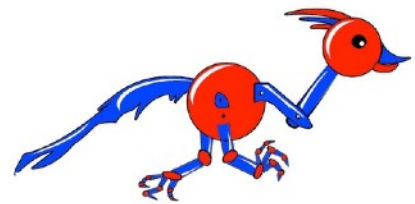
Wiring your robot

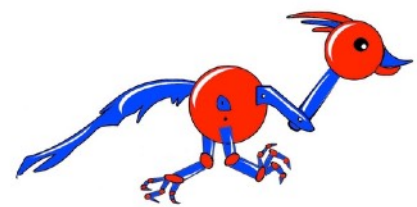
Scott McMahon, Mentor



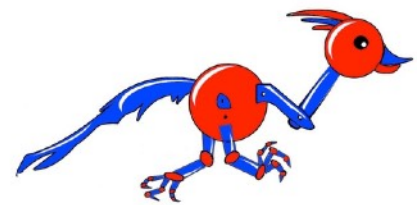
Outline

This is the first part of a six part series in the Control System of an FRC robot. The parts include:

1. Components and tools
2. Best practices
3. Useful links
4. Step by step

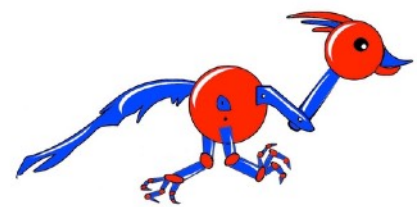


Components and Tools



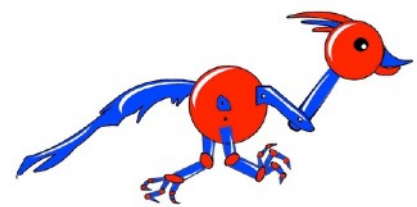
Build vs buy

- In general, 2468 likes to buy something rather than make it
  - Quality is usually better
  - Time to make things are less
  - e.g. PWM wires are better bought from REV or AndyMark than hand made
- But…
  - The purchased item may not be as optimal as it could be (e.g. wire lengths longer than necessary)
  - Purchased items may be made for less than buying



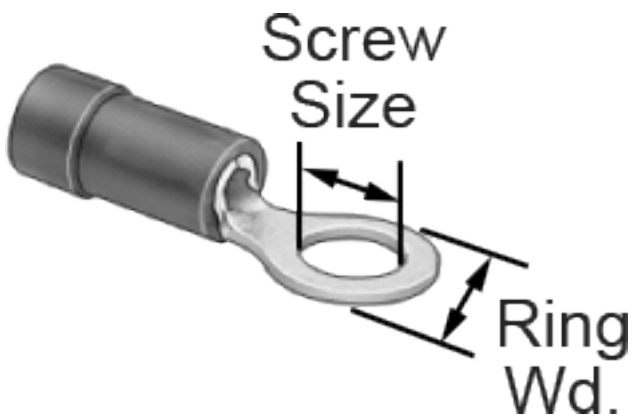
Components

- Terminals
- Butt Splices
- Ferrules
- Anderson Power Products

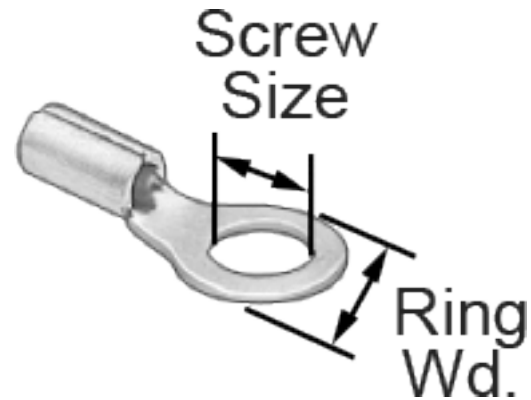


Crimp terminals

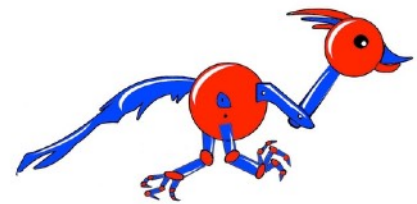
- Terminals are things that you attach to the end of wires in order to connect the wire to *something* (a motor controller, switch, etc.)
- Terminals can be insulated or non-insulated
  - Insulated terminals cover the wire/terminal overlap with built-in insulation, non-insulated require you to insulate later (e.g. cover with shrink wrap)



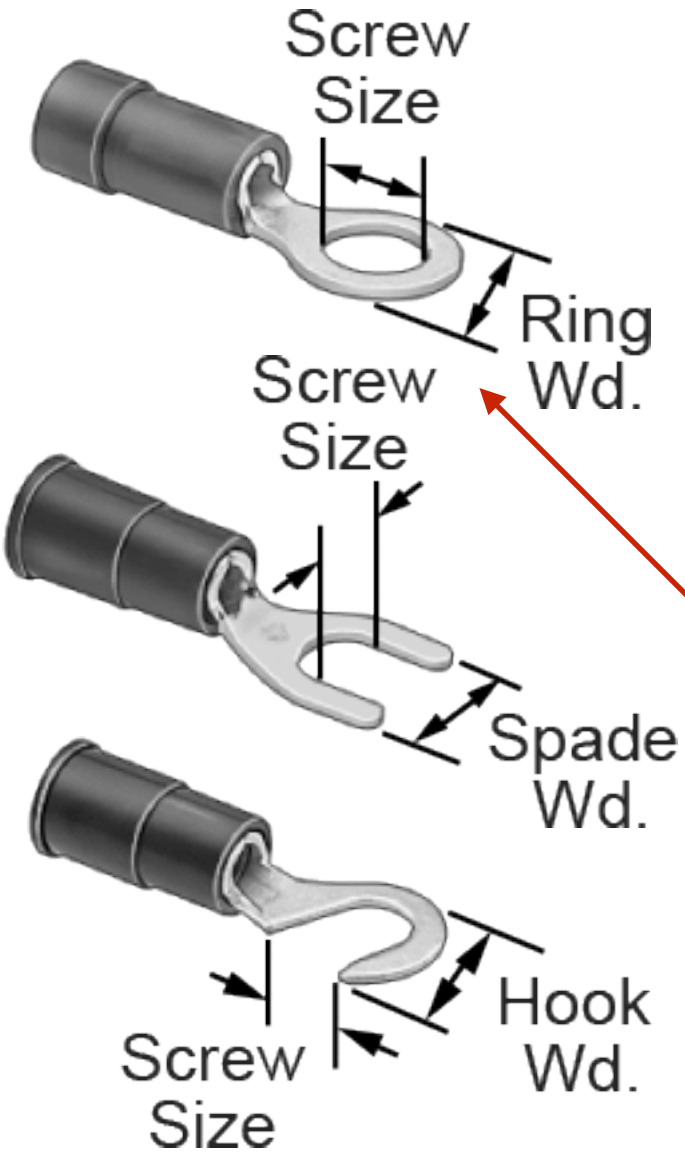
(insulated)



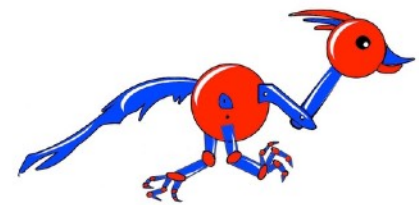
(non-insulated)



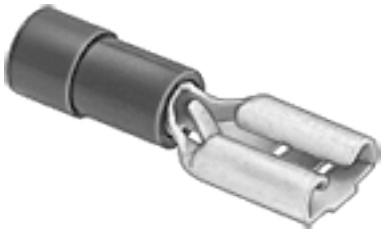
Wire to screw terminals



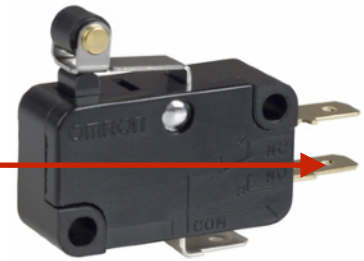
Rings, forks, and hooks are the best way to connect wire to a screw terminal.



