How to build a combat robot

A guide to support teachers looking to run a Robot Wars club

Contents page

Introduction

This guide is designed to give someone interested in building a combat robot a good foundation of knowledge to safely take part in this hobby. The information is suitable for an enthusiastic builder but has been written for teachers looking to run a Robot Wars club in a school context, some of the information therefore may not be required by the individual builder.

Combat robotics is an engaging hobby that stretches competitor's abilities in; problem solving, engineering, design, CAD, fabrication, electronics and much more. As a vehicle for classroom engagement the learning opportunities are vast; maths, physics, engineering, materials science, team work and time management are all skills required to successfully build a combat robot.

This guide is not exhaustive, the information found here is the key information for someone to safely design and build a robot, but additional research will usually be required throughout a build. Hopefully with this guide, and a few basic workshop tools, you and your students will have the satisfaction of designing and building your own combat robot.

Disclaimer

Fighting robots has some inherent dangers associated with it. This guidebook covers the essential information required to safely build and compete in this sport, but the responsibility for the safety of students and members of staff lies with the teachers in charge. Machines can be built safely in a school context, but the teacher must assess the risks for their own workshop and pupils. No company, organisation or individual mentioned in this guide take responsibility for any injury caused while designing, building, testing or competing in combat robotics.

General information

1. Safety
   There are some dangers in building and competing in this hobby. For the most part these risks can be managed by understanding the building processes and components being used.
   a. Fabrication – The majority of accidents occur during the build of a machine. Standard workshop risk assessments are necessary to minimise the potential danger to yourself and students.
   b. Electronics – The batteries used in combat robots have the potential to be quite volatile, if using LiPo batteries make sure you read through the guidance on p11 +p12 thoroughly. Short circuits will quickly get very hot and can instantly damage electronics and cause burns. A visual check of the wiring loom, and close teacher supervision, is advised each time the robot is powered up
   c. Testing – Make sure the robot is tested in a safe environment. Be aware when testing that there is always a small a chance of radio interference. Plan where you will test so the robot won't endanger anyone should control be lost.
2. Combat robot weight categories
   a. Antweight up to 150g
   b. Beetleweight up to 1.5kg
   c. Featherweight up to 13.6kg
      i. This is the recommended weight category for a school project. A heavyweight requires expensive machinery and often welding equipment to fabricate, the cost is also considerably larger. A beetle weight is a viable option for students, but with the small weight limit and resulting size

constraints Beetleweight robots need to be built with a greater level of precision, and have a greater potential for an unsatisfactory outcome.

d. Heavyweight up to 110kg

3. Competition rules
   a. Familiarise yourself with the rules for the competitions you are looking to enter. The FRA build rules are a good starting point, but each competition may have its own variances on those rules.

      http://www.fightingrobots.co.uk/documents/Build-Rules.pdf

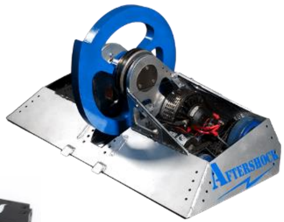
4. Advice to teachers
   a. It is advisable to keep the group size to a maximum of 6, but 2 to 4 is preferable. Any larger and students will struggle to have work to complete each session.
   b. Consider carefully where you should assist with the fabrication to keep the project progressing and students engaged.

Designing

Standard robot designs

Pusher or ram bot (Tornado) - These are the simplest machine to build and should definitely be considered for a first time builder. These machines rely on their power and armour to ram their opponents. They are often 4WD, but 2WD and 6WD have been successful.

Horizontal spinner (Carbide, tombstone) - Horizontally rotating disk or bar, usually with a large diameter.

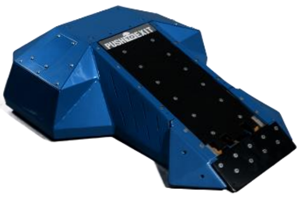


Vertical spinner (Aftershock, nightmare) - Vertically rotating disk or bar, usually with a large diameter.

Drum spinner (Minotaur) - Wide vertically rotating drum with a small diameter.

Fully body spinner (Ringmaster) - Effective, but complex design where the entire outer shell rotates acting as both armour and weapon.

Rear hinging flipper (Explosion) – A compressed gas (pneumatic) piston lifts the front section of armour. With the hinge being at the top competitors are lifted up and forwards.



Front hinging flipper (Push to exit) – This less conventional flipper configuration has the hinge at the front, meaning opponents are pushed forward more than up.

