combots like to play with, pictured to the right. Use the hit-break-fix it technique, until your robot does not break anymore. It is important to test the robot well in advance, to make sure that there will be time to fix it before the event.

Drop your robot from 3 feet (about 1 meter) in the air over a rigid floor. It needs to resist this fall, no matter which weight class it belongs to. From fairyweights to super heavyweights, all of them are usually thrown higher than that during battle. Drop it several times and always verify if something broke or got loose. If you really trust in your robot’s resistance, try dropping it from 6 feet (about 2 meters). Most well designed combat robots can survive such 6 foot fall. During RoboGames 2006 we were able to verify that: the heavyweight Sewer Snake (pictured to the right) was still functional even after it was launched several feet into the air by the super heavyweight Ziggy.

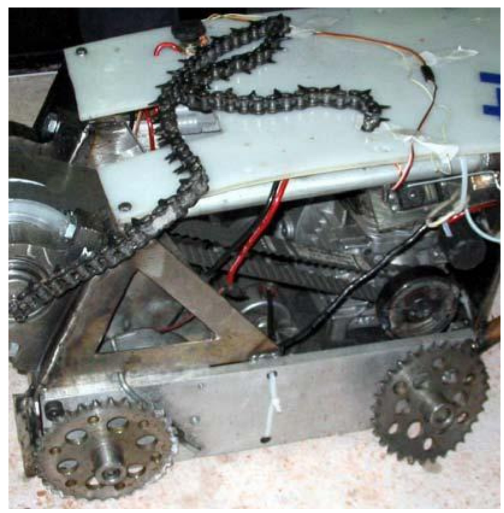
Tests will expose the robot’s weak points. It is usually possible to correct them without changing too much the original design. Even a tiny flaw can sometimes be enough to make you lose a match. Therefore, it is very important to have redundancy. For instance, if your robot uses 2 or more batteries in parallel, guarantee that it will keep moving if one of them fails. If your robot has 4 active wheels, guarantee that if one of them is destroyed all the other three will still be able to drive it. If you use belts or chains in a critical component such as the weapon, consider the possibility of using a double pulley or double sprocket. During Touro’s first match ever, at RoboGames 2006, its opponent was able to tear one of the drum V-belts. However, Touro’s weapon continued to spin because of the redundancy from the second V-belt, allowing it to win the match by knockout.

9.1.2. Prevent Common Failures

The 20 most common causes for a combat robot to lose a match, according to the website http://www.solarnavigator.net/robot_building_tips.htm, and our proposed solutions, are:

1. Battery connectors or other wires getting loose – always use good quality connectors such as Deans or Powerpole, always use ring terminals (not fork terminals), tighten each terminal connection using pressure washers (but never place them between the electric contacts, since their electric resistance may be high), and use liquid electrical tape or hot glue;

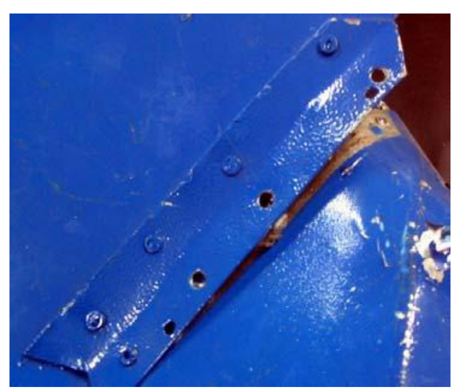
2. Motors, batteries or other components getting loose – avoid using nylon ties or clamps, even the metal ones, always verify any loose parts and tighten critical screws before each match, use threadlockers or spring locks;



3. Chains coming off from the sprockets – make sure that the sprockets are well aligned, avoid exposed sprockets (as in the special drive system for ice arenas from the robot pictured to the right); if possible, replace the chains with timing belts (such as in the weapon system of the same robot to the right), which can withstand larger misalignments;

4. Radio interference or signal loss – if using 75MHz or lower frequency radios, place the antenna outside the robot, without touching the metal surfaces, and use an amplified antenna such as the Deans Base-Loaded Whip (chapter 7); if using 2.4GHz or higher radio frequencies, or if the covers are not metallic, then the antenna can be left inside the robot;

5. Improperly charged or low capacity batteries – always use electronic chargers such as Triton, check the battery voltage before each match, and calculate and test the robot's consumption under real conditions; before an event it is a good idea to apply several discharge-charge cycles to the batteries;



6. Smoking speed controllers – always match the maximum acceptable current in the controller with the motor specs; if a wheel or a spinning weapon gets stuck during a match, turn it off to avoid stalling the motor;

7. Rupture of rivets, screws, nuts – never use rivets (seen in the picture to the right), always use hardened steel screws and nuts, class 8.8 or 10.9 for hex screws and 12.9 for Allen, and with appropriate diameters as discussed in chapter 4;

8. Low clearance robots getting stuck in the arena – from hobbyweights to super heavyweights, make sure that you have a ground clearance of at least 1/4”, preferably 3/8” or more; don’t forget to consider the wear and tear of the wheels, and use flat head screws on the robot's bottom cover to make sure they won’t get stuck on the arena floor;
9. Low power wheel and weapon motors – use motors with enough power to guarantee that your robot’s drive system acceleration is high enough for your strategy, preferably taking less than 2 seconds to reach top speed; if you have a spinning weapon, make sure that it can reach damaging speeds in less than 4 seconds;
10. Burning fuses – do not use fuses in combat, otherwise you can lose a match only because of a brief current peak; use a current limiting circuit if needed, but not a fuse;
11. Shorting of wires and electric components – always isolate the terminals with electrical tape (either regular or liquid, as pictured to the right), heat shrink and/or hot glue; always protect any electronic component that can be shorted out if metal debris enters the robot;

12. Overheating motors – avoid overvolting too much the motor; several motors can take up to twice their nominal voltage, but it might be necessary to use a current limiting circuit; in a few cases it is possible to mount fan blades onto the rear end of the motor shaft to improve cooling; avoid stalling the motors during combat;
13. Broken gears – all gearboxes need to be well designed and built, with well aligned and precisely spaced gears; the gear thickness and teeth dimensions must be proportional to the torque it carries; therefore, to optimize weight, use heavier duty gears in the last stage and lighter ones in the first; always use hardened steel gears instead of mild steel or cast iron ones;
14. Internal combustion engines that die or won’t start – use an automatic ignition system, controlled by a separate radio channel (see chapter 5);
15. Shaft mounted components getting loose – never use set screws or pins, either in shaft couplings (as pictured to the right) or in other shaft mounted components such as pulleys or sprockets; always use keys and keyways (or keyless bushings such as Trantorque) to transmit torque, and very tight shaft collars to avoid axial displacement;