Wire to other things

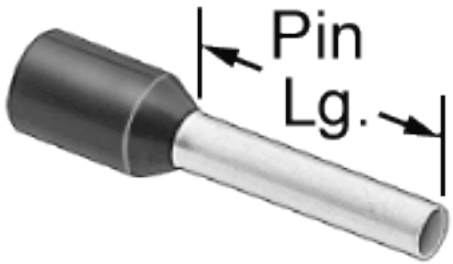


Quick disconnects help connect wire to a blade or flat connector

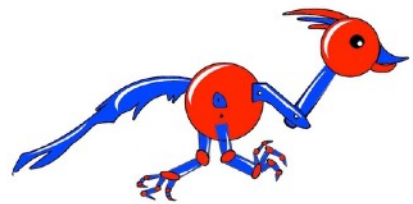


(example: limit switch)

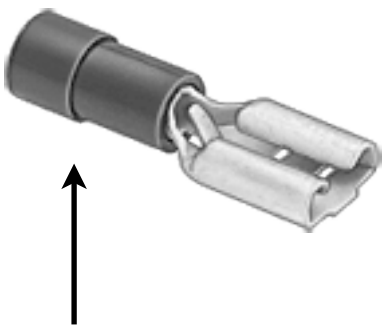
A butt splice connects two wires together



A ferrule is used on an end of stranded wire to prevent the stands from fraying and shorting to adjacent conductors



Insulation color has meaning



Insulation

6 AWG

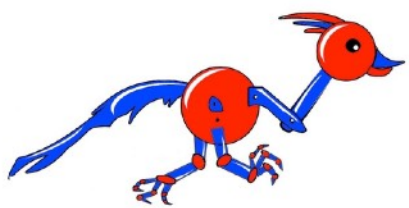
8 AWG

10-12 AWG

14-16 AWG

18-22 AWG

The color code repeats, but where there is a duplicate, it should be obvious when you eyeball the size!

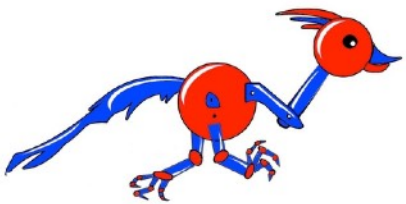


Tools are marked

18-22 AWG

14-16 AWG

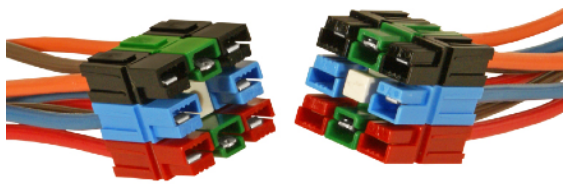
10-12 AWG



Anderson Powerpole connectors

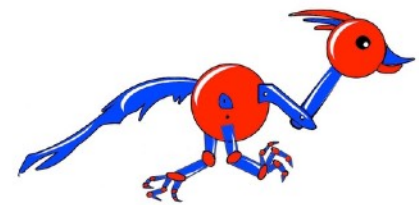
PP15/PP30/PP45
(Housing and contact)

SB50/SB120
(Housing and contact)



Colored housings can aid in identifying the function of a wire (e.g. black is ground, red is 12V, etc.)

Housings can be attached together into blocks

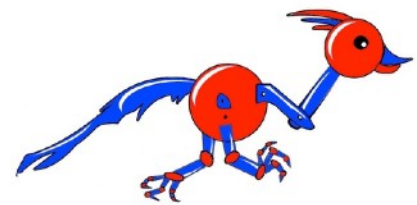


Power

Note the positive and negative markings

Note shape differences!

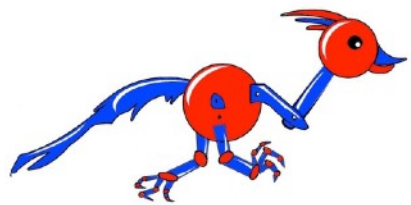
Only housings of same color connect with each other because of the shape of the block between the contacts (although pink and red can mate)



Standards/conventions

Follow a standard, and you'll avoid mistakes later!

Red (12V) on left, Black (Gnd) on right



PP15/PP30/PP45 crimpers

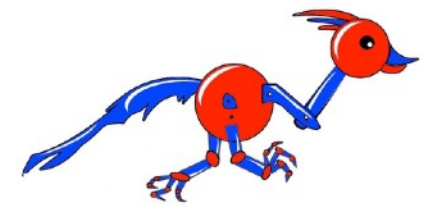
TRIcrimp
$40
PP15/PP30/PP45

Cheapest!

OR

Anderson 1309G3
$259
PP45

Anderson 1309G2
$259
PP15/PP30



SB50/SB120 crimpers

HexCrimper
$90
SB50/SB120

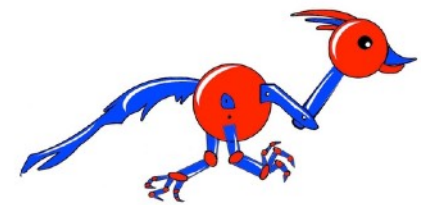
Only SB120 option!

OR

Anderson 1309G4
$260
SB50

Cheapest!

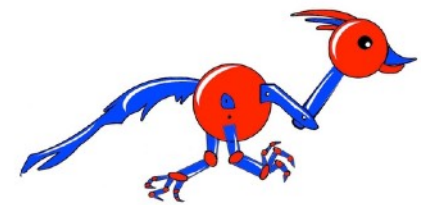
PowerWerx Economy
$17
SB50



Anderson accessories

Roll pins are inserted between two PP housings to ensure the housings do not slide with respect to each other

Retention clips hold connected pairs of wires/connectors together to avoid disconnect



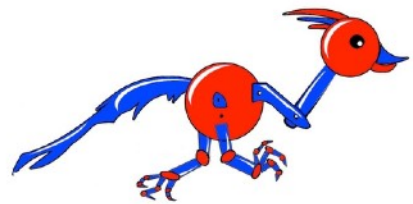
Anderson accessories

Reducing bushings allow large gauge contacts to be used with smaller gauge wire

(wire inside reducing bushing inside contact)

The handle kit can make separating connectors easier

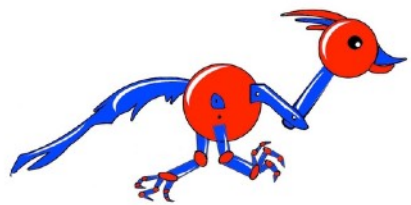
(easier to grab)



Anderson accessories

Spacers allow one to create keyed blocks of the same number of housings and reduce connection errors

A “keyed” connector is one that mates with the opposing connector in only one way.



Ferrules

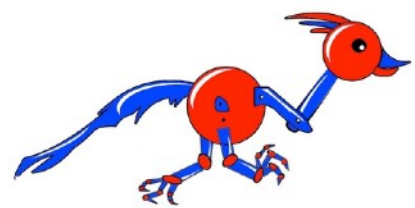
There are two kinds:

1. Ferrules for connecting to the Wago connectors of the PDP

   DN-CT series from Automation Direct

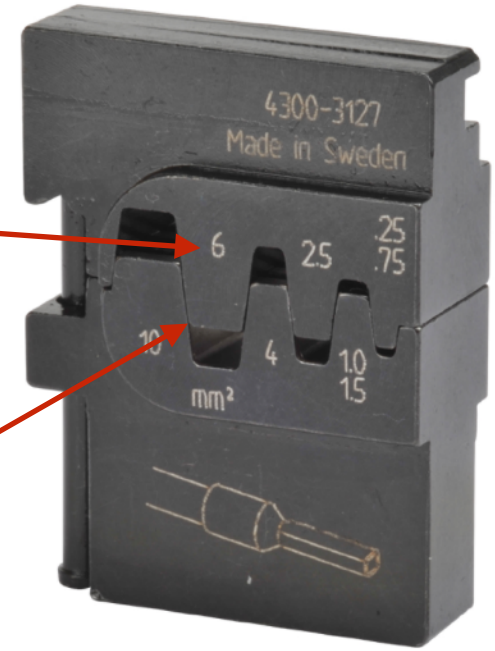
2. Ferrules for connecting to the Weidmuller connectors as used on the roboRIO, PDP, PCM, and CAN Connector

   Weidmuller from Cross the Road Electronics



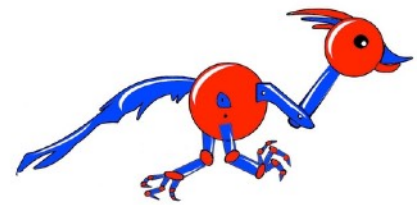
DN-CT

- Source: www.automationdirect.com
- Tools Handle DN-CT-HDL ($56) and Die DN-CT-D4 ($37)
- The handle supports interchangeable die
- Die has wire size in mm on one side and AWG on the other
- Crimper creates D-shape on ferrule with ridges on the flat which are good to face up into the Wago gate



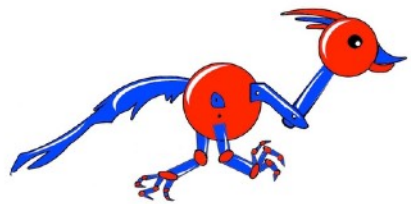
- Color of insulation indicates wire gauge (see below)
- Suggested ferrules