Axebot (Thor, Beta) – These machines use compressed air or electric motors to drive an axe down on opposition.

Non-standard weapons - Flame throwers, crushers, grab/lift and 4 bar lifters should be initially avoided due to their complexity and competition regulations.

General design advice

1. Start simple - Designing, building, wiring and testing a 2WD ram bot is a huge accomplishment, and a great learning experience for students.
2. Look at what people have entered already, read through a few build diaries (see FRA forum).
3. When designing remember your machine will not be the same shape after combat. Include an air gap between the outer armour and the inner components, this will allow the outer armour to distort without damaging the internal components.
4. With the advances in material technology sharp weapons designed to cut through armour are generally ineffective. A blunt weapon designed to transfer large amounts of kinetic energy are more common.
5. Reliability is key, try to find any weak links in your design before you start to build.
6. Try to design your machine so it can be easily assembled and disassembled.
7. Avoid designing around a weapon that look suitable. Off the shelf cutting / grinding disks for example are rarely capable to withstanding the forces of combat.
8. Avoid the temptation to build something never seen before. It is better to have a successful simpler robot, than a ground breaking machine that is unfinished or unreliable.
9. Having a robot that can either run inverted or has a self-righting mechanism (SRMech) it strongly advised.
10. All active weapons (ones with moving parts) must have a locking bar or other means of physically preventing the weapon moving when not in the arena.

Design process

Draw out a range of designs on paper, try and weed out design elements that are overly complicated. It is strongly advised to build a full 3D CAD model of your robot before you start to build. Try to include as many correctly sized components as you can. Make sure you leave room for the wires. This process takes time, but will greatly increase the success of your build.

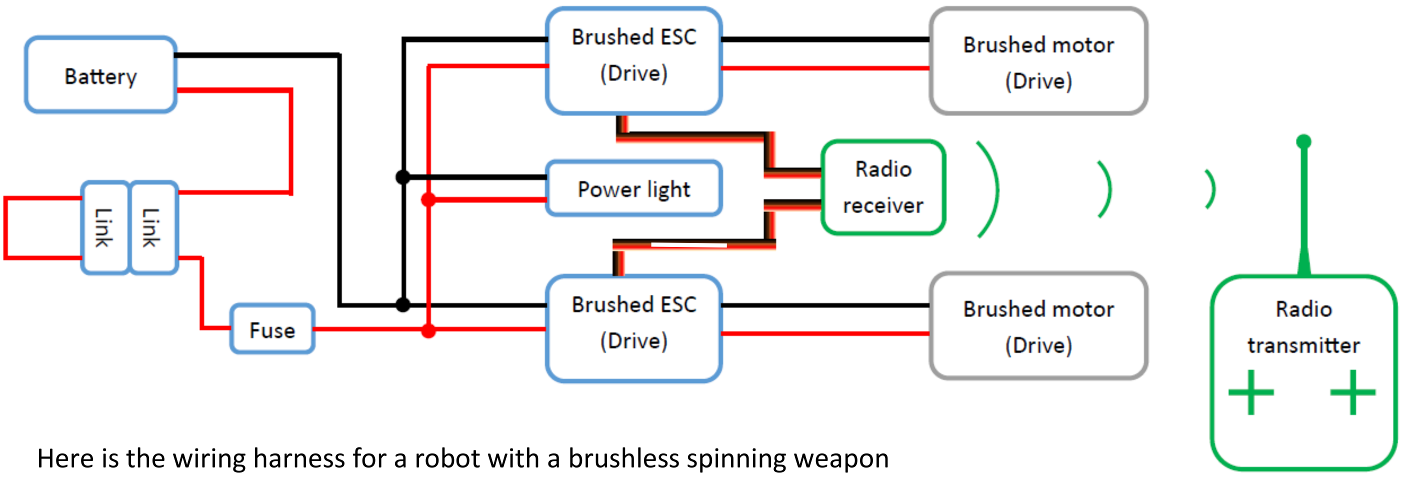
CAD software

Autodesk Fusion 360 and SketchUp are great CAD packages to use. Autodesk is more capable and free to schools, also a number of suppliers will provide Fusion CAD files of their components (VEX)