16. Broken or bent shafts – never use shafts made out of mild steel (also pictured to the right) or aluminum, always use hardened steel or titanium grade 5; make sure that the shaft diameter is large enough to keep the stresses below the material yield strength;
17. Wheels getting stuck in the robot’s bent structure or armor (also pictured to the right) – leave a significant clearance between the wheels and any armor or structural part of the robot that could get bent;

18. Flat tires – use solid wheels such as Colsons or, if using pneumatic wheels, make sure that they're filled with polyurethane foam, such as the NPC Flat Proof wheel pictured to the right; a few pneumatic kart wheels, aimed for rental karts, are so sturdy that they could be used in a robot without having to be inflated or filled with foam;

19. Robot failure due to arena hazards – this only applies to arenas with hazards, such as saws coming out of the floor or large sledgehammers; against saws, make sure that your robot has a thick bottom plate or cover it with alumina tiles; against sledgehammers, use a shock mounted top cover;
20. Home-made speed controllers and electronics – building a reliable speed controller that can withstand hundreds of amps is not a simple task, do your research and thoroughly test your system if you plan to develop it by yourself; see chapter 7 for more information.

9.1.3. Lose Weight

Make sure that your robot is not over its weight limit. When designing it, estimate the weight of all the components, to avoid unpleasant surprises. CAD programs can provide very precise calculations if you feed them with the correct part weights and material densities.

And don't forget to include the weight of the screws. We forgot to include the screws when carefully designing and calculating Touro's weight back in 2006, just to find out after it was built that it was almost 6.5lb (almost 3kg) overweight. Just because of the screws. To lose weight, there are a few techniques, as described next.

Rearrange your robot's components

If you're still in the design phase, try to rearrange the robot's internal components to reduce the chassis dimensions. If your robot has several empty spaces in it, it won't be difficult to make it smaller.

Consider all possible component arrangements, but don't forget to leave enough space for the wiring. Try placing the batteries in different orientations.

If it's a 4 wheel-drive design with 4 motors, try using only 2 motors with a timing belt or chain transmission to drive all wheels. If your design does not depend too much on traction, such as with powerful spinners, try using only 2 wheels, with the robot's center of mass located close to the line that joins their centers.

Change the battery type

Switch SLA batteries to NiCd or NiMH. Most 24V SLA batteries have a capacity density of about 1.25A·h/kg, however this number does not consider the de-rating factor (see chapter 8) for a 3 minute run time. It does not consider the worst case scenario, where it will be fully discharged at the end of a 3 minute match. The de-rating factor in this case is about 0.28, which would result in a capacity density of only 0.28 × 1.25A·h/kg = 0.35A·h/kg.

The de-rating factor of nickel batteries in 3 minutes is much better, about 0.9, therefore a typical 24V NiCd pack would have 0.9 × 2.1A·h/kg ≅ 1.9A·h/kg, while a typical 24V NiMH pack would have an even better 0.9 × 2.9A·h/kg ≅ 2.6A·h/kg. In this way, without decreasing the robot's battery capacity, you can lose 80% of the battery weight when changing from SLA to NiCd. Changing from NiCd to NiMH will result in an additional weight loss of about 30%. But be careful with NiMH packs because, despite their greater capacity, they cannot supply the high current peaks that a NiCd pack with same capacity can, which makes a big difference especially for the weapon acceleration.

To lose weight even more, you could migrate to lithium batteries (see chapter 8), such as Li-Po, Li-Mn, or Li-Fe-PO_4 (A123 or K2), however with a higher cost.

Reduce shaft dimensions

To lose weight, try reducing the diameter of the robot's shafts. This can make a difference especially if they're made out of steel, which has a high density. This will also reduce the size and weight of other components such as bearings and their mounts. Check if the shaft length can be reduced. Using a lathe, drill an internal hole through the entire shaft, as long as it hadn't been tempered, to transform it into a cylinder. If the shaft has diameter D and the hole d, the weight will be decreased by a factor d^2/D^2, while the bending and torsion strengths (which usually are the most important in shafts) will decrease by only a factor of d^3/D^3. In this way, for instance, if a hole with diameter d = D/2 is drilled, the shaft weight will decrease in $(D/2)^2/D^2 = 0.25 = 25\%$, while the bending strength will only be $(D/2)^3/D^3 = 0.125 = 12.5\%$ lower.

Change the shaft material

An excellent technique to lose weight, although costly, is to switch all steel shafts to titanium grade 5 (Ti-6Al-4V), without increasing their diameter. We had to do this with Touro, its 1.5" diameter weapon shaft was originally made out of tempered 4340 steel, weighing 6lb (2.7kg). Since it had already been tempered, it would be very hard to drill it, as explained above, to lose weight. The solution was to replace the shaft with a Ti-6Al-4V one, which only weighed 3.5lb (1.6kg), resulting in a 2.5lb saving. And the shaft strength was not significantly lowered, because this titanium alloy has excellent mechanical properties. The cost was not too expensive, considering that it is a critical part of the robot: about US$150, in the US.

Avoid the temptation to switch steel to aluminum in shafts. If the shaft diameter is maintained, low and medium strength aluminum alloys will easily yield, and most aerospace alloys will possibly break due to their lower impact toughness. Aerospace aluminum could result in a lighter shaft with the same strength as a steel version, but the increased diameter needed by the resulting shaft would significantly increase the weight of its bearings, collars, and all other shaft mounts. So, as extensively discussed in chapter 3, choose titanium and hardened steel shafts instead of aluminum or magnesium ones.

Change the material and dimensions of robot components

Wisely changing the material of a robot component is not a simple task. This was thoroughly discussed in chapter 3. The best material choice to reduce weight depends on the functionality of the component. For instance, if a robot's armor is shock-mounted to its structure, then most structural parts could have their stiffness maximized without worrying too much about impact toughness, while the armor should withstand impacts without worrying too much about its stiffness. In this case, very thick magnesium or aluminum alloys would be a good choice for a light structure, while thinner titanium Ti-6Al-4V would make a tough and light traditional armor.

But there are several other cases and options. See chapter 3 for a more detailed discussion on weight saving techniques based on changing both the material and dimensions.

Reduce the thickness of plates

If after optimizing the materials of the entire robot it is still too heavy, then it might be necessary to decrease the thicknesses of its plates.