BM-00508 FERRULE GREY 4X9 PK 200 12AWG SHORT
BM-00506 FERRULE BLUE 2.5X8 PK 250 14AWG SHORT
BM-00504 FERRULE RED 1.5X8 PK 500 16AWG SHORT



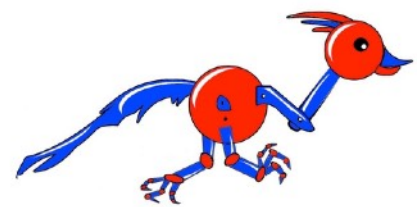
Weidmuller

- Source: www.ctr-electronics.com
- Tools IWISS Crimper
- The crimper supports 10-23 AWG
- Crimper creates a rectangular shape
- Color of insulation indicates wire gauge



PWM cables

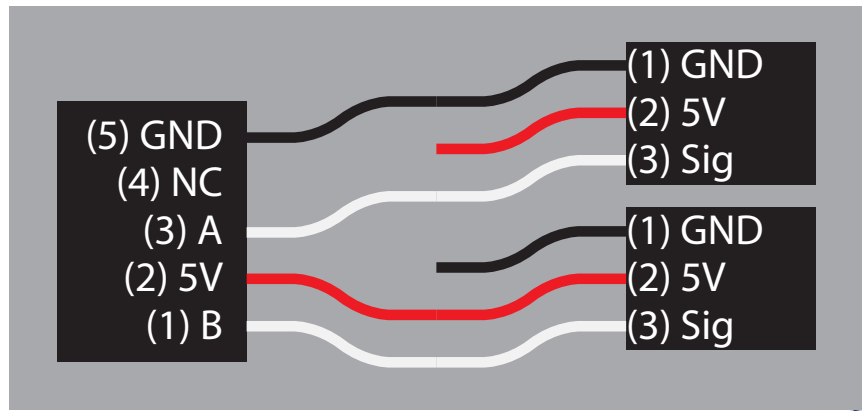
- Recommendation is to buy these rather than make them
- Why?
  - First, to do a decent job you should have a ratcheting crimper which cost about $40
  - Hand-made 2 ft cable costs approx $1.95,
    Housings ~$0.25 ea, pins ~$0.07 ea, wire ~$0.50/ft
    (Note: prices depend on quantity purchased)
    am-0694 is $3.25 (single cable, bulk option is cheaper still)
- But, if you want to make your own, Hansen Hobbies (link) sells parts at reasonable cost
  - They also provide a youtube video showing the process to make a PWM connector (link)



PWM cables

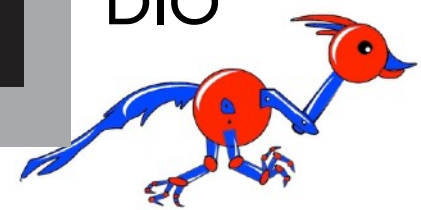
- When is it really advantageous to be able to make your own PWM-like cables?
  - When you need to make a cable for a sensor that uses a 0.1" pin/stake-style header
    - Like the 63R-series incremental encoder from Grayhill
  - You can make a cable assembly with:
    A 1x5 on one end, and
    Two 1x3s on the other, resembling a Y so that the A+PWR is connected on one 1x3 and B+GND is connected on the other

5-pin header



DIO

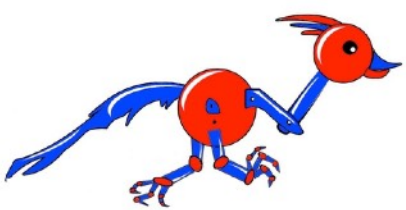
DIO



Power Wire

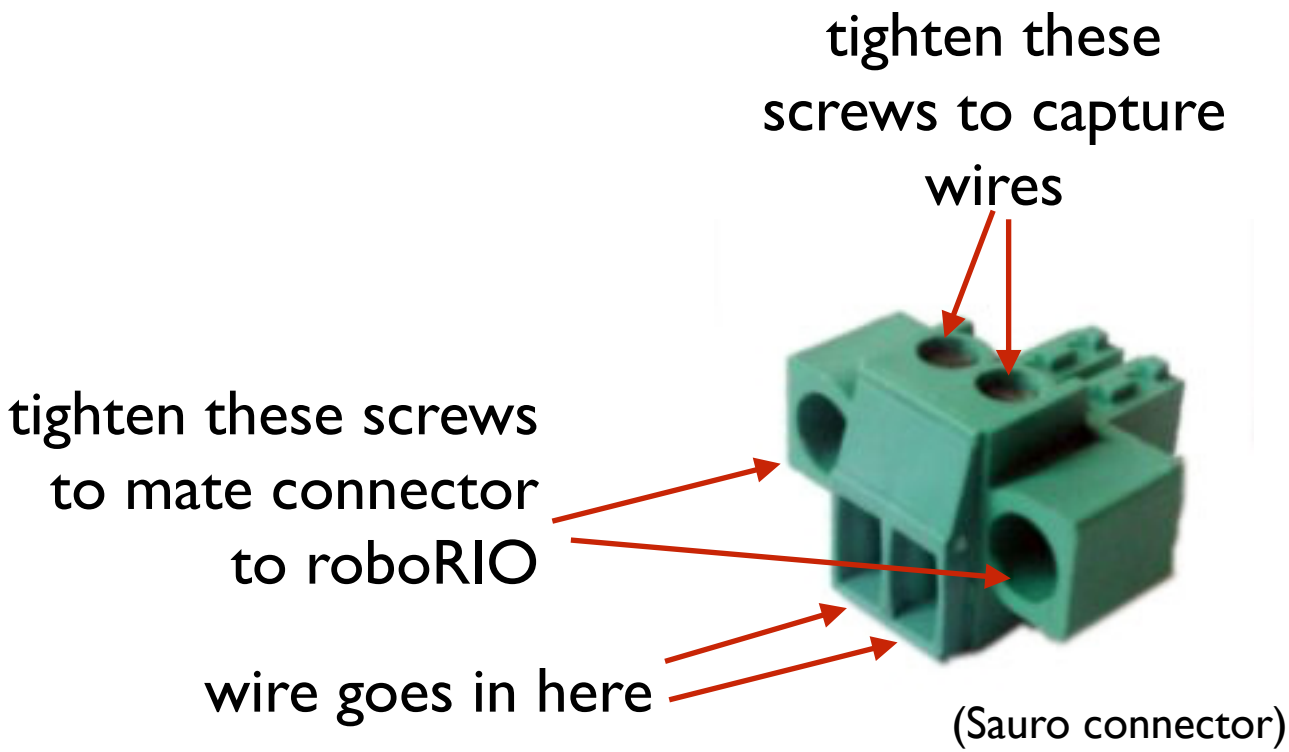
- Power wire
  - Find a flexible, stranded wire
  - Either separate or zip
- Silicon wire (vexpro.com)
  - Flexible and easy to use

- Zip wire (www.powerwerx.com)
  - Zip wire is two-conductor, bonded wires
  - 6-26 AWG

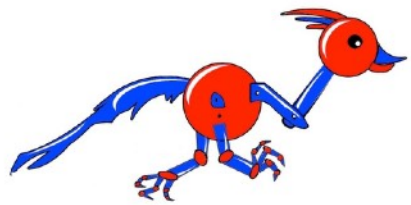


Sauro connector

- The connector used to provide power to the roboRIO controller

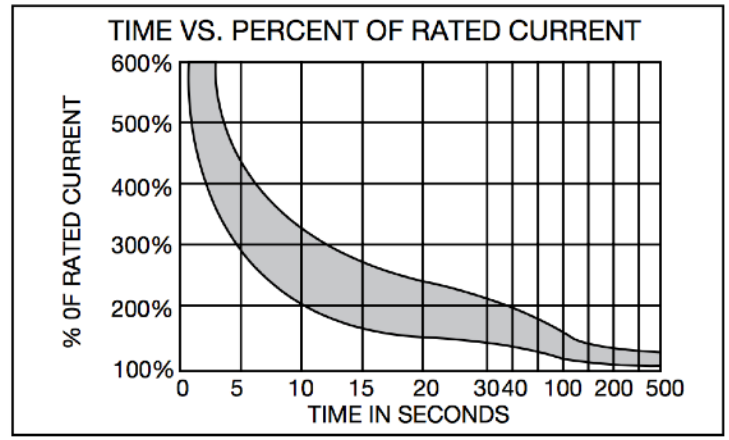


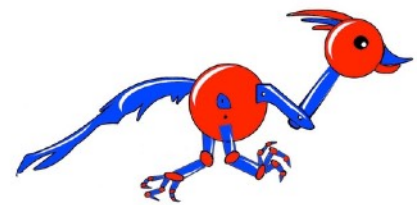
(Sauro connector)