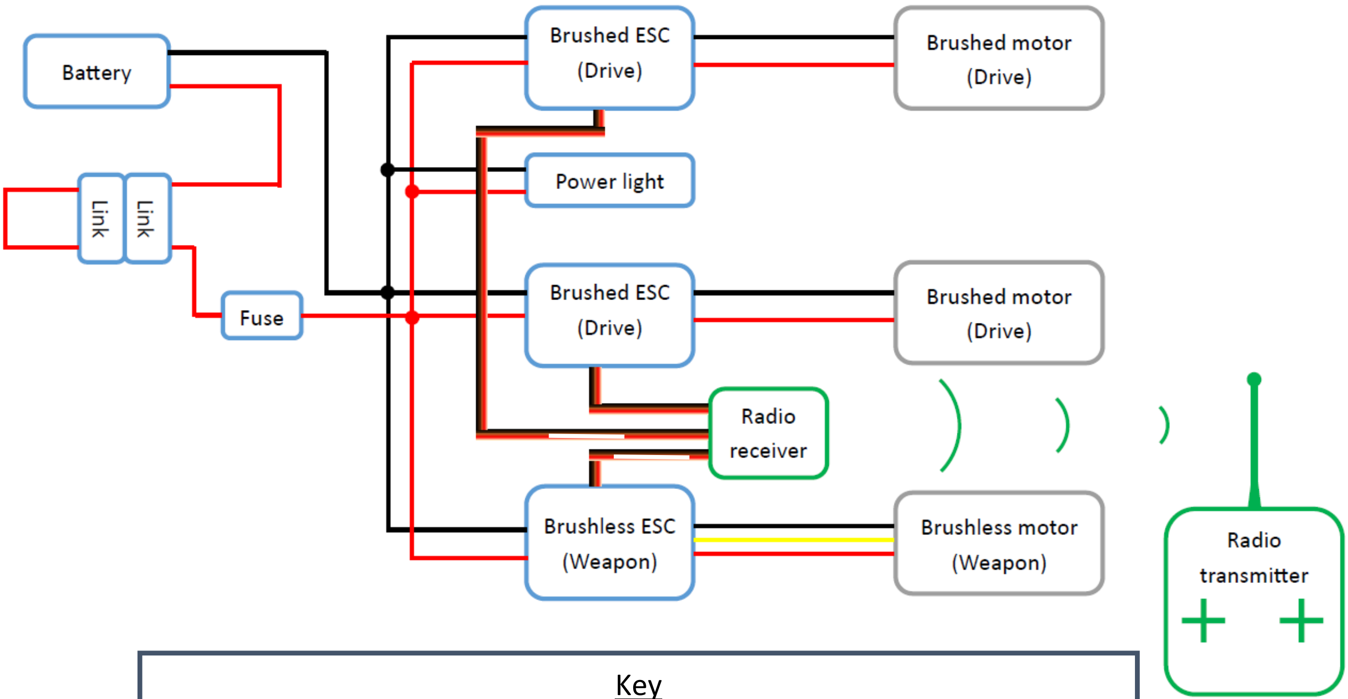
Building - Electronics

Electronics

Here is a wiring loom for a basic 'ram bot' style robot.



Here is the wiring harness for a robot with a brushless spinning weapon



Key

Red wires = Positive wires

Black wires = Negative wires

Yellow wire from the ESC = Brushless motor wire

The wires going to the radio receiver from the ESC will either be Brown, Red, Yellow or Black, Red, White. Brown or Black wires are the negative (ground) the Red wires are positive and the Yellow or White is the signal cable.

Note that only 1 red wire connecting ESC to the receiver remains intact, the others have been cut. This is because the receiver is powered by a BEC (Battery Eliminator Circuit) inside the ESC, and requires power from only one source.

General electronics advice

1. Work out what drive motors you will be using first, this will determine the voltage of the batteries you will need. By looking at the motors spec sheet you should be able to determine their maximum amperage draw, and this will help you select your ESC's.
2. It's essential you consider the voltage (V) you are supplying the motors with and the current (A) that they will require. If you apply too many volts to a motor it will burn out, and if the motor requires more amps than the ESC can handle it will damage the ESC.
3. Make sure all the wiring is of a suitable gauge for the amperage you intend to use. 10 or 12 AWG silicon wire should be suitable for most featherweight applications.

Connecting wires together

As a general rule, regardless of the connector type used, you want to avoid any exposed wires. Make sure you cover all joints in heat shrink to prevent the risk of a short circuit.

1. Soldering – Standard school soldering irons can be used, but you may find that the large gauge wire conducts heat away too quickly. A high power soldering iron or gas powered iron is recommended.
2. Terminal blocks – These are easy to use, and good for testing but are generally avoided as they can work loose during combat.
3. XT60 connectors are easy to solder and widely used (For higher amperage applications consider Anderson or XT90 connectors). Once completely assembled hold the two connectors together with a zip tie to ensure they won't disconnect during combat.