The first idea that comes to mind is to drill holes in the plates, turning them into Swiss cheese. This should only be considered in an emergency, during the event. Holes are a bad choice, because they let debris enter the robot, which can short out the electronics, not to mention the higher vulnerability against hammerbots, spearbots or overhead thwackbots with thin weapon tips, which could reach internal parts, as well as against flamethrowers. Besides, circular holes have a stress concentration factor of about 3 under tension and 2 under bending. In other words, even a small hole will locally multiply the mechanical tensile stresses by 3 and bending stresses by 2 (the stress concentration factors of several geometries can be seen in the Appendix C). These higher stresses make it easier to initiate cracks at the borders of the hole.

In addition, you would need too many holes to significantly lose weight, as seen in the next example. Consider, for instance, a 0.5m × 0.5m cover plate made out of 1/4" (6.35mm) thick aluminum. Its mass is approximately $2800\text{kg/m}^3 \times 0.5\text{m} \times 0.5\text{m} \times 0.00635\text{m} = 4.45\text{kg}$ (9.8lb). Let's try to lower its mass in 25%, to 3.33kg (7.3lb), using a hole saw to drill several 1" (25.4mm) diameter holes. Each hole would only relieve $2800\text{kg/m}^3 \times \pi \times (0.0254\text{m})^2/4 \times 0.00635\text{m} = 0.009\text{kg}$ (0.02lb). In other words, to lose 4.45 – 3.33 = 1.12kg, you would need 1.12/0.009 ≅ 124 holes! In addition to the hours spent drilling 124 holes, the robot would suffer from the problems discussed above regarding debris, piercing opponents and flamethrowers.

A better solution is to mill the aluminum plate. In the previous example, we could decrease the plate thickness down to 3/16" (4.76mm) through milling, resulting in a 25% lighter plate. The bending stress of a plate depends on the square of its thickness, therefore it would be multiplied by $(6.35/4.76)^2 = 1.78$ in the thinner plate, which is lower than the factor 2 that would be obtained by drilling holes. And, since the tensile stress along the plate depends directly on its thickness, it would be multiplied by a factor 6.35/4.76 = 1.33, much smaller than the tensile factor 3 of the holed version. Therefore, the milled plate would have a higher strength than the holed one.

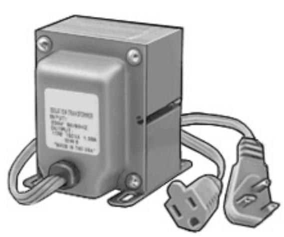
An even better solution is to selectively mill the plate. In other words, to reduce the thickness of the plate only in a few areas, leaving it with the original thickness at the most stressed areas. This was the procedure adopted in the 5/16" thick top cover plate of our middleweight Touro, to lose weight. We've selectively milled 1/8" deep pockets on its outer surface, as pictured to the right. The thickness was neither reduced near the screws (not to compromise strength) nor where the weapon motor is mounted (by the RioBotz logo in the picture). The strip-shaped area between the pockets was also kept with its original thickness, acting as a rib to keep high the plate bending stiffness.

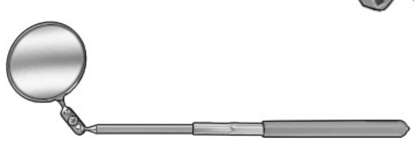
9.1.4. Travel Preparations

Once your robot is built and tested, making sure that it is not overweight and that it complies with all the event rules, then the next step is to make travel arrangements. Plan the trip well in advance, you'll get cheaper fares and hotel rates.

What to bring

Before the trip, make a list of tools. Avoid the temptation (which I have) of bringing your entire machine shop to the event. Choose wisely which tools you'll really need, among the ones listed in chapter 2. A few very useful items, but usually forgotten, are a portable vacuum cleaner (pictured below, to clean the robot interior in between matches, because small metal debris can cause shorts), a large fan (to cool down the batteries after each match, before charging them), a 220V/110V transformer if needed (pictured below, rated to at least 1kVA if using several power tools and chargers at the same time), heavy-duty electric extension cord, plug strip (pictured below), flashlight (for repairs inside the robot, preferably with a swivel head, as seen below) or headlight (for hands-free operation), telescopic mirror (to inspect the robot's interior without disassembling it, see picture), telescopic magnet (to pick up screws or nuts that fall inside the robot, see picture), and J.B.Weld and duct tape (for desperate emergency repairs in the robot). And don't forget the battery chargers and their power supply.


Have at least 2 sets of batteries, 3 or more if possible, and bring spare parts. It's a good idea to have robots that share parts, in this way you'll need to carry fewer spares. For instance, because both Touro's drivetrain and Touro Light's weapon system use Magmotors S28-150, it might be enough for both robots to only bring one spare. They also use the same front skids, battery packs, receivers, Victor speed controllers, TW C1 solenoids and MS-2 switch, not to mention several of their 8mm diameter screws. This helps a lot with spare part management and transport, in special if competing in overseas events.

Bring spare screws, in special if they're oddly sized or difficult to find. Remember that it will be more difficult to find metric screws to borrow in US events, and vice-versa, few Brazilian builders will have inch sized screws to lend. This also applies to tools that come in different systems of measurement, such as wrenches or sockets.

Traveling by plane

If you're traveling by plane, remember that most robot parts won't be allowed in the cabin, they'll need to be checked. Since your checked luggage will most likely be X-ray inspected and opened, it is a good idea to write down on each checked robot part what it is, such as "discharged dry cell battery pack" or "aluminum plate."

When traveling to RoboGames, we also include in every luggage a copy of Dave Calkins' invitation letter, explaining that the robots and parts are for competition purposes only. We also carry a picture of each robot (or its trading card, if it has one), in case the luggage is opened in our presence. In this way, it is easier to explain to the TSA officer why we're checking a sharp spinning bar or so many aluminum plates. If you're lucky, the TSA officer may even know your robot, as it once happened with Touro, making the inspection process very fast and friendly.

We've never had problems traveling by plane with NiCd packs, as long as they are discharged and placed into the checked luggage. Since no wet cell batteries are allowed in the plane, it's a good idea to write "discharged dry cell battery pack" on every pack.

Also, make sure that all the electric wires are very well organized and placed inside a different luggage than the one with the battery packs. Trust me, a luggage full of NiCd packs and random electric wire will draw a lot of unnecessary attention in the X-ray.

Apparently, lithium batteries such as LiPo or A123 can be carried with you inside the cabin, we've never had problems with them even when they were inspected. Otherwise, notebooks and their batteries would need to be forbidden as well. But they can be dangerous if shorted, so we always carry them partly discharged (not too much to avoid damaging them) and inside a fireproof LiPo sack such as LP-Guard (pictured to the right) or LipoSack.