Circuit breaker (120 A)

- The 120 A circuit breaker provides two functions:
  - Safety function – in case the robot draws excessive current — No, it doesn't trip immediately when the robot is using 120 A (see datasheet)
  - On/Off switch to the robot



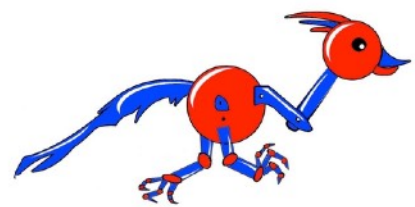


Power Distribution Panel (PDP)

- Direct connect of battery/circuit breaker
- Eight high-current connectors, each protected by 40 A circuit breaker
- Eight medium-current connectors, each protected by a 20-30 A circuit breaker, although you can use these for 5 and 10 A circuit breakers too
- Dedicated roboRIO power (CONTROLLER PWR) protected by 10 A fuse (red)
- Dedicated VRM and PCM power (VRM PCM PWR) protected by 20 A fuse (yellow)
- CAN connection allows logging and inspection of current for debug and control

(PDP)

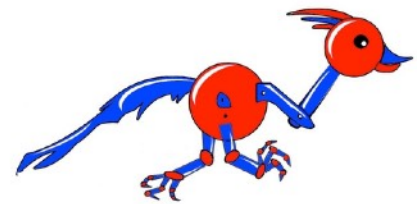
Power Distribution Panel User's Guide

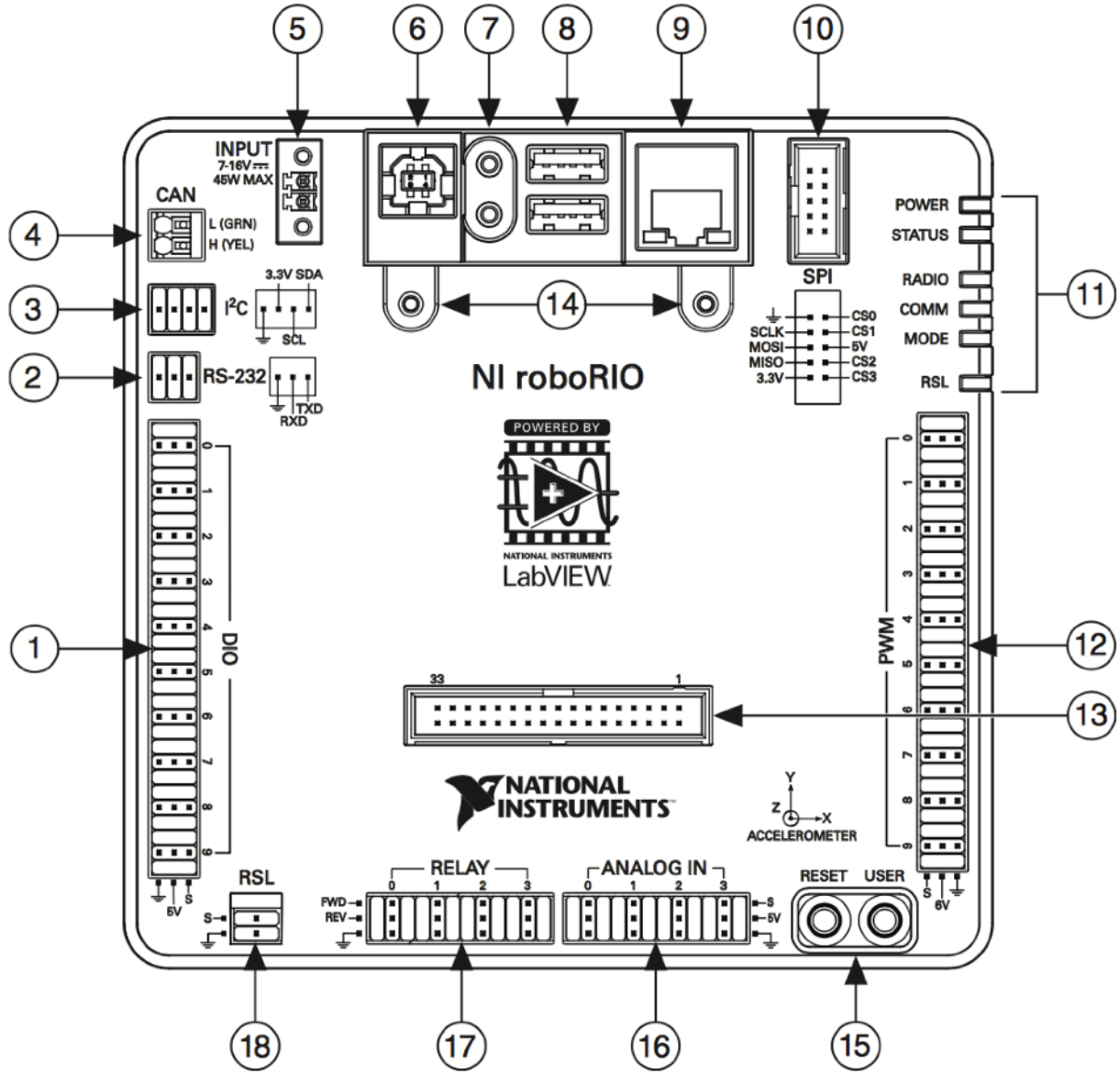


roboRIO

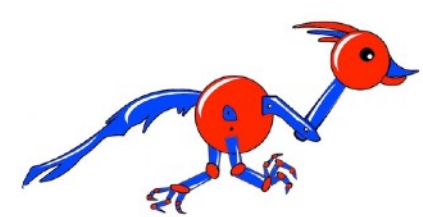
- Control computer for FRC
  - PWM outputs for driving motors
  - Digital and analog I/Os for simple sensors
  - Ethernet and USB
  - UART, I2C, and SPI interfaces to connect to advanced sensor
- Runs Linux
- Robot applications written in LabVIEW, Java, or C++

(roboRIO)





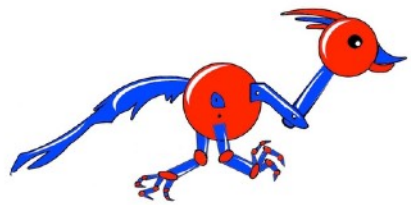
1	Digital input and output (DIO) port
2	RS-232 port
3	I²C port
4	CAN port
5	Power connector
6	USB Device port
7	USB Host retention mount
8	USB Host ports
9	Ethernet port
10	Serial peripheral interface bus (SPI) port
11	LEDs
12	Pulse-width modulation (PWM) port
13	myRIO Expansion Port (MXP)
14	MXP retention mount
15	User and Reset buttons
16	Analog input (AI) port
17	Relay port
18	Robot signal light (RSL) port



Radio

- 802.11ac radio
- 12V power connector (2.1 x 5.5 mm barrel)
- Two Ethernet ports, one PoE capable (provide 12V in PoE RJ45)
  - Why power this via PoE? Because the connector has a latch!

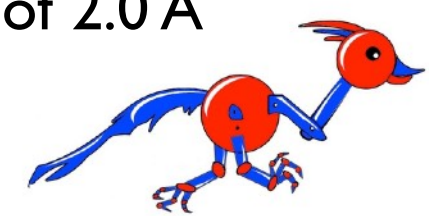
(radio)



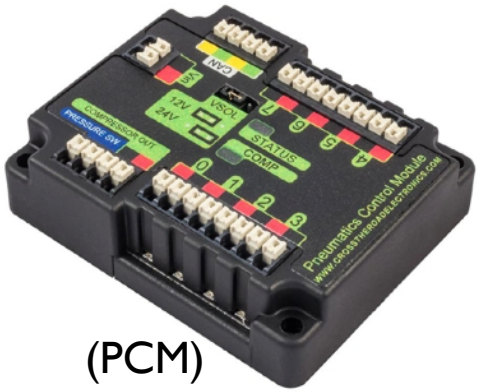
Voltage Regulator Module (VRM)

(VRM)

- Reliable power for radio, even if battery drops to 4.6 V
- 12 V input from PDP
- Provides four 12 V outputs
  - Two combined for a max of 0.5 A
  - Two combined for an avg 1.5 A, max of 2.0 A
- Provides four 5 V outputs
  - Two combined for a max of 0.5 A
  - Two combined for an avg 1.5A, max of 2.0 A
- LEDs indicate status of 0.5 A supplies

