Introduction to Control System and Sensors for FRC

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## FRC Team #116

What We'll Talk About

- Goals of this presentation
- Limit sensors
- Position sensors
- Speed sensors
- Distance sensors
- Direction/tilt sensors
- Cameras
- Interfacing to sensors
- Using auxiliary hardware
- Summary

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Goals

- The goal of this presentation is to acquaint you with the myriad of sensors that you are likely to encounter in building your robot

- We clearly can't explain all of the possibilities due to time constraints

- But, you should leave here with a better understanding of the sensor types and how they're used

- Hopefully, this will enable your team to do some really cool control systems

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The 2020 Control System

2020 FRC® Control System Layout

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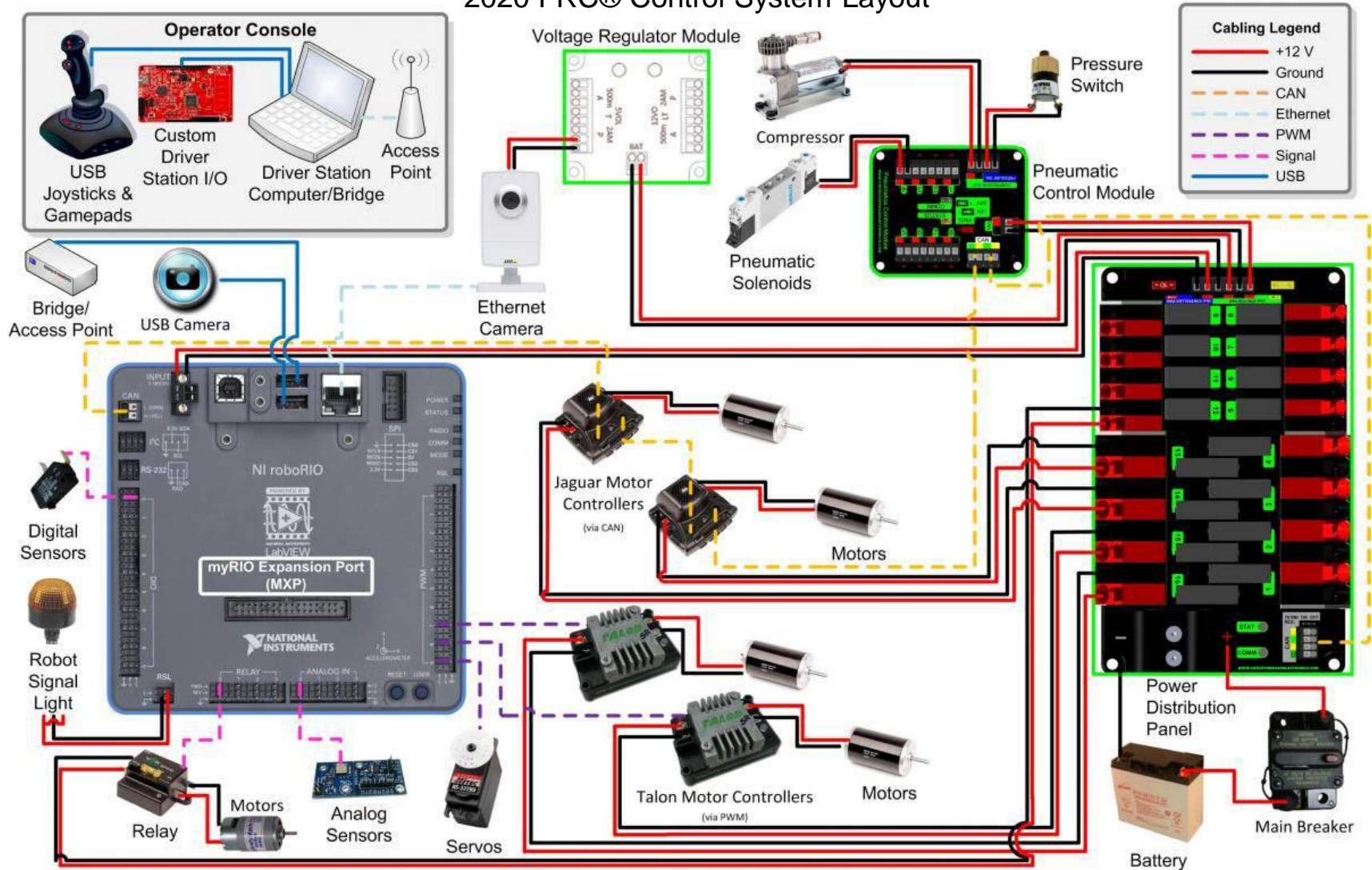
Annotated RoboRIO