You can ship your robot fully assembled in a crate. However, for international flights, you might need to apply for a temporary export of your robot if it is shipped fully assembled in a large crate. This is usually expensive, and it involves a lot of bureaucracy. Shipping the robot by sea is also risky, because even if sending it well in advance it might arrive at the event after it is over.

The cheapest solution is to carry your robot in your checked luggage, not in crates. If your robot is a middleweight or from a heavier weight class, you will need to partly disassemble it if you want to split it into two or more pieces of luggage. Lightweights or lighter robots can be checked fully assembled if the weight limit allows and if they fit inside the luggage. Our lightweight Touro Light is checked inside a 10lb luggage, reaching exactly the 70lb allowance for each checked item in international flights originated in Brazil.

A very good investment is to buy a digital scale, bringing it with you to weigh all pieces of luggage before each flight, using up the entire weight allowance. The 150lb capacity Pelouze digital scale with remote display, pictured to the right, is a good option.

Note that fees are less expensive to check in an extra luggage than to have several overweight bags. For instance, international tickets bought in Brazil have a 70lb allowance per bag, allowing 2 checked bags, with a US$100 fee for a third piece of luggage. Checked items between 70 and 100lb are subject to a US$100 fee per item, and bags over 100lb are forbidden. Therefore, if you're carrying for instance 180lb worth of robot parts, it is better to pay US$100 for an extra 70lb bag (which will allow you to carry 60lb worth of parts in each of the three bags, as long as each empty bag weighs up to 10lb), instead of paying US$200 for two overweight bags with 100lb each (90lb worth of parts in each plus the own weight of the luggage).

Get to the airport well in advance, in special because of the odd and heavy luggage you'll be carrying. For international flights, register the robot parts at the customs office from your airport of origin before leaving the country, it will simplify your reentry with them. You can do this in the same day of your departure, before checking your bags, but you need to arrive early. You only need to register foreign parts, but it is also a good idea to register custom-made parts such as the robot itself or large disassembled parts of its chassis. Parts might need to have a serial number to be registered. If they don't have it, check with the customs officers if they accept serial number plaques issued from a University, for instance. Most manual and electric tools don't need to be registered, they're considered as tools for professional use. But it is always a good idea to register any expensive part of tool.

Finally, if you're carrying a lot of weight, then rent a car or van at your destination. Choose to pick it up and also to drop it off at the airport. It's less expensive and more practical than riding a taxi carrying heavy luggage full of robots all over town.

9.2. During the Event

Finally, the great day(s) has arrived. How will the event be? We will describe the typical procedures based on our personal experience at RoboGames, in the US.

9.2.1. Getting Started

After getting your badge and the ones from your other team members, you will be assigned a table in the pits, where you'll place all your tools and robots. Unless you are competing with a single featherweight, you'll probably have to manage well the pit space to store all the robots and tools, as pictured to the right. Try to place the robots, all important and frequently used tools, radios, batteries and chargers on the table. Place all electronic equipment (such as soldering iron, electronic board support), radios, batteries and chargers close together on one end of the table, and the robots closer to the other end. In this way, there's less chance of dropping some heavy component on a delicate electronic board. Make sure you have plug strips on both ends of the table, one for the delicate electronic equipment, and the other to be used in power tools while working on the robots. The remaining items, such as large or infrequently used tools, should be placed under the table in an organized way, easily accessible.

Do not place any items on the neighboring tables, used by other teams, even during a frantic pitstop, unless they allow you to do that. I'm not a good example of this, I'm sorry if RioBotz ever invaded your table...

Arrive early. Try to pass safety inspection on the first try, and as early as possible. "This will give you time to relax and socialize with the rest of the competitors," as pointed out by Mr. Tentacle in his webpage http://architeuthis-dux.org/tips.asp.

Organize the team members so that each one of them has a defined function. Label your tools. Make sure that everybody knows where each tool is stored, either on top or under the table, and always return this tool to its place after using it. This can make a difference during a quick pitstop.

Have a notepad to write down all the ideas that you have during the event. Ideas will come either from what you've learned talking with other builders, or from what your robot learned while struggling in the arena. This information will be very useful later. Several important upgrades in our robots came from crumpled pieces of paper covered in grease and pizza sauce written during the event. Also, don't forget to tape and to photograph the entire event, several ideas will come up while reviewing the pictures and videos.

During the event, it is important to keep in mind that rivalry should stay inside the arena. Unlike these famous builders on the right, do not tease your opponents! Unless if it’s playfully, of course.

Talk with other builders, show them your robots, exchange information, lend tools. This sport is still relatively small, it is fundamental to help other teams and to learn from them, to improve the level of the competition, attracting spectators and sponsors.

Don't be afraid to show the interior of your robot to other builders, even if you'll face them in the next match. There aren't many secrets in this sport that haven't been revealed, in special if you search through the great number of websites, posts, build reports, tutorials and books on the subject. If you don't show your robot to other builders, you'll probably waste the chance of learning from their comments about your robot or from exchanging information by looking at theirs.

Let other people take pictures or tape your robot. This is good for your sponsors, in special if their logo shows up in the pictures or videos. Let them take pictures from your robot's interior. Even if another builder discovers a small weak point in your robot, he/she won't be able to explore it in the middle of a fight, there's not enough precision in combots to deliver a surgical strike. If your robot has a serious weak point, any experienced builder will figure it out even if you try to hide your bot. So, let them look at it, thoroughly if they ask to. In the next chapter, all RioBotz robots are exposed in details, including their interior components, through pictures and CAD drawings.

Walk along the pits to check the robots from the other teams, as pictured below. Unless the other builders are too busy repairing their robot, try to talk with them. But always ask for their permission to take pictures from their robots, in special if you want to touch some part of the bots. If you need to borrow a tool, these teams will most certainly be much more helpful if you have been polite with them.

A nice picture from the RoboGames pits is shown in the next page.

9.2.2. Waiting for Your Fight

Pay attention to the schedule of your next fight, not to get caught by surprise. Even if your fight will be much later that day, have your robot ready and checked. If you check your robot well in advance, you'll have more time to fix any eventual problems. In addition, if your opponent is also ready beforehand, you both can ask the event organizers for an earlier fight. Win or lose, this will leave more time after the match for you and your opponent to fix your robots.

About 30 to 40 minutes before the scheduled time of your fight, charge the robot's batteries one last time, to compensate for any self-discharge, which can be significant in nickel batteries. After this brief charging period, check the battery voltage with a voltmeter and close the robot.