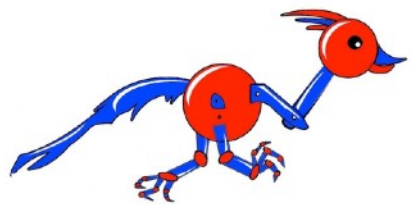


Pneumatics Control Module (PCM)

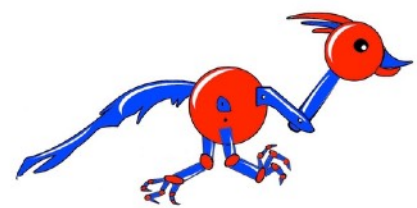


(PCM)

- Automatic control of compressor motor
- Direct interface to pneumatic pressure sensor switch
- CAN connection to roboRIO
- Use one or two PCMs
  - Direct connect of first to PDP 12 V Weidmuller and the second connects to a Wago connector
- Each PCM provides eight solenoid outputs
  - Four double solenoids, or
  - Eight single solenoids

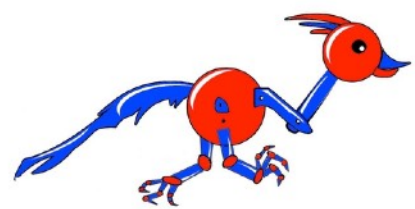


Best Practices



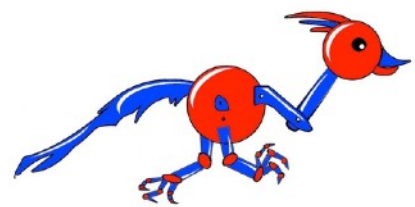
Think ahead – far ahead

- Always be trying to think of the next problem you will face before you get there
- Being able to anticipate issues will save hours of rework
- How do you do this?
  - Use that amazing brain and imagine performing the next steps
  - But you need to think as detailed as you can
  - Will something fit? Will something interfere with something else? Will a short develop? Will there be excessive vibration or wear? Will something next to it be hot and melt something else?



Keep clean and tidy

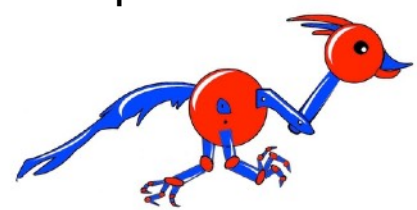
- Believe it or not, electronics and Chicken McNuggets do not mix well
  - Chemicals used in soldering aren't all that tasty or good for you – wash those hands well before eating
  - Greasy hands transfer McNugget oil to bare wires and can affect crimps or soldering – wash those hands well after eating
- In fact, avoid contact of bare wires with you hands if at all possible
  - While stripping insulation, try to keep the end being removed completely and use the insulation to twist the wire



Crimping

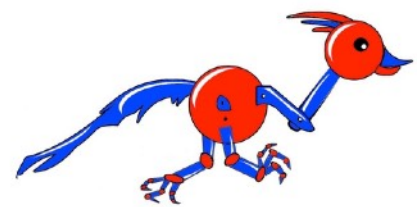
- Always be aware of alignment
    - Look at how the wire, terminal, and target need to line up before making the crimp
- Failure to think ahead and align may result in you twisting wires and developing internal forces that may lead to an eventual failure
- This applies to ferrules*, terminals, power poles, etc.

* – DN-CT ferrule crimpers for power leave a D-shape with ridges on the flat, so the flat should be face up in the PDP. This doesn't apply to Weidmuller ferrules whose crimper forms a square shape.



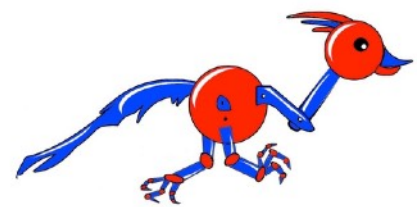
Insulate early

- Short circuits can make robots fail
- Intermittent short circuits can be very hard to diagnose in addition to making the robot fail
- Shorts can be mitigated by ensuring electrical connections are well insulated with things like shrink tubing
- Shrink tubing also helps prevent wire movement which can lead to issues
  - Shrink tubing is generally better than electrical tape
  - But shrink tubing use must be planned in advance
- Multiple layers of shrink tubing can be advantageous too

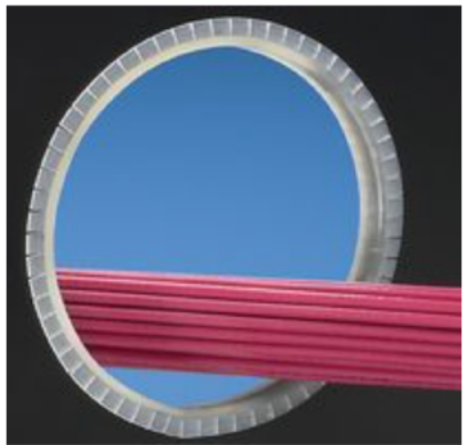


Wiring the PDP with zip wire

- If you're using zip wire and inserting or removing wire
- Open both red and black connectors with a Wago tool – in other words, use two tools at the same time
- Since zip wire joins red and black and 12 AWG can be mildly stiff opening both connectors removes unnecessary wire bending
- Wago connector is available here ($6.04) and here ($9.99)

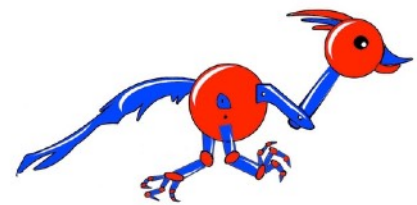


Prevent insulation wear

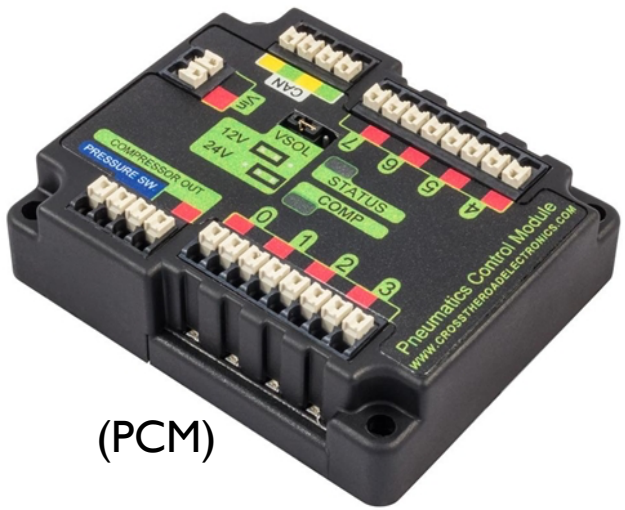


Caterpillar grommet is used to protect wire insulation from rubbing on metal edges. Cut to length and hot glue in spots to tack in place.

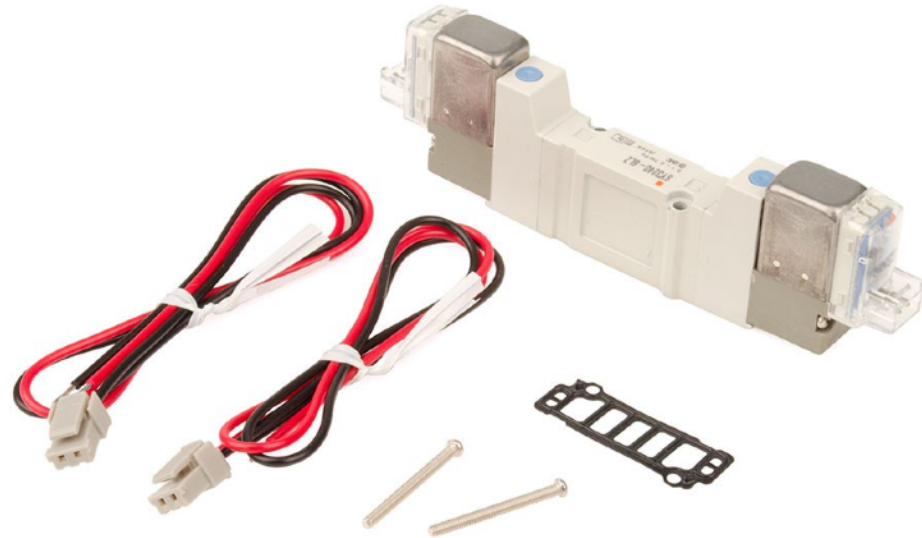
Braided sleeving encapsulates wires or wire bundles from abrasion along length. Cut to length less a small quantity (0.25" each end). Cover both ends with 0.5" length of heat shrink with center on edge of sleeving to prevent fraying. To open, squeeze braiding together similar to finger puzzle.



