WPI Robotics Library User's Guide

Worcester Polytechnic Institute Robotics Resource Center

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January 5, 2011

		Jan
Brad Miller	November 2009	Rev 1.0
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Contents

Stuff to do

TODO: redo Joe's pictures and get some better explanations.

TODO: make the serial and I2C sections about communications.

TODO: Find the comments in the Java and C++ forums about the documentation

Using the WPI Robotics Library

The WPI Robotics library (WPILib) is a set of software classes that interfaces with the hardware and software in your FRC robot's control system. There are classes to handle sensors, motors, the driver station, and a number of other utility functions such as timing and field management. In addition, WPILib supports many commonly used sensors that are not in the kit, such as ultrasonic rangefinders.

What is the WPI Robotics Library?

The National Instruments compact RIO-9074 real-time controller or "cRIO" for short is currently the robot controller provided by the FIRST Robotics Competition (FRC). It provides about five hundred times more memory than previous FRC controllers.

The WPI Robotics library is designed to:

- Work with the cRIO controller.
- Handle low level interfacing of components.
- Allow users of all experience levels access to the features.

C++ and Java are the two choices of text-based languages available for use on the cRIO. These languages were chosen because they represent a good level of abstraction for robot programs than previously used languages. The WPI Robotics Library is designed for maximum extensibility and software reuse with these languages.

WPILib has a generalized set of features, such as general-purpose counters, to provide support for custom hardware and devices. The FPGA hardware also allows for interrupt processing to be dispatched at the task level, instead of as kernel interrupt handlers, reducing the complexity of many common real-time issues.

Exceptions conventions

The WPI Robotics library does not explicitly support the C++ exception handling mechanism, though it is available to teams for their programs. Uncaught exceptions will unwind the entire call stack and cause the whole robot program to quit, therefore, we caution teams on the use of this feature. In the Java version exceptions are used with the following conventions:

Exception type	How they are used
Checked exceptions	Used in cases where runtime errors should be caught by the user program. Library methods that throw checked exceptions must be wrapped in a try-catch block.
Unchecked exceptions	Used for cases like bad port numbers in initialization code that should be caught during the most basic testing of the program. These don't require try-catch blocks by the user program.

Resource reservations

Objects are dynamically allocated to represent each type of sensor. An internal reservation system for hardware is used to prevent reuse of