If you're using wheels with polyurethane treads, such as Colsons, it is a good idea to clean their treads using WD-40. Just spray a little bit on the tread, all around the wheel, and wipe it off with a dry cloth or paper towel. Even though WD-40 is a lubricant, it will start to react with the polyurethane tread surface, making it very sticky and improving the robot's traction. The downside is that the arena dirt will also tend to stick to the treads, meaning that you'll need to clean the wheels before every match. But it is worth it. Another great suggestion to improve traction is to engrave grooves on the polyurethane treads. In addition to the use of WD-40, we manually carved in our hobbyweights the Z-shaped grooves seen on the right, improving wheel traction a lot, in special in dirty arenas.

It is also a good idea to mark the robot’s bolt heads with, for instance, a Sharpie. Then it will be easy to know if one of them got loose and needs to be retightened. After applying threadlockers and tightening each bolt, you’ll just need to draw a short straight line starting on the bolt head, and extend it onto the robot structure. Before the match, the very existence of the markings will help you make sure that all bolts have been tightened and have threadlockers. And, after the match, it will be easy to spot any loose bolts just by checking the alignment between the markings on the bolt head and on the robot structure, such as in the middle screw from the picture to the right. We’ve developed this technique after riding too many roller coasters and observing their similar bolt head markings.

If your robot does not use a spread spectrum radio system such as a 2.4GHz one, then you have to pick up the appropriate transmitter clip featuring the channel you're using, as pictured to the right. For instance, for a 75MHz radio system, you'll need to pick up a clip corresponding to one of the channels between 61 and 90 (see Appendix D). It is forbidden to turn on any radio without the clip, to avoid accidents that could happen if another robot uses the same channel as you. More recently, several competitions have required the use of radio systems featuring some sort of binding, such as the 2.4GHz ones, eliminating the need for radio clips.

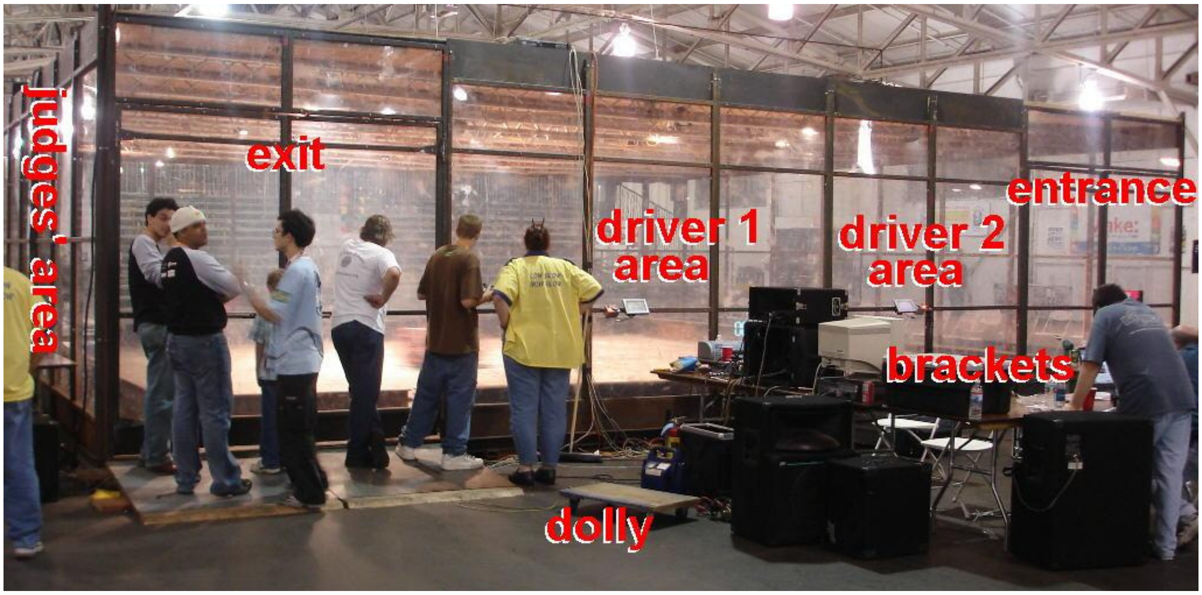
If the event staff allows, make a quick drivetrain test at the pits, but with your robot well secured and with its wheels lifted off the ground. Do not test the weapon, and use some weapon restraint at all times. The restraint should only be removed inside the arena, after you've been told to do so.

Go to the queue with your robot as soon as you're called. Lightweights or heavier robots should be carried on a dolly (as pictured to the right) or pushcart, to avoid accidents such as dropping them on the floor. Once at the queue, you will be standing beside your opponent (as seen in the picture). Exchange conversation, show your robot. Do not be afraid of answering any questions about your robot. At this point it won't make any difference, it is just a way to talk and relax.

If your next opponent asks for the match to be postponed, and the event staff allows it, then don't hesitate to agree. You came all the way here to fight, not to win by WO. The spectators, pictured to the right, came here to see exciting combats. They might boo you and your robot if you don't agree to grant a brief postponement.

9.2.3. Before Your Fight

A typical arena in the US has two doors, one for the robots from the next match to enter, and another one for them to leave, as pictured below. Next to the arena there is usually a table with a computer that allows you to check in real time the fight brackets and schedule. Next to the arena there is also the judges' table. If you're the robot driver, enter the arena from its entry door when your called, carrying your robot with a dolly or pushcart.



After entering the arena, you will take your robot to its starting position, as pictured to the right, which is determined by the event staff. Wait beside your robot. When requested, turn on the robot and remove the weapon restraint (if any).

Get outside the arena and position yourself in the areas reserved for each driver. After the arena is locked, you can touch very briefly the radio control just to see if the robot is responding. When you're ready, press the button "Ready / Surrender" from your driver area, pictured to the right. A few seconds after both drivers have pressed their buttons (which seem to last eternally), a series of lights will be turned on, until the green one is lit, starting the fight.

9.2.4. During Your Fight

The matches usually last up to 3 minutes, except for insect classes in the small arena, where the matches are restricted to 2 minutes. Check the specific rules of your competition. The complete set of RFL rules can be found in www.botleague.net/rules.asp. A few of them are described next.

If a robot does not move for 5 seconds after the opponent has ceased attacking, a 10 second countdown will be issued, at the end of which it will lose by KO if it doesn't show any controlled translational movements.

Pinning or lifting your opponent is allowed, however it is limited to 15 seconds (10 seconds for antweights or lighter). After releasing the opponent, you must move far enough away to let it escape from that pinning position.