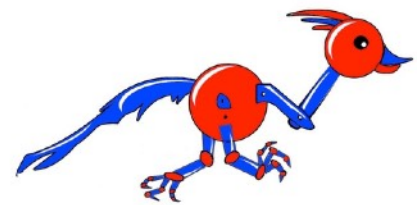
Use ferrules on ends of pneumatic solenoid wires



(PCM)



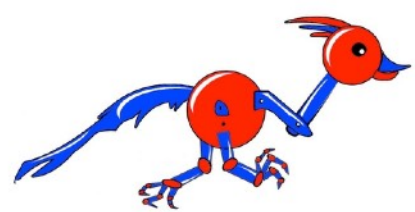
Terminate end of wires with ferrules (Weidmuller)



Labels

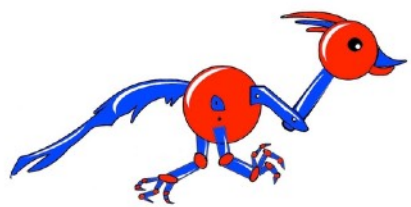
- Using labels to indicate the purpose of components can be a useful aid when figuring out why something isn't behaving as expected (debugging)
- Labels are best when associating component to function (e.g. LEFTDRIVE2 could describe components associated with the chassis left side drive motors #2 in a multi-motor gearbox)
- The same label can be applied to the PDP, motor controller, motor, and wires.
- It would help if the instance in software is also called the same thing!

```
TalonSRX *LEFTDRIVE2 = new TalonSRX(1);
```

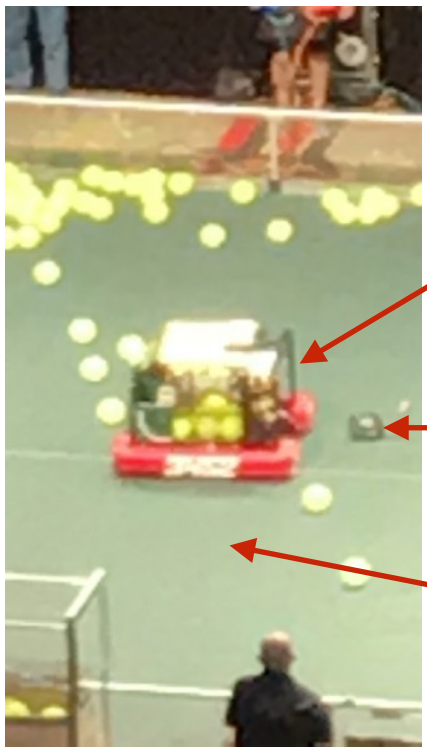


Tie downs

- Secure components to the robot
- Wires that move relative to components are wires that will disconnect themselves over time through the loosening of connections or breaks in wires
- Wires will move under their own inertia as the robot accelerates and decelerates and that is akin to wiggling them
  - The heavier the wire/connector, the more it suffers
- This includes the battery's wires and connectors

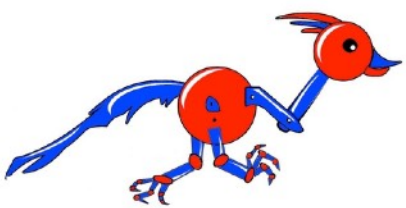


Securing the battery

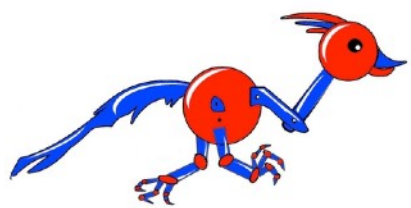


It happens, even to the best!

- The battery weighs about 14 lbs
- It must be secured from impacts or becoming inverted; you do not want the battery to fall out and get damaged
- The heavy battery wires should also be secured from moving
  - Teams have experienced battery wire movement turning off their robots!
- Battery wires can be secured using velcro in addition to tie wraps/zip ties

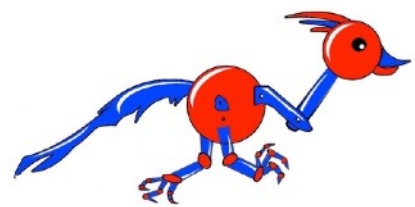


Useful Links



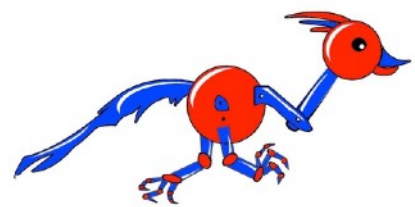
Links to Useful Documents

- Screen Steps Live – Provides on-line step by step instructions for control system info, including wiring, programming, trouble shooting, etc. Probably the most useful resource available (link).



Links to Useful Documents

- PDP User's Manual
  Power Distribution Panel User's Guide
- VRM User's Manual
  Voltage Regulator Module User's Guide
- PCM User's Manual
  Pneumatic Control Module User's Manual
- Radio
  Datasheet
  Setup directions
- roboRIO
  NI roboRIO User Manual

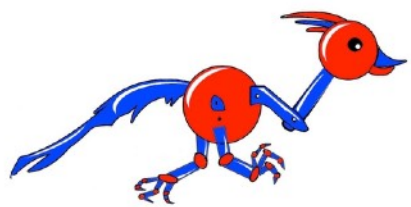


Links to Useful Documents

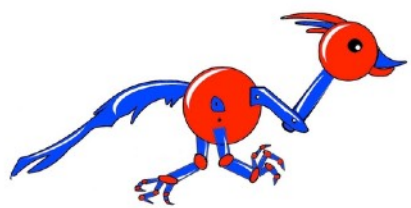
- Victor SP
  Victor SP Quick Start Guide
  Victor SP & Talon SRX Info Sheet

- Talon SRX
  Talon SRX User's Guide
  Talon SRX Software Reference Manual
  Talon SRX Motion Profile Reference Manual
  Victor SP & Talon SRX Info Sheet

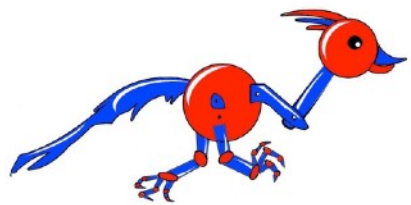
- Spark
  Spark Motor Controller User's Manual
  Spark Motor Controller Quick Start Guide



Step By Step

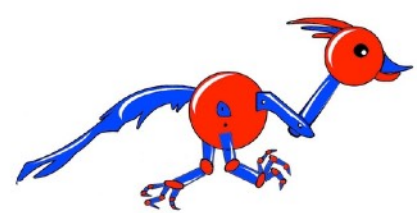


The following is intended to take one through wiring an FRC robot, using best practices.



Wiring the Battery and PDP

Connection	From	To	Wiring
1	SB50	Circuit Breaker	SB50 connector (+, red) wire to ring terminal. The ring terminal connects to the BAT terminal on circuit breaker.
2	Circuit Breaker	PDP	Ring terminals on each end, the AUX terminal is connected to the PDP's (red +) terminal.
3	SB50	PDP	SB50 connector (–, black) wire to ring terminal. The ring terminal connects to the PDP's (white –) terminal.
4			Remember to use the 6mm split-lock washers provided with the PDP between machine screw and terminal.
5			Place plastic cover over inputs and screw down to secure.
6			Terminal characteristics: 0.5 inch wide, 0.25" hole for stud (PDP and 120A circuit breaker).
7			Insulate the terminals so that nothing can be touched,



Wiring the Radio (Options)

..to VRM..

..to radio power..

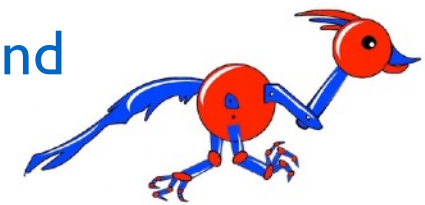
(opt A) OR (opt B)

..to VRM..

..to roboRIO..

..between roboRIO and radio..

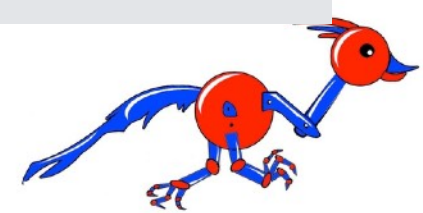
..between injector and radio PoE port..