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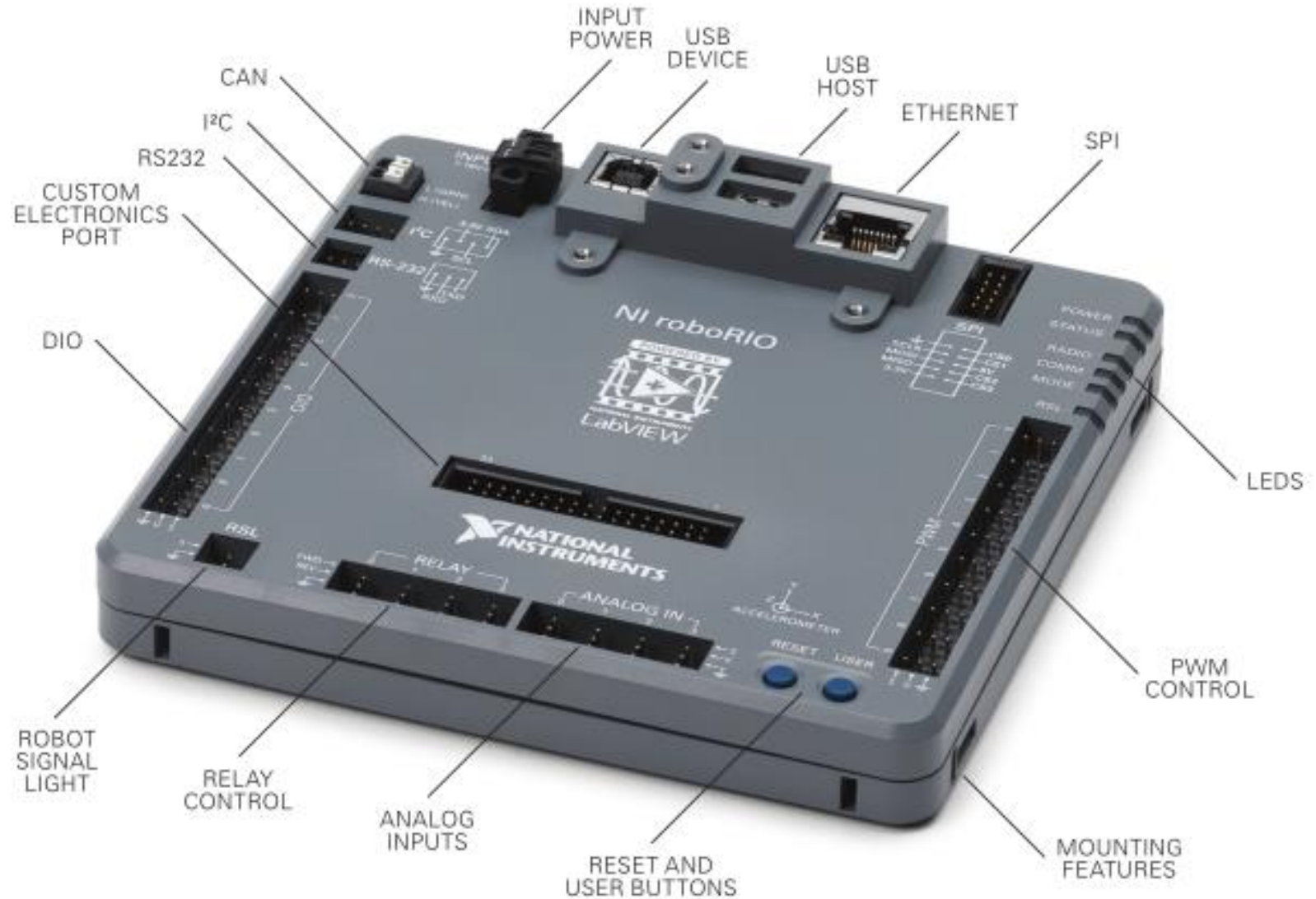
Limit Sensors