If a robot gets stuck on the arena through its own action, not due to some direct action of the opponent, then, depending on the event rules, it may (or may not) be granted one free release per match. If the combatant becomes stuck again during the same match, no intervention will take place: it will have 10 seconds to free itself not to lose the match by KO.

Arenas usually have a Death Zone. The first robot to contact the floor on the Death Zone is declared dead, regardless of which robot initiated the entry.

To surrender during a match, just press again the button "Ready / Surrender." Sometimes it is wise to surrender if your robot has suffered enough damage to make it impossible to win the match, in special if you're still on the winners' bracket in a double elimination competition. This will prevent further damage and allow you to rebuild the robot in time for the next match. But always think twice before throwing in the towel, not to regret it. Even if your robot is barely moving, there's a chance that the opponent robot suddenly dies for some reason, in special in very violent matches. But if your expensive electronics and batteries are hanging out of your robot, and your opponent seems to be in good shape, then don't hesitate to surrender.

At the end of a match, when requested to, put back your robot’s weapon restraints (if any) and turn it off. Greet your opponent, independently of the result. Remember that your opponent was just trying to win, he/she didn't have anything to do with the judges' decision.

9.2.5. Deciding Who Won

Don't argue with the judges, even if you don't agree with their decision. Their decision is final. Sometimes, from the point of view of the loser combatant, a decision on a very close match might seem unfair. This does not mean that it was a wrong decision, it could just be a matter of point of view, since there always is a subjective aspect in the judgment. The proof of that is the very existence of split decisions.

This is why the judges follow very specific and objective guidelines, which are summarized below, extracted from the website www.robogames.net/rules/combat.php. It is important that all combatants are familiarized with these guidelines, so they can better understand the reasons behind the judges' decisions.

An odd number of judges, usually three, decide the winner of the matches where no robot is defeated during its 3 (or 2) minutes. There is also one Judge Foreman, who ensures that all judges are conforming to the guidelines.

In a judges' decision, the points awarded to the combatants by the panel of judges are totaled and the robot with the majority of points is declared the winner. Points are awarded by each judge in two categories: aggression, worth 5 points, and damage, worth 6 points. All 11 points must be awarded by each judge, who determines how many points to award each combatant. Therefore, a 3-judge panel will award a total of 33 points, which must be equal to the sum of the scores of both robots. Therefore, the closest possible win in this case would be by a score of 17-16, which can only happen in a split decision by the judges.

Aggression

Aggression is based on the relative amount of time each robot spends attacking the other, in a controlled way. Attacks do not have to be successful to count for aggression points, but the attacking robot must move towards the opponent, not just wait for it to drive into the attacker weapon.

The distribution of the 5 aggression points from each judge between the robots is of three types:

- a 5-0 (or 0-5) score, if one of the robots never attempts to attack the other, while the other consistently attacks;
- a 4-1 (or 1-4) score, if there's significant dominance of attacks by one robot, with the other only attempting to attack a few times during the match;
- a 3-2 (or 2-3) score, if both robots consistently attack each other, or if both robots only attack each other for part of the match. If both robots spend most of the match avoiding each other, then the judges will decide which one made more attempts to attack, awarding it 3 points and 2 to the other robot. Note that a robot that attacks a full-body spinner, intentionally driving towards it, is automatically considered the aggressor in the attack.

Note that there can be no ties in aggression, since its number of points is odd. Judges must decide which robot is more aggressive than the other.

Damage

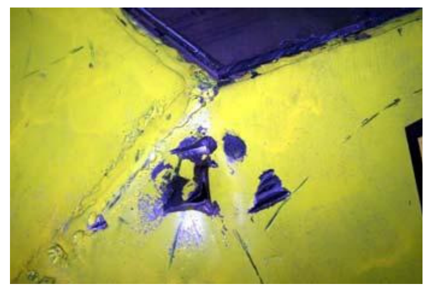
Damage points are awarded to the robot that can make the opponent lose functionality in some way. Damage does not have to be visually striking, it has to do with functionality, with incapacitating the opponent. For instance, titanium will send off bright sparks when hit, but most of the time it will be undamaged. Also, a gash in an armor plate may be very visible, but it only minimally reduces the armor's functionality.

But a bent armor or wedge that prevents the robot from resting squarely on the floor, reducing the effectiveness of the drivetrain, counts as damage. A small bend in a lifting arm or spinner weapon may dramatically affect its functionality by preventing it from having its full range of motion, so it is also considered as damage. A wobbly wheel is also a sign of damage, probably indicating a bent shaft, compromising drivetrain performance.

There are 6 levels of damage:

- trivial: being flipped over causing no loss of mobility or loss of weapon functionality (such as in an invertible drumbot that is able to spin its drum in both directions), direct impacts that do not leave a visible dent or scratch, sparks resulting from strike of opponent's weapon, or being lifted in the air with no damage and no lasting loss of traction.
- cosmetic: visible scratches to armor (as pictured to the right), non-penetrating cut or dent or slight bending of armor or exposed frame, removal of non-structural or non-functional cosmetic pieces (dolls, foliage, foam, or ablative armor), or damage to wheel, spinning blade, or other exposed moving part not resulting in loss of functionality or mobility.

- minor: being flipped over causing some loss of mobility or control or making it impossible to use a weapon (such as in an invertible drumbot with a drum that can only spin in one direction, because while inverted it would not be able to launch opponents), intermittent smoke not associated with noticeable power drop, penetrating dent or small hole (as pictured to the right), slightly warped frame not resulting in loss of mobility or weapon function, or removal of most or all of a wheel or weapon part without loss of functionality or mobility.



- significant: continuous smoke or smoke associated with partial loss of power of drive or weapons, damage or removal of wheels resulting in impaired mobility, damage to rotary weapon resulting in loss of weapon speed or severe vibration, damage to arm, hammer, or other moving part resulting in partial loss of weapon functionality, visibly bent or warped frame, and torn, ripped, or badly warped armor or large hole punched in armor (as pictured to the right).

- major: smoke with visible fire, armor section completely removed exposing interior components, warped frame causing partial loss of mobility or complete loss of functionality of the weapon system, internal components broken free from mounts and resting or dragging on the arena floor, significant leak of hydraulic fluid or pneumatic gases, or removal of wheels, spinning blade, saw, hammer, or lifting arm, or other major component resulting in total loss of weapon functionality or mobility.
- massive: armor shell completely torn off frame, major subassemblies torn free from frame (as pictured to the right), total loss of power, or loss of structural integrity such as major frame or armor sections dragging or resting on the floor.