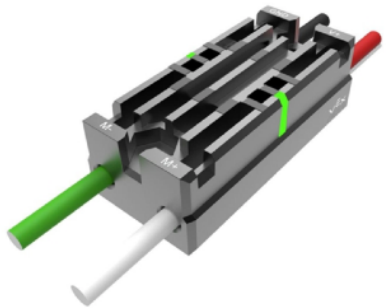
Wiring the Controls

Connection	From	To	Wiring
1	PDP	roboRIO	A custom wire with ferrules on both ends. One end inserted into Sauro connector and screws tightened. Sauro connector inserted into roboRIO and screws tightened. The red wire is connected to the Sauro connector closest to the outside of the roboRIO. Other end inserted into PDP Weidmuller “Vbat CONTROLLER PWR”.
2	PDP	VRM	A custom wire with ferrules on both ends. One end connected to the PDP Weidmuller “Vbat VRM PCM PWR” and the other connected to VRM Weidmuller “12Vin”. Connect red–red and black–black.
3	VRM	Radio (opt A)	A custom wire with ferrules on both ends. Connect one end to VRM Weidmuller “12V/2A” and other end to male jack connector. Plug jack into radio and optionally secure with tape. Connect Ethernet cable between roboRIO and radio.
4	VRM	Radio (opt B)	A custom wire with ferrules on both ends. Connect one end to VRM Weidmuller “12V/2A” and other end to male jack connector. Plug jack into passive PoE injector. Connect Ethernet end of injector to roboRIO. Connect Ethernet end of injector to radio’s PoE Ethernet input (note lettering on radio!).

See following diagram for opt A and B illustration



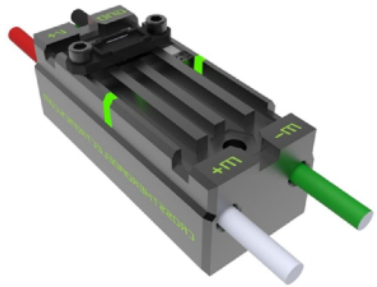
Motor Controllers



Victor SP

Spark

Victor 888

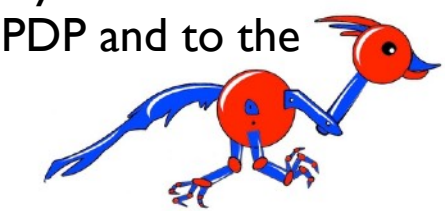


Talon SRX

These motor controllers have captive wires for power and motor connections. So the red/black wires can connect directly into the PDP and the green/white wires can connect to the motor via a PP45, butt splice, or other connector

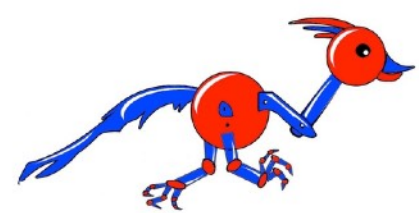
Jaguar (Black)

These motor controllers have screw terminals for power and motor connections. They must have wires built to connect them to the PDP and to the motor



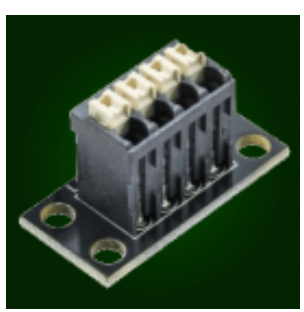
Wiring Motor Controllers (Power)

Connection	From	To	Wiring
1	PDP	Victor SP Talon SRX	Crimp ferrules on red (V+) and black (GND) wires of motor controller. Insert into PDP's Wago connectors
2			Crimp butt splice, PP45, or other connector on white (m+) and green (m–) wires of motor controller. Crimp matching connector on wires of motor.
3	PDP	Spark and others	A custom wire with ferrules crimped on one end and ring/for/hook terminal on the other end. Insert ferrule end into PDP's Wago connectors. Connect other end to motor controller's power screw terminals (V+ and – to red and black wires, respectively).
4			A custom wire with a ring/fork/hook terminal on one end and butt splice, PP45, or other connector on the other. Connect the terminal end to the motor controller's motor screw terminals (M+ and –) and the connector end to wires of motor.

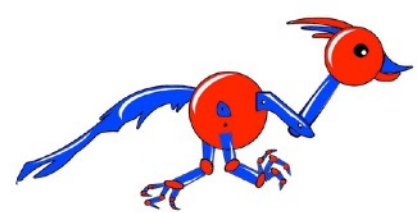


Wiring Motor Controllers (Data)

Connection	From	To	Wiring
1	roboRIO	Victor SP	Connect integrated PWM cable to roboRIO PWM port (black wire of the PWM cable to the outside of the roboRIO).
2	roboRIO	Spark	Use a COTS 3-wire PWM cable of appropriate length. Connect female end to roboRIO PWM port (black wire of the PWM cable to the outside of the roboRIO). Connect the male end to the motor controller.
3	roboRIO	Talon SRX	The SRX is connected over the CAN network. The SRX provides two pairs of CAN wires, one for downstream and one for upstream. Wires can be connected together using a Cross the Road Electronics CAN Connector (P/N 15-676778, link $4/unit), or the ends of wires can be stripped and twisted around a matching upstream or downstream pair, soldered, and heat shrink insulated. Connect green-green and yellow-yellow



Cross the Road Electronics CAN Connector
Connects two devices similar to the PDP and PCM.

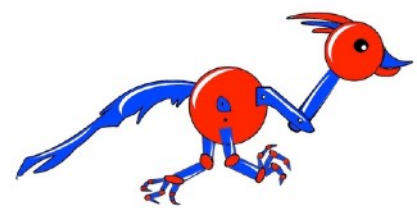


Wiring Pneumatics

Connection	From	To	Wiring
1	PDP	PCM	A custom wire with ferrules on both ends. One end connected to the PDP Weidmuller “Vbat VRM PCM PWR” and the other connected to PCM Weidmuller “Vin”. Connect red–red and black–black.
2	PCM	Compressor	Crimp ferrules onto the compressor leads, or create a custom wire with ferrules on one end and a butt splice, power poles, or other connector on the other end. Plug ferrules into the PCM’s “COMPRESSOR OUT” Weidmuller connectors. Connect red-red and black-black.
3	PCM	Pressure Switch	A custom wire with ferrules on one end and ring/fork/hook terminals on the other. Plug the ferrule end into the PCM’s “PRESSURE SW” Weidmuller connectors. Connect the other end to the pressure switch.
4	PCM	Solenoid(s)	Crimp ferrules on the ends of the solenoid wires. Solenoid wires typically come attached to the solenoid or with a connector pre-installed. Install wires into PCM’s solenoid channels (0-7). Be aware of polarity.
5	PCM	CAN	Crimp ferrules onto ends of CAN wires. Install wires into PCM’s CAN Weidmuller connectors. Connect green-green and yellow-yellow.
6	PCM		Set the VSOL jumper to the appropriate location based on the voltage requirements of the solenoids being used.

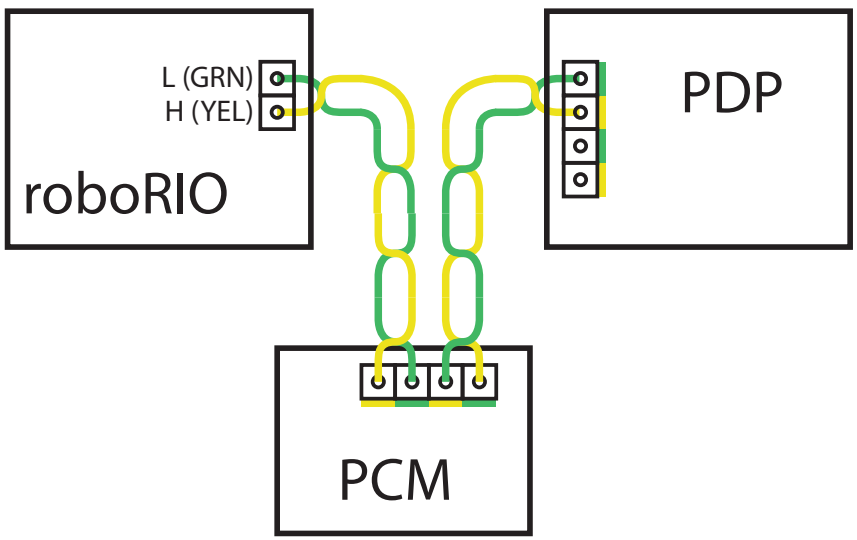
Wiring Pneumatics (2nd PCM)

Connection	From	To	Wiring
1	PDP	PCM	A custom wire with ferrules on both ends. One end connected to the PDP **Wago** connector and the other connected to PCM Weidmuller “Vin”. Connect red–red and black–black.
4	PCM	Solenoid(s)	Crimp ferrules on the ends of the solenoid wires. Solenoid wires typically come attached to the solenoid or with a connector pre-installed. Install wires into PCM’s solenoid channels (0-7). Be aware of polarity.
5	PCM	CAN	Crimp ferrules onto ends of CAN wires. Install wires into PCM’s CAN Weidmuller connectors. Connect green-green and yellow-yellow.
6	PCM		Set the VSOL jumper to the appropriate location based on the voltage requirements of the solenoids being used.