- Probably the easiest of all of the sensors is the limit switch
- Typically implemented as a simple switch attached to actuator that indicates that you've reached some end condition
  - ▸ Switch can be NO or NC depending on your logic in the software
- Generally, these will be attached to one of the DIOs of the RoboRIO
- Modern motor controllers such as the CTRE Talon SRX, the Mind Sensors SD540 or the Rev Robotics Spark have inputs for forward/reverse limit switch connections on the controller itself
  - ▸ Uses a closed-loop control to simplify software
  - ▸ Good as a safety if/when your other sensors fail
  - ▸ We'll look at these in more detail later…

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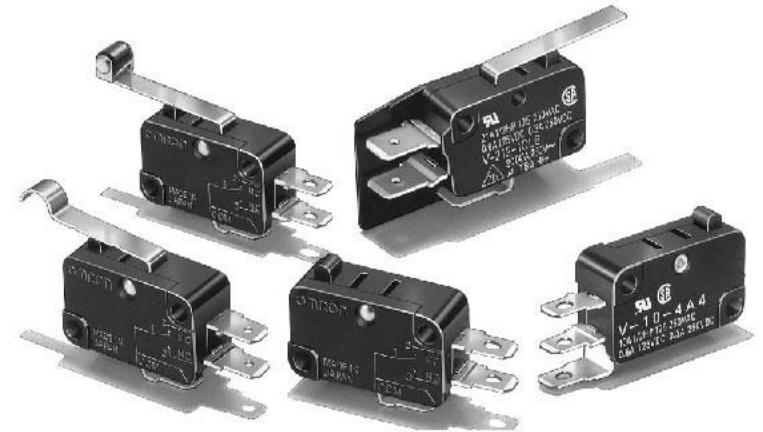
Absolute vs. Relative Measurements

- Much of the role of sensors is to measure quantities

- These measurements can be:
  - ▸ Absolute
    - Turn due East based on the compass
    - Speed up the shooter wheel to 3500 RPM
  - ▸ Or Relative:
    - Turn completely around from where you are right now
    - Spin the shooter wheel 25% faster

- Whether you use absolute or relative measurements depends on the application
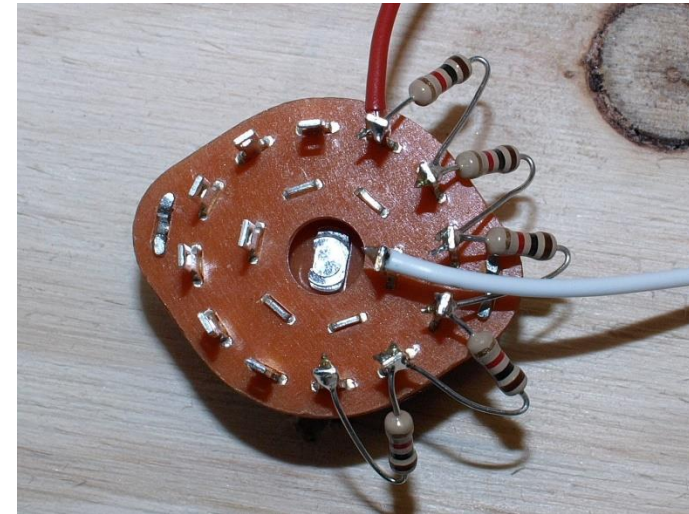
Position Sensors