If your robot is in good shape at the end of a close match, it is a good idea to demonstrate operability of the robot's drivetrain and/or weapon for a few seconds immediately after the end of the match, without touching the opponent. In this way, the judges will ascertain that your robot is still functional, and not sluggish or dead.

Scoring of damage points is based on relative grading of each robot's damage, as described below:

- a 6-0 (or 0-6) score is awarded when one robot suffers nothing more than trivial damage, and the other is at least significantly damaged, or one robot has suffered major or massive damage and the other is no more than cosmetically damaged.
- a 5-1 (or 1-5) score, if one robot suffers at least minor damage and the other suffers major or worse damage, or one robot has suffered cosmetic damage and the other has suffered at least significant damage.
- a 4-2 (or 2-4) score, if both robots have suffered nearly the same level of damage but one is slightly more damaged than the other.
- a 3-3 score, if both robots have suffered the same level of damage, or neither robot has even cosmetically damaged the other.

Damage that is self-inflicted by the robot's own systems, and not directly or indirectly caused by contact with the other robot or an active arena hazard, will not be counted against that robot for scoring purposes. In addition, any pre-existing damage in a robot before the match should not be counted against it.

9.2.6. After Your Fight

After your fight, immediately take your robot back to your pit and service it, even if it doesn't look damaged. Your first priority is to take care of the (probably hot) batteries.

Take care of your batteries

Immediately open the battery compartment. Carefully touch the battery packs to check their temperature. For NiCd packs, it’s normal if they’re warm or even fairly hot. But if they’re too hot even to be briefly touched, this means that their temperature is much higher than 140^{o}F (60^{o}C), which is a cause of concern: the battery life might be significantly shortened. If one pack is much colder than the other(s), this might be an indication that its circuit was open during the match, either due to a broken solder inside the pack or to a connector malfunction, which can be easily checked with a multimeter. After checking their temperatures, immediately place the battery packs over a large fan to be cooled down (see chapter 8). Only start recharging them after they get cold.

Access damage

After taking care of the batteries, inspect the entire robot for any structural damage. Look for any large debris that might have entered the robot, such as metallic parts that could shorten your electronics or pieces of rubber or foam tire treads that could get stuck in the clearances between your wheels and structure.

Turn the wheels by hand to feel if there's any problem with the drivetrain. A stuck wheel could be either due to debris in the transmission (either foreign debris or from the own robot, such as a broken gear tooth inside a gearbox), or due to bent armor/structure interfering with the wheel. If the wheel gets stuck only in a few positions, this might be an indication of a broken gear tooth or a bent shaft. If the wheel gets stuck once at every turn, then the problem might be in its shaft or in the last stage of the reduction. If it gets stuck once every few turns, the problem might be in the previous stages. On the other hand, if the wheel easily turns by hand without any mechanical resistance from the motor, then you might be facing a broken key or shaft coupling, a stripped gear, a loose pinion, a ruptured belt, or a derailed chain from its sprocket, depending on your transmission system.

After checking the drive system, look for damage in the weapon, focusing on the most stressed parts, such as on the teeth of a drum, or the center section of a spinning bar. Check the condition of all belts and chains, from both the weapon and drive systems, and change them if necessary. If you previously marked the robot's bolt heads with a Sharpie, as explained before, it will be easy to spot if any of them got loose and needs to be retightened.

Remove damaged screws

There are several ways to deal with a screw with a stripped or broken off head. On socket head cap screws with hexes that have been stripped out, you can take a slightly larger Allen wrench and grind it just enough for it to be hammered into the stripped recess, and then unscrew them.

For screws with broken off heads, try to unscrew the remaining stub with a vise-grip. If this doesn't work, then use a Dremel (as seen in the left picture) to cut two parallel chamfers in such a way that an open-end wrench could do the job (as seen in the right picture above).

If the stub is entirely embedded into the robot, then you can use a screw extractor, such as the ones pictured below. This tool drills a pilot hole into the screw stub, and then a left-handed thread takes care of unscrewing it. If the damaged screw is a high strength one, you'll need special screw extractors, which can drill even class 12.9 hardened steel bolts.

If you don't have screw extractors, another option is to use a Dremel to cut a channel in the middle of the embedded stub, and then use a large flathead screwdriver to unscrew it. This method is not as good as the previous ones, but it may work if the stub is not too bent.

If everything else fails, then another tip is to weld a nut onto the stub (as pictured to the right), and then use an open-end wrench that matches the nut. If the stub is entirely embedded into the robot, it might be easier to first weld a washer to the stub, and then weld the nut onto the washer.

If the broken stub is deeply embedded into the robot, then another option is to weld a long and thin steel strip (as pictured to the right) and use a vise grip to unscrew it.

If the workpiece is made out of aluminum, then there's one last resort, which is to dissolve away the steel stub with nitric acid (HNO_3). Be very careful, do not immerse the workpiece in the acid, just put a couple of drops in the hole and, when no more gas comes out, wash out and repeat. Nitric acid dissolves the edges of the screw stub (or the stub of a broken tap), reducing its diameter and easing removal. It reacts much faster with hardened steel than with aluminum, so the threads in the workpiece won't be compromised.

But, if the workpiece has a high value, it might be worth looking for a bolt disintegrator device. In this technique, the workpiece is immersed in water or oil, while the bolt (or tap) is electrically eroded. You will probably have to look for a machine shop that offers this service.

Socialize

If your opponent from the previous match is not busy working on his/her robot, go to his/her pit after the match to check the damages, to talk about the match, to take pictures, and to invite him/her to see the damages caused in your robot.

It is very common to give your opponent unusable parts from your robot that were destroyed by him/her during the match. These are called "trophies," they are memories to keep from the combats. It is an honor to receive them, and giving them away is another way to be polite and to establish friendships with other builders.

The picture to the right shows a few of our most cherished trophies, which we had the honor to receive (or scavenge in the arena, in a few cases) along the years, since RioBotz was born, in 2003.

Our "trophy box" has now more than 50 pounds worth of good memories.

9.2.7. Between Fights

Between fights, do not perform any dirty jobs on your pit table, such as grinding large parts sending sparks everywhere. Most events have a designated area for this. Otherwise, find an isolated area to use such tools. If it is a very small job, then ask for other team members to form a protection barrier to avoid sending sparks to neighboring tables. Several builders are already stressed trying to get their bots ready for combat, so it is wise to avoid conflicts.