A good technique for soldering 3 or 4 wires together is to remove 15mm of insulation from each wire and 'tin' (pre-load) each wire with solder. Then bundle all the wires together and tie them with a loop of thinner gauge wire. Apply the soldering iron to the whole bundle then feed in the solder, this technique requires quite a lot of solder but makes a strong connection. Trim what protrudes of the thinner wire loop after soldering and cover the whole bundle in heat shrink.

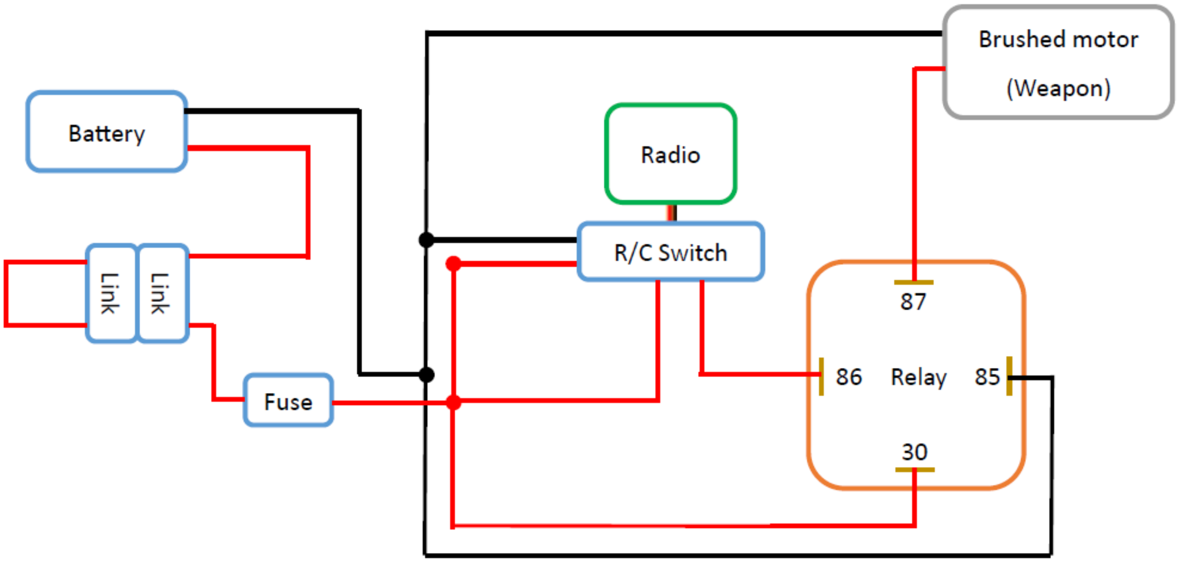
Electronic Speed Controllers (ESC's)

These take the power from the battery and distribute it to the motors. ESC's are one area worth investing in as they frequently get re-used in future machines. They connect to the R/C receiver and regulate their output depending on how the sticks on the transmitter are moved. Fully forward will give full power forward, if the stick is half way back the motor will run in reverse at half speed. There are 2 main motor types to be aware of; brushed and brushless, each requires its own ESC.

1. Brushed – Brushed motors are an older technology, but still the most widely used option for drive motors, brushed motors will require a brushed ESC. One point to note is that a lot of brushed motors are used for R/C planes or boats, in these applications reverse isn't required so make sure the ESC you buy has forward and reverse. Research the maximum amperage draw of the motors you are using for drive and buy an ESC that can handle at least the right voltage and ideally more amps than required.
2. Brushless – Brushless motors require brushless ESC's. These cannot change direction when in use, but can be set to run in either direction when being wired. As with brushed ESCs find the maximum current draw for the brushless motor you plan on using, at the voltage you will use, and buy an ESC that exceeds that amperage draw.
    a. To reverse the direction of a brushed ESC unplug any 2 of the 3 wires and swap them around.