- Position sensors often take the form of a potentiometer attached to a linkage

- Potentiometers are generally an analog sensor
  - The means you'll connect it to the analog inputs on the RoboRIO

- Usually, a potentiometer has 3 wires
  - VCC, GND and a signal return

- The analog input of the RoboRIO has a 12-bit resolution
  - 0-4096 range and you can use the value to calculate an approximate position in space based on the measured return voltage

Rotating Dial
Resistive Element
A
W
B
Connection Leads
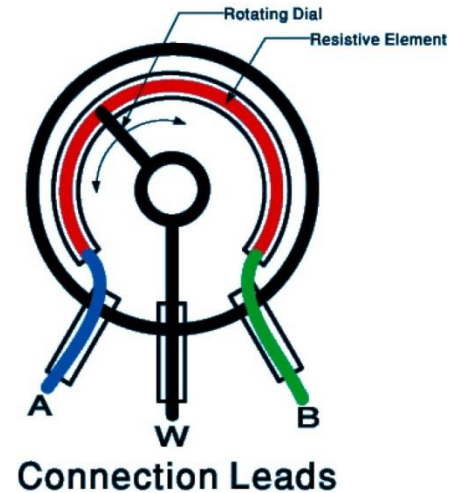
Play Selection Switches

- Often in autonomous mode we will need to select different plays based on our alliance partner's capabilities
    - ▶ Can use a series of digital inputs and toggle switches but this eats up DIOs
- Often this is accomplished using rotary switches with resistor ladders
    - ▶ Use the analog input to measure which switch position is selected

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Position/Speed Sensors

Branded face   Branded face

- Hall-effect sensors use metal moving through a magnetic field (induction) to indicate motion
  - ▸ Can also be used as a limit switch
- Can be used to count rotations or calculate position based on the number of gear teeth that have passed the sensor
- Can also be used as a tachometer
- Would typically be attached to a DIO on the RoboRIO
  - ▸ However, speed of rotation with the sensor may put a significant load on the RoboRIO
- Best to attach it to one of the DIOs and designate the DIO as a counter
 - ▸ Uses the FPGA in the RoboRIO to reduce the compute load

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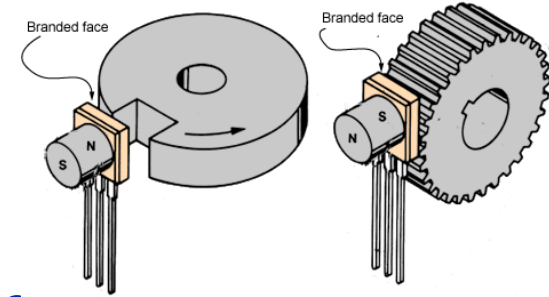
Position/Speed Sensors #2

- Another position encoder is a rotary encoder
- These encoders will have a number of pulses per revolution
  - Given the diameter of the attach point, you can determine how far the system has moved based on the number of pulses
  - Can also be used as a tachometer
- Make sure you purchase the encoder rated for the speed you're trying to measure
- Like the Hall-effect sensor, high PPR can burden the RoboRIO
  - Hook up to a DIO and declare the DIO a counter

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Position/Speed Sensors #3

- The last of the position sensors we'll talk about is the quadrature encoder
- These are similar to the rotary encoder except that you can determine forward vs. reverse motion
  - Also have a PPR rating that you need to know when declaring a quadrature encoder instance in WPILib or LabView
- Usually a "quad shaft encoder" is attached to the axle of a wheel
  - Many gear boxes have specific mounting points for quadrature encoders
- Given the diameter of the wheel, you know how far it's moved based on the number of pulses
- Also attached to a DIO input of the RoboRIO
 - 2x DIOs per encoder