Never test your robot's weapon in the pits. Keep the safety restraints on the weapon at all times. It is usually OK to test the robot drivetrain if its wheels are lifted off the ground, but always check with the event staff.

A very useful accessory is a 2-way radio (pictured to the right), which can be used by 2 or more team members, especially to communicate with the driver. This gives more freedom for your teammates, allowing them to wander around the pits between fights, until their presence is required to fix a robot or to drive it. Use a headset (earphone and microphone) for a hands-free experience. It is important for the radios to have a vibrating alert, because loud noises and music from the pits and arena might make it difficult to listen to sound alerts from the incoming calls.

Even if you have been eliminated, try to attend the event until its end. In this way you won't miss the show, you'll watch the fights and championship matches from a privileged position from the pits, and you'll be giving prestige to your peer builders that are still competing. At the end of the event, you will have learned more than you could imagine. And you'll have made many friends and met great builders. After all, it’s not every day that I get to meet legends such as Matt and Wendy Maxham, as pictured to the right.

Attending a combot event is a wonderful experience. And competing is even better, it is not easy to describe with words. You have to experience it yourself. Get ready for a major adrenaline rush.

9.3. After the Event

After each event, get together all your personal notes, and organize them while the information and memories are still fresh in your mind. They will be very useful to improve your robot and its future versions.

9.3.1. Battery Care

It is a good idea to store your batteries adequately, especially if you won't go to an event within the next months. If you'll be practicing driving your robot regularly, which is a good idea to improve your skills, choose perhaps 1 or at most 2 sets of batteries to be used on a daily basis, and store all others to save them for the next event.

SLA batteries should be stored at full charge, keeping their terminals very well isolated to avoid shorts. Recharge them at least every 6 months, even if you don't use them, due to self-discharge. You don't need to keep them in a refrigerator, as long as they're stored below 80^{o}F (27^{o}F).

Nickel batteries such as NiCd and NiMH, on the other hand, should be stored fully discharged, as discussed in chapter 8. But never below 0.9V per cell. It is a good idea to discharge them using an electronic charger such as Triton, see chapter 8. Then, place the batteries in a refrigerator at 5^{o}C (41^{o}F), not a freezer. This is so important that we have a dedicated refrigerator just for that, as pictured to right. But always store the batteries inside a sealed plastic bag such as ziploc, to protect them from humidity. In this way, the batteries can last up to 20 years, but you'll need to completely charge and discharge them at least every 6 months for that. When you remove the batteries from the refrigerator, wait for them to get to room temperature before charging. Never freeze the batteries.

Lithium batteries should also be stored in a refrigerator, inside a sealed plastic bag. But, instead of fully discharged, which could make them permanently unusable, they should be stored at about 40 to 60% of their charge level. Storing the battery at 100% charge level applies unnecessary stress and can cause internal corrosion. Recharge them back to 40 to 60% at least once per year, due to battery self-discharge.

9.3.2. Inspect Your Robot

After taking care of the batteries, disassemble your robot to access damage, several problems are not easy to spot in a fully assembled robot. Switch the screws that are in bad shape, either bent or with stripped heads. If you're having trouble removing a damaged screw, follow the screw removing techniques explained before.

Verify the condition of the belts or chains, this is a good time to change them if needed. Clean up very well your robot, acetone is very good to clean metallic parts (but don't use it on Lexan).

Then, visually inspect critical components, such as shafts, looking for cracks. Several times, visual inspection is not enough to spot a crack, because cracks usually have their mouth closed when the part is not loaded, only leaving a very subtle trace on its surface. One efficient way to detect a crack is to use a low-cost technique called dye penetrant inspection (DPI). DPI is based upon capillary action, where a low surface tension fluid penetrates into surface-breaking cracks.

To perform DPI, you only need two spray cans, one with the penetrant dye and the other with a white developer, found for instance at McMaster-Carr under Dye-Penetrant Detection Kit. The inspection steps are described next, applied to the tempered 4340 steel weapon shaft from our middleweight horizontal bar spinner Ciclone.

(a) (b) (c) (d) (e)

(a) pre-cleaning: the test surface is cleaned to remove any dirt, paint, oil or grease, using for instance acetone; do not leave fingerprints;

(b) application of penetrant: the penetrant is applied to the surface, in general as a spray; the penetrant dye can be colored, usually red as pictured above, or fluorescent, to be later inspected under ultraviolet light; always use gloves, because the dye will penetrate all the way under your fingernails if you're not careful (unless you want to save money on nail polish);

(c) waiting period: wait from 5 to 30 minutes for the penetrant to soak into any cracks or flaws; very small flaws may require a longer waiting time;

(d) application of developer: completely remove the penetrant from the surface using a dry lint-free cloth (do not use acetone in this step, it could remove as well the penetrant absorbed by the cracks), and then apply the appropriate white developer to the entire surface, until the surface looks like it's frozen (as pictured above), forming a semi-transparent, even coating;

(e) inspection: wait for 10 minutes for the blotting action to occur, where the developer will bring any trapped penetrant to the surface, exposing cracks or flaws through the form of thin red (or fluorescent) lines under white (or ultraviolet) light; do not wait too long to inspect, because the thin lines may "bleed out" and make it difficult to evaluate the size of the crack, if any; inspect very carefully near geometry changes such as notches, where it is more likely to find a crack; beware with false positives, because very small harmless scratches (generated either during manufacturing or combat) can result in very thin lines - it is up to the inspector to distinguish between cracks and scratches, depending on the thickness of the developed lines; fortunately, Ciclone's shaft was free of cracks in the above inspection.

Finally, completely assemble your robot as soon as you finish servicing and inspecting it. With your robot fully assembled, it will be impossible to misplace any of its components. Misplaced components will most likely be lost forever if you only look for them several months later, near the date of the next event.

9.3.3. Wrap Up

Update your homepage as soon as possible. During or immediately after an event is the best time to do that, in special if you want to increase the number of hits in your webpage to please your sponsors. Most builders and enthusiasts that didn't attend the event will certainly be searching for photos and videos during it, and mostly everyone will be looking for them right after the event ends. Make sure you post announcements of your updates, for instance, on the RFL Forum in the appropriate topic related to the event.

If you don't have a webpage, make one. It is important that your team has visibility to be able to get sponsors. Nowadays it is very easy to design and upload a webpage. A basic one will take you less than an hour to prepare.

Check the current ranking of your robots at both www.botrank.com and www.buildersdb.com websites, and keep in mind the dates of the next events.

Now relax, and review the pictures and videos from the event. Win or lose, celebrate with your teammates and other builders. Cheers!