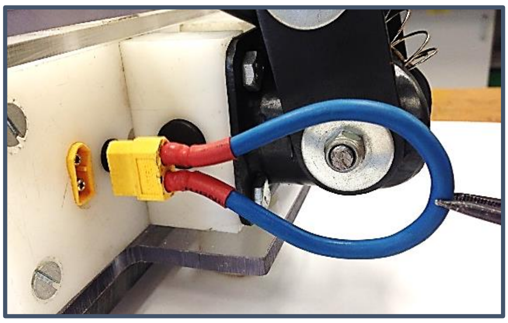
Relays and R/C switches

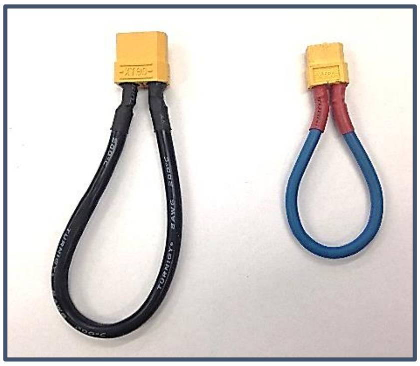
1. If you are using a brushed motor and require a simple on/off function (a spinner for example) you could use a combination of a relay and R/C switch (ensure it can handle the voltage / current your weapon motor requires)
2. In the diagram below the high current supply for the weapon motor enters 30 and leaves at 87. The switching connectors 85 and 86 use a small amount of current from the R/C Switch to operate the relay. When current passes through 85 and 86 the high current connectors (30 and 87) close allowing the electricity to flow to the weapon motor.



Removable link

1. Every robot needs to have an easily accessible means of disconnecting power to the robot. This has to be in the form of a removable link. The easiest way to accomplish this is to have one wire from the battery go through an XT60 connector and loop back on itself.
2. The removable link can be on the positive or negative side of the battery
3. The wire must be of a suitable gauge for the maximum total current your robot can draw.





Fuses

1. You need to include a fuse directly after the battery just below its safe burst discharge rate.
2. You may also want to install fuses before the ESC's, just below their maximum amperage rating to protect the ESC should a motor draw excessive amps (If for example a wheel were to get jammed)

Remote control

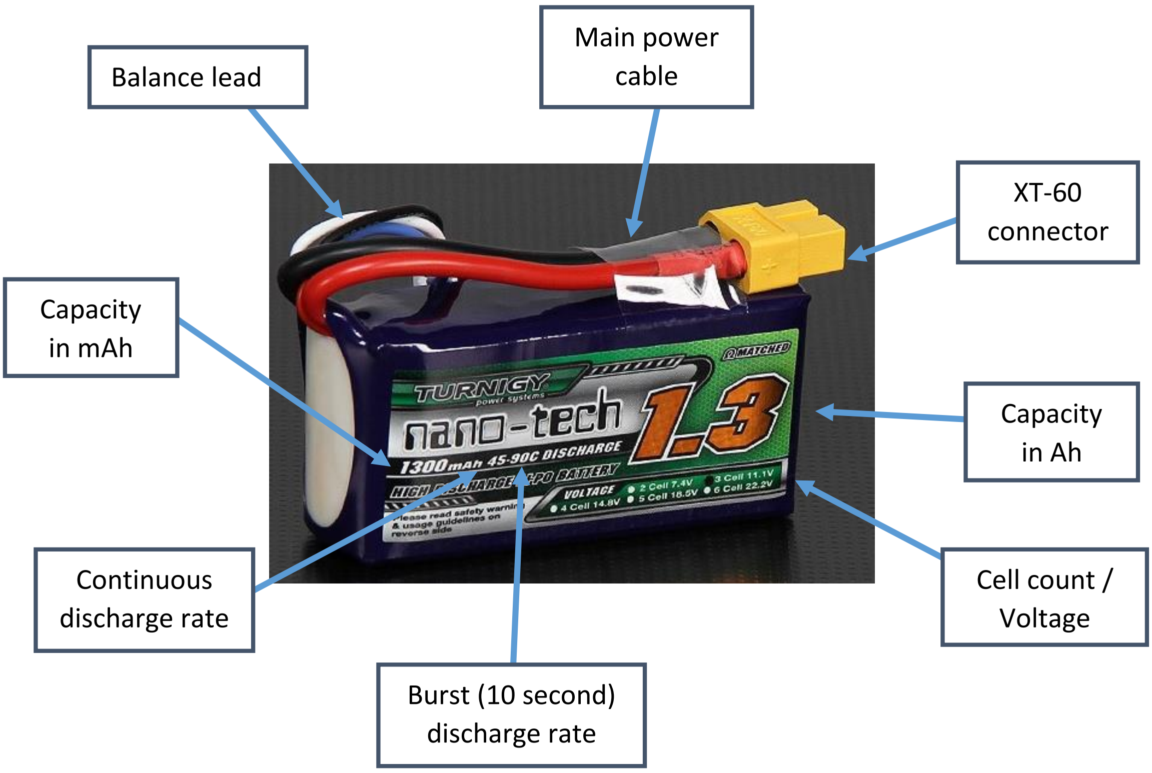
1. The standard R/C equipment used in the hobby is 2.4 GHz. You will need to have a 2.4 GHz transmitter and 2.4 GHz receiver. It is advisable to buy these together to ensure they are compatible.
2. Transmitters generally come in either 'pistol grip' or 'airplane (two stick) style'. Although some teams use a 'pistol grip' transmitter, it is advisable to start with a traditional two stick model.
3. Transmitter and receivers have a number of 'channels' of information they can deliver.
   a. Each channel can control one ESC, R/C switch etc.
   b. A standard robot will require at least 3 channels, one for each wheel and one for a weapon. It would be advisable to invest in a 6 channel receiver, the small additional cost of buying a transmitter with more channels will future proof your radio gear should you require more in future. The Spektrum Dx6i is a popular choice.
   c. Usually competitors use the right stick to control the movement of the robot, to achieve this the elevator and aileron channels must be mixed together. If you search elevon mixing for your particular transmitter you will find out how to achieve this. Alternatively you can buy off the shelf mixers that connect between the receiver and the ESC's
   d. 'airplane (two stick) style' generally come in 2 configurations; Mode 2 and Mode 1. These refer to the layout of the sticks, Mode 2 is the most common configuration used in combat robotics.
4. Fail safe – It is important that should the radio signal get interrupted or the transmitter loose power the robot enters a 'fail safe' state. In this state the weapon shouldn't be running and the robot should remain stationary. Most transmitter manufactures will have a method of setting the 'fail safe' mode, you must ensure the robot will 'fail safe' in order to compete.