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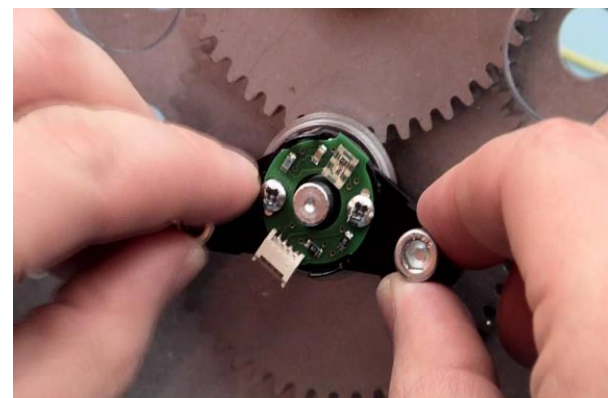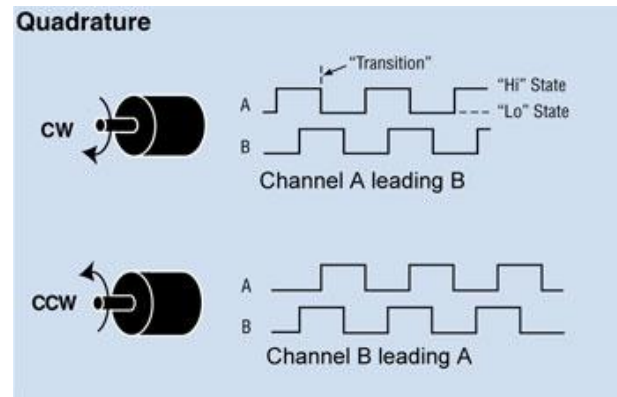
Rotary Position Sensor

- CTRE has a new magnetic rotary encoder that plugs into the Talon SRX
  - ▸ Supports closed loop operation with the Talon SRX
- Can be used for absolute or relative position sensing as well as velocity
- The encoder senses the magnetic field of a diametrically polarized magnet to determine rotational position with 12-bit accuracy
- Provides Quadrature interface that can be used for relative positioning and a PWM output for absolute position measurement

Distance Sensors

- Distance sensors typically all work in the same general way
- A pulse goes out and you measure amount of time it takes to return
  - ‣ Then you apply a formula to convert time into distance
- Common distance sensors use either infrared or ultrasonic modalities
- Beware, not all distance sensors are created equal
  - ‣ Some can range 30' others only a few inches

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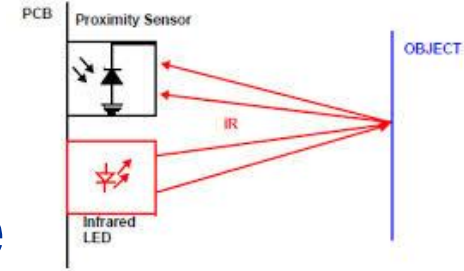
Example Distance Sensors
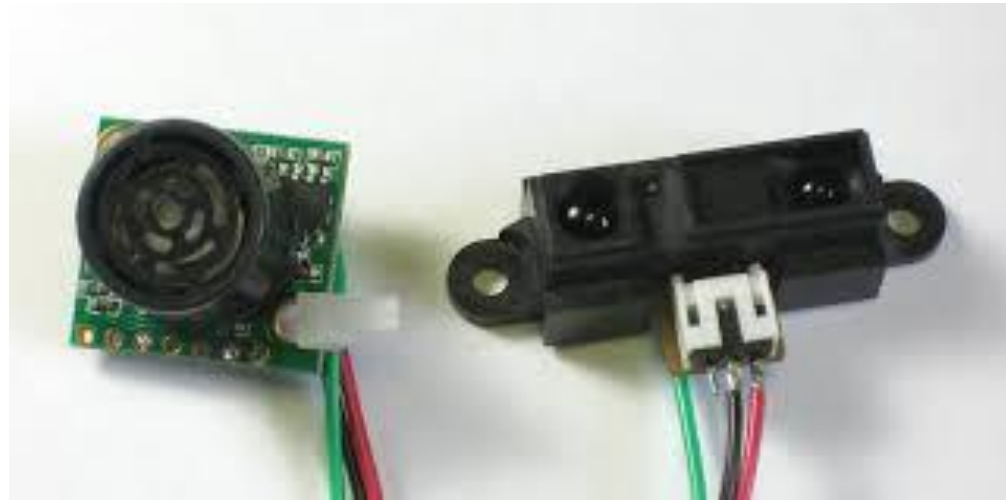
Ultrasonic