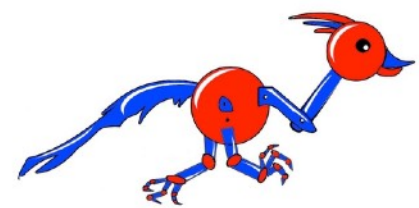


Wiring CAN

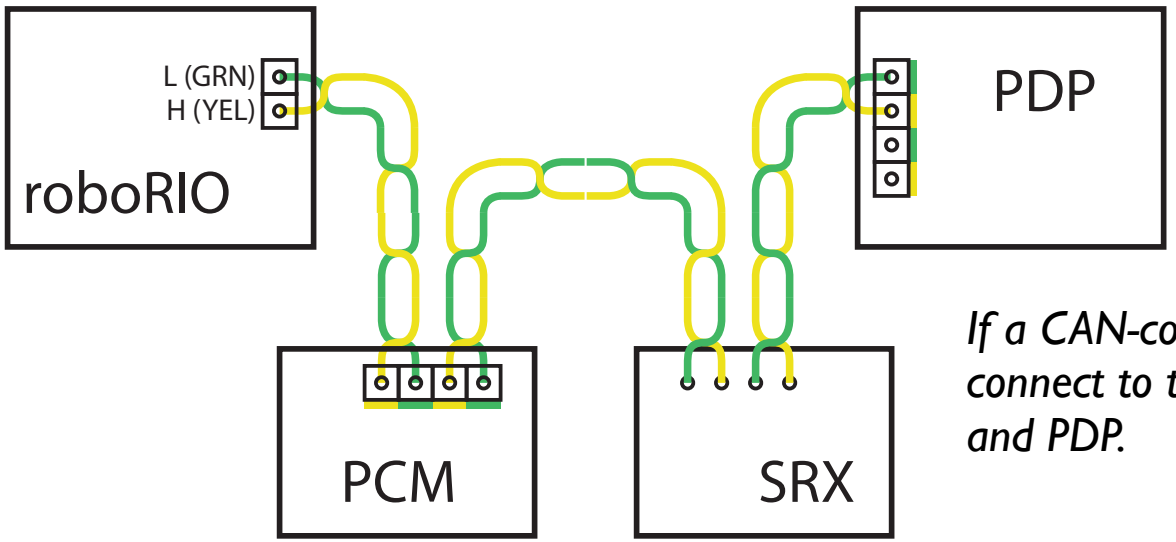
The minimum CAN network required is the roboRIO connected to the PDP. These are the two devices with a 120 Ω CAN terminator included (although PDP must have jumper set to enable it). These devices should be located at the end of the CAN network.



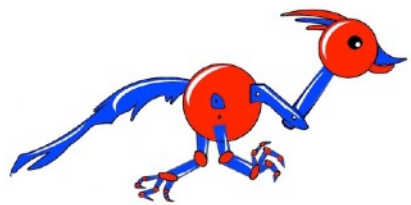
If pneumatics are used, all PCMs must connect to the CAN network between the roboRIO and PDP.



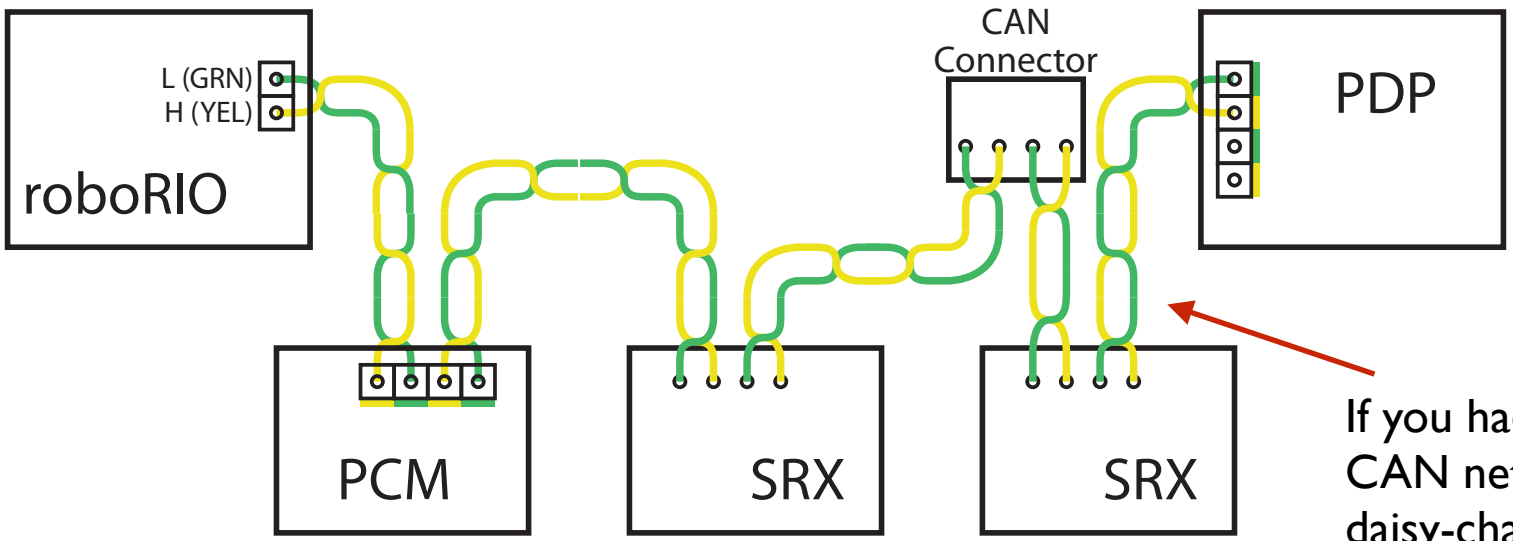
Wiring CAN



If a CAN-controlled motor controller is used, all must connect to the CAN network between the roboRIO and PDP.



Wiring CAN



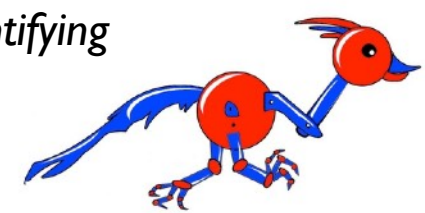
A CAN network with pneumatics and two Talon SRXs.

If you hadn't realized it yet, a CAN network is made from a daisy-chain of devices.

The biggest issue you face is ensuring you don't swap yellow and green accidentally.

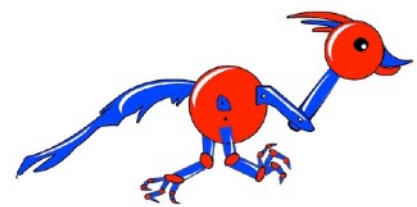
Debugging Tip

If you've accidentally swapped green and yellow along the path, only the devices in the un-swapped portion will be seen and those who are at or after the swap will not. So, identifying devices with their CAN Id is a good practice.



Wiring CAN

- Other CAN devices beside roboRIO, PDP, PCM, and CAN-enabled motor controllers?
- Yup!
  - CTRE's Gadgetteer Pigeon IMU
    This is an integrated navigation sensor.
    This must be powered by a 12V source.
    The CAN bus and power wires must be soldered by you.
  - CTRE's new CANifier
    This is an I/O and LED-strip driver module controlled over CAN and can be useful for connecting sensors, etc.
    This must be powered by a 12V source.
    The CAN bus and power wires must be soldered by you.



Miscellaneous

Connection	From	To	Wiring
1	roboRIO	RSL	Start with an AndyMark 2-wire cable (am-2133, $2.50) and cut one end off close to the connector. Strip both ends and put a ferrule on the end of the black wire. Cut a 1.5 inch of red wire (same size as the AM cable) and strip both ends. Crimp a ferrule to one end. Insert stripped ends from AM and short wires into a ferrule and crimp (joining the two wires together with the ferrule). Insert ferrules of red wires into La and Lb terminals (outer) of RSL connector, tighten to secure. Insert ferrule of black wire into the middle terminal of the RSL connector and tighten to secure. Plug 2 pin connector into roboRIO, red wire connecting to the S pin and black to the ground pin.
2			
3