LiPo batteries

LiPo (Lithium Polymer) batteries are the most common type of battery used in combat robotics today, they are low cost, light weight and powerful. If used correctly these batteries are safe, but they do have the potential to be quite dangerous if not handled and used carefully.

Important information for using LiPo batteries safely

1. LiPo batteries voltage range – All LiPo batteries are made up of individual cells, to operate safely each cell shouldn't be discharged below 3.0V or charged above 4.2V, the 'nominal' voltage for a cell is 3.7V.
2. The number of cells (S) will determine the battery packs voltage. For example a 3S pack contains 3 cells. 3 cells at 3.7V each = 11.1V
3. Capacity – All batteries will indicate their capacity in mAh. For example a 2000mAh pack can output 2000mAh (2 Amps) for 1 hour
4. Discharge rate (C Rating) – LiPo batteries will indicate the maximum safe rate they can be discharged at and a burst rate that it can withstand for 10 seconds at a time. This is known as the C rate.
    a. Continuous - If a 2000mAh (2Amp) pack has a continuous discharge rate of 30C it means it can give out (30 x 2A) 60 Amps of power continuously.
    b. Burst rating – The same pack may have a burst rating of 50C. This would mean that for up to 10 seconds it can output (50 x 2A) 100Amps. This is useful for spinning weapons that draw a lot of amps to start spinning and fewer to maintain the weapon spinning.
5. Charging rate – It is advisable not to charge a LiPo at a rate higher than 1C (Modern packs may withstand higher). A 2000mAh battery pack charging at 1C means you can charge it at up to 2A.



6. Charging – When charging a LiPo battery it is important that each cell has the same voltage at the end of the charge. To use LiPo batteries you will need a special LiPo charger that can 'balance charge' the pack. A LiPo battery will have 2 main output cables, the positive (red) and negative (black). There will also be a balance lead that connects to each individual cell. Some cheaper chargers just charge via the balance lead, more expensive models will charge through the main positive, negative leads and will plug in the balance leads to check and top up each cell to ensure they end up balanced, these charge much quicker.
7. Safety – Low voltage alarm. When in use the voltage of each cell must not drop below 3.0V or the pack will swell and will not be able to be safely recharged. A low voltage alarm plugs into the balance lead of the LiPo battery and monitors the voltage level of each cell while the battery is draining. When one of the cells drops to 3.0V it will sound an alarm, at that point stop driving the robot and recharge the batteries.
8. Safety – Charging sack. When charging there is a small chance for the LiPo to catch fire, generally this will only happen with damaged packs or damaged/incorrect chargers. It is essential that LiPo batteries are always charged inside a flame proof LiPo charging sack, in a safe area a good distance from any combustible items.
9. Safety – As well as ensuring the LiPo doesn't over charge, or the voltage doesn't drop too low, you need to make sure they are handled carefully. If these high power batteries are punctured they vent harmful gas and can even catch fire.