Infrared

Ultrasonic

LASER-Based
on servo

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LASER Range Finders

- This unit uses a LASER to measure distance
- FIRST restricts the power and type of LASERs on the robot
  - Must be Class 1 LASER, typically in the near IR spectrum
    - It's invisible to the human eye, but your cell phone camera can see it
- The "LIDAR" from SparkFun is 5V and has a range of 35-40m
  - Programmable with I2C or PWM
- Very accurate and very fast distance acquisition
 - Maybe a little too accurate because it reads a specific point in space

Spinning Lidars

- There is a new class of Lidars that are now coming into the realm of affordability for FRC teams
  - The $400/item limit had kept these out of reach
- The RPLIDAR A1M8 - 360 Degree Laser Scanner Development Kit
  - Essentially the lidar on a rotating motor mount for $99
- This uses a serial port and can measure up to 6m distances in 360 degrees
- When combined with other sensors, you can develop a Simultaneous Location and Mapping (SLAM) system to know exactly where your robot is on the playing field
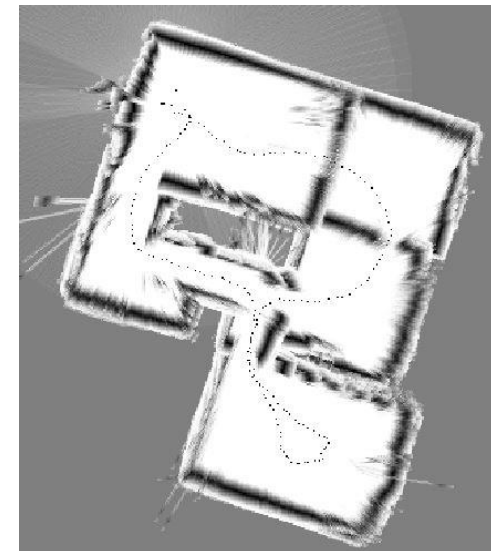
Direction Sensors

- In order to determine the direction of your robot, there are a number of possibilities

- Gyroscopes
  - ▸ Measure the *rate* of turn
  - ▸ WPILib has integrated functions to determine the angle of the robot relative to the starting direction using the gyro class

- However, gyroscopes are subject to drift and can be off by quite a bit in the face of multiple hard hits by other robots
  - ▸ Use the accelerometer to know that you've had collisions
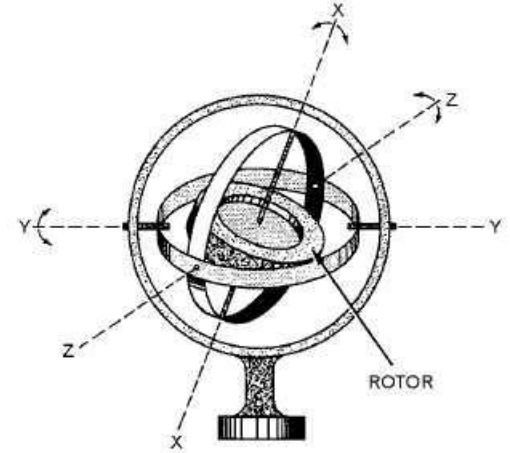
Direction Sensors (2)

- Another means to determine heading is via a Magnetometer (digital compass)

  - You can read an absolute measurement of direction relative to magnetic north but they are subject to interference from large magnetic fields (like motors)

- Gyros and magnetometers are typically implemented as solid-state MEMS sensors

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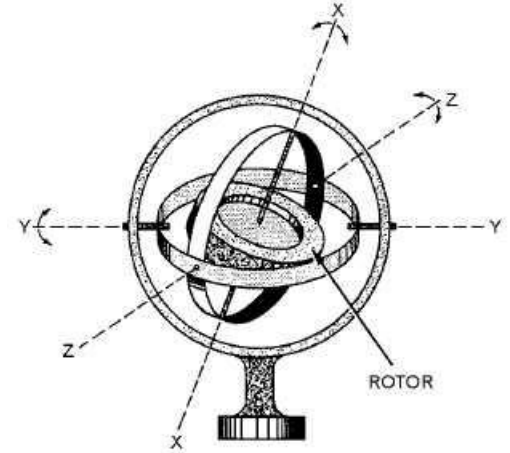
Measuring Acceleration

- There is another sensor known as an accelerometer that measures acceleration or vibrations in terms of "G"s
  - Normal gravity at sea level is defined to be 1G
- Can be used to detect tilt like in the 2012 Rebound Rumble game
- Can also be used to detect impacts and make adjustments to the gyro to correct for drift
- There is a 3-axis accelerometer in the RoboRIO

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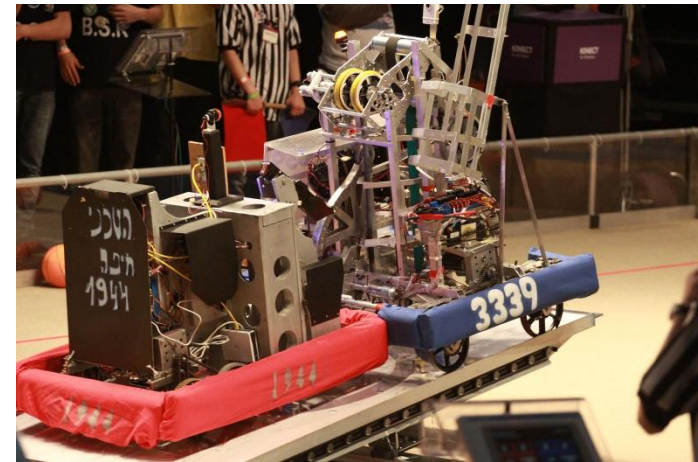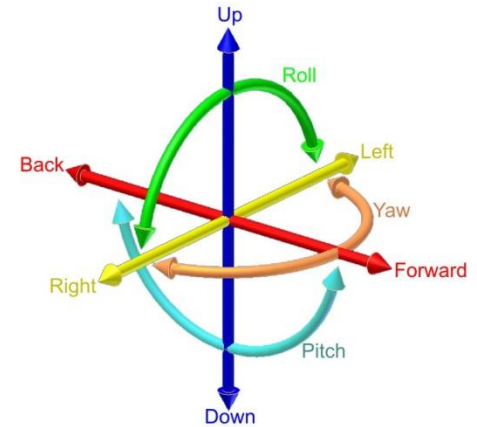
Inertial Measurement Units (IMU)

- If we combine the gyro, accelerometer and magnetometer sensors together, we can create an Inertial Measurement Unit (IMU)
- This allows you to know where your robot is in the physical world and allows for precise navigation
    - ▸ Used frequently in drones
- E.g., the NavX-MXP unit from Kauai Labs for the RoboRIO MXP connector

- With an IMU, it's relatively easy to maintain a heading even when getting hit by other robots

Sensors on the Motor Controllers

- The new motor controllers from 2017+ all have inputs for limit switches
    - Can be used to set a range of motion
- However, the Talon SRX has additional capabilities for closed loop operations
    - Quadrature encoder
        - Position sensing
    - Current sensing
    - Speed sensing
    - Limiting range of motion using a potentiometer on the analog input
    - Controlled via CAN bus

Data Port Pinout
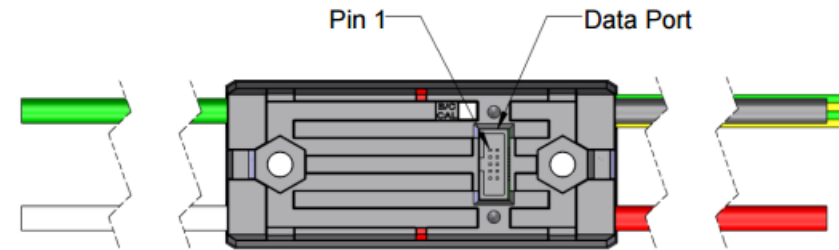
	Pin		Pin	
+3.3V	1	● ●	2	+5V
Analog Input	3	● ●	4	Forward Limit
Quadrature B	5	● ●	6	DO NOT CONNECT
Quadrature A	7	● ●	8	Reverse Limit
Quadrature Index X	9	● ●	10	GND

"Gadgeteer Port"

New Motor Controllers w/ Sensors

- Introduced in 2019, the REV Robotics SPARK MAX motor controllers were the first brushless motor controllers for drive trains

  ▸ When used with the Neo Brushless motors, you had an onboard encoder plus limit switches

  ▸ CAN, PWM or USB control interfaces

- New for 2020 is the CTRE/VexPro Falcon 500

  ▸ Integrated brushless motor with motor controller and encoder in a single package

    • Available for CAN or PWM

    • Half the weight of the CIM motors with > 80% efficiency from 7A – 40A

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Pigeon IMU

- New from the 2017 season is the Pigeon IMU from CTRE

- 9 DoF IMU with several different interfaces including UART and the Gadgeteer port on the Talon SRX

- This allows the Pidgeon to be seen as a CAN bus device by the RoboRIO

- CTRE has examples of code for FRC on their github repository

Current Sensing

- The CAN bus interface on the RoboRIO can talk to the Power Distribution Panel
  - ▸ Gives you the ability to measure current draw from any of the power slots
- Useful for locating bad motors or flaky gear boxes via monitoring for excessive current draw
  - ▸ Or, detecting when your motor stalls like when it reaches the end of its movement

Pressure Sensor

- The Pneumatics Control Module has a built-in interface for the pressure switch used with the pneumatics sub-system on the high-pressure side
  - Automatic cut-off of compressor wher to a certain value

- REV Robotics has introduced an analog pressure sensor for measuring the current pressure in the tanks
  - Useful for seeing if you have enough pressure for the task

Interfacing with Sensors

- WPILib has a collection of interface support
  - ▸ Serial, I2C, SPI, DIO, analog input to name a few
- When selecting a sensor, make sure you know what sort of interface it has and compare that to the number you currently have available on the RoboRIO
  - ▸ You may have to add aux interfaces to the robot via the MXP connector
- Make sure that you allow for power and ground return in addition to the sensor wires themselves
  - ▸ Mount in a safe place and make sure you don't use the robot chassis for ground
- Verify what kind of power the sensor needs before attaching to the RoboRIO
  - ▸ 3.3V, 5V, etc.

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Cameras

- The final sensor we'll talk about is the camera

- The camera can be set to filter based on certain colors
  - ▶ Retroreflective tape and a colored LED allows you to do target detection
    - Your image processing can do automatic targeting

- The use of dual cameras will allow you to do distance estimation
  - ▶ However, because of the known size of the field and the game elements, you can also do estimation with a single camera

- The OpenCV libraries in the RoboRIO allow you to do significant image processing on the robot

Auxiliary Processors

- If you find that the RoboRIO doesn't provide enough sensor inputs you can also augment it with Arduinos, RaspberryPi, Beaglebone Black and more

  - ▸ Useful for interfaces to switch settings for initial plays in autonomous mode or for more IO if you need it

  - ▸ Can also be used for high-interrupt measurement like tachometers

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Summary

- In this session, we have only touched on a small number of the variety of sensors that can be used on the robot

- Any sensor with RS-232, I2C or SPI interfaces is also possible including barometric pressure, heat, gas sensors and more

- Your imagination is your largest limiting factor
  - The RoboRIO has connectivity for almost any option or it can be augmented with aux processors if needed