<u>Alternative battery types</u>

NiMH – This is an alternative power source. This older technology is safer but heavier, more expensive and less powerful. You will require a NiMH charger to use these batteries, but do not need to worry about them being overcharged or discharged to dangerous levels.

NiCD – These are similar to NiMH batteries but have a lower capacity and can suffer from memory if not fully discharged between uses.

SLA (Sealed Lead Acid) – These batteries are very heavy, but as with the NiMH & NiCD batteries overcome most of the issues surrounding LiPos.

Building – Mechanical hardware

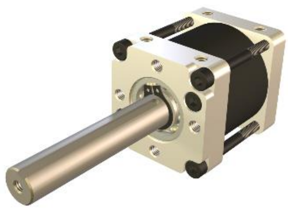
Drive motors

Deciding what motors you will use for drive is a good starting point for any combat robot project. There are a range of options available.

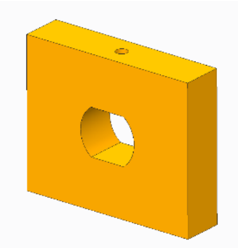
1. Drill hack – This is the cheapest method of driving the wheels. (Instructables has a good article on this titled – '*Hacking Drills- Cheap/Powerful Gearmotors for Robotic Applications*').
    a. It is worth noting that the screw thread in the end of a drill motor is a reverse thread. Make sure to keep the bolt safe, and use thread lock to ensure it doesn't work loose.
2. Off the shelf motors. There are many companies selling motor/gearbox combinations for robotic applications. VEX, Ranglebox and BaneBots are worth considering.
3. Motor with custom gearbox. Many top teams will design and build their own gearbox around a motor that provides the power they require. This complex option should be avoided when starting out.

Securing motors to chassis

There are 3 main ways to secure motors into your robot, all methods rely on securing the gearbox to the chassis and the motor to the gearbox. Mounting to the bulkheads via screw threads on the front face, mounting to the bottom armour plate via screw threads on the bottom face or by cutting the correct profile in a bulkhead for a hacked drill motor and gearbox to be mounted.

VEX's VersaPlanetary and Ranglebox's Saturn-16 gearboxes have multiple threaded holes on the front and top for mounting to the bulkheads or armour plating

Mounting a hacked drill motor in the bulkhead is usually achieved by cutting a hole that matches the profile at the end of the gearbox. A grub screw is often used to stop the motor slipping out.

Weapon motors

a. Increasingly featherweight weapons are being powered by brushless motors. These are smaller, lighter and spin faster. For high torque applications a gearbox or brushed motor is advisable. Research what robots of a similar design have used, and try to match the spec of their motors to your own.
b. Brushless motor ratings – Brushless motors come in a range of voltages and also have a kV rating (This is not kilovolt). The kV number indicates number RPM per volt. For example a 3,000 kV motor on a 3S (11.1v) LiPo battery will rotate (3,000 x 11.1) 33,300 revolutions every minute! Generally the lower the kV the higher the torque of a motor.

Alternative weapon systems to be aware of: Linear actuators (Linacs) are very high torque motor/gearbox combinations that move in a linear motion. Solenoids also move in a linear direction, but far faster with much lower torque.

Power transfer

1. For the drive motors the simplest method of transferring power to the wheels is to have a wheel that mounts directly to the output from a planetary gearbox. VEX and Banebots supply a good range of quality wheels and adapters. These wheels often have hexagonal holes through the middle, ensure the hub adapter matches the hexagonal profile and the diameter of the motor output.
2. Sprocket and chain – Useful for transferring power in high torque applications where 'slip' isn't acceptable, a lifter mechanism for example.
3. Belt drive – Timing belts and pulleys are very popular methods of driving featherweight spinning weapons. Having a pulley with teeth on the motor and a smooth surface or pulley on the weapon will allow 'slip' on impact where the weapon can stop dead and the motor can continue to move. This prolongs the life of the motor.

Building – Chassis and armour

The materials included in your robot will largely depend on the fabrication facilities in school, abilities of the pupils and the size of your budget. Although many teams will be making use of CNC machinery very successful machines have been built with little more than a hacksaw, soldering iron and a drill. If you have very limited facilities there are a number of companies who sell adjustable frames that can be customised to suit your design. The VEX Versa frame is a good example.

Robot layout

A standard combat robot layout consists of flat top and bottom plates of armour with vertical 'bulkheads' mounted between them. All electronics, motors and weapons are then be secured to either the top/bottom armour or to the bulkheads.

INCLUDE PHOTO OF BULKHEAD TO ARMOUR PLATE

Suitable chassis/bulkhead materials:

1. HDPE – Easy to work with, high impact resistance. Care needs to be taken if routing as it can melt easily
2. Nylon – Very easy to work, can crack under extreme loads. Easy to cut with CNC machines
3. Aluminium – There are lots of different grades available, all are suitable for robot chassis but 2014, 6082 and 7075 are particularly strong.
4. 3D printing is becoming increasingly common and school and can feature in a robot, but shouldn't be used externally. It can be used effectively to make internal housings for the electronic components.

Suitable armour materials:

1. Steel – Effective low cost, but heavy armour.
2. Polycarbonate (Lexan) – Bulletproof glass. Low cost, low weight, reasonable impact resistance and easy to machine, although not suitable for laser cutting. This clear plastic is widely used in armour, but can crack under high impact. 8mm would be suitable for most applications.
3. Hardox – A heavy wear plate steel. Extremely popular due to its resistance to impact. As a guide 3mm Hardox is frequently used in featherweight armour. Thicker sections are often used in bar spinner's weapons.
4. Titanium – Very expensive, hard to machine, and bend but extremely reliant to distortion and makes very effective, lightweight armour.

Methods of fixing the bulkheads to the armour

1 Tapping threads - This works particularly well if the bulkheads are made from aluminium or nylon

2 Nut and bolts – Make sure you use Nylock nuts and/or thread compound to prevent the nuts working loose during combat.

3 Threaded insert - A larger diameter hole is drilled where the thread is required and an insert screwed in. Both wood and plastic inserts work well.

4 Avoid using adhesives or welding as they don't allow for easy disassembly or replacement of damaged parts.

Shopping list

Use this space to research and record what you need to buy:

Item	Model	Cost	Recommendations
Radio transmitter			Spektrum Dx6i in mode 2
Radio receiver			Spektrum DSM2 receiver
Battery			
ESC			Botzbitz 85a ESC & the VEX Talon SRX
Motors			VEX VersaPlanetary & Ranglebox's Saturn-16 gearboxes.
Weapon motor			
Wheels			
Wires			
Fuses			
Connectors			
LED			
Bulkhead material			Aluminium, nylon or HDPE
Top and bottom armour			Lexan or Hardox
Misc			
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Competitions

Entering a robot into a local or national competition is a great result for a team of students and a valuable opportunity to test their machine against other builders. There are a few considerations and rules to be aware of when taking students to a competition.

1. Pit safety – The pit (Work area) at a competition can be a brilliant opportunity for students to see other team's machines and learn from others, but it can also be dangerous with power tools, soldering irons and LiPo batteries common place. Clear guidelines for your team members are a must to ensure they remain safe.
2. Pit space - Space is often limited at competitions with teams usually having one table to work on. It would be advisable to contact the event organiser to inform them that you are bringing students, they may be able to provide additional space or position the team is a quieter part of the pit.
3. Cradle – All robots must be sat on a cradle when being worked on. The cradle needs to fully support the robot with its wheels off the ground.
4. Tools – Bring a good range of basic tools to the event, due to the tight space limitations you may only be able to store a small tool box under the table, but it would be a good idea to bring more tool including drills/ chargers etc. and store them in your transport.
5. Food – Make sure students have plenty of food, drink and snacks. Events often take place at exhibitions where food can be very expensive and a distance from the pit area.
6. Battery transport –You must have a safe means of safely transporting and charging LiPo batteries. Each event will have guidelines on the safe handling and charging of batteries, make sure you are familiar with these.
7. General advise
   a. Make sure you thread lock every bolt so it won't work loose during the competition.
   b. Check all wheels can freely rotate after each fight.

Troubleshooting

Due to the nature of robot combat problems often arise during the course of an event. Usually these can be overcome in the pit, below are a few common issues.

Always remove the battery before conducting any troubleshooting.

1. A low power supply – Often a loss in radio link or intermittent drive can be solved by simply changing the battery pack for a fresh one.
2. Poor radio signal – Sometimes your robot will be working well outside the arena, but not inside. This can be down to a range of factors, but checking that the receiver's antenna isn't obstructed helps reduce interference.
3. Poor radio signal –The signal cables that connect the RX to the ESCs are susceptible to electrical interference from the high current cables powering the weapon and drive motors, where possible try to router the signal cables away from wires that carry a large amount of current.

Example build process

Here is an example build process

1. Sketch
2. CAD model
3. Parts list
4. Delivery of parts
5. Fabrication
6. Photos of any outsources manufacturing
7. Assembly
8. Finished robot
9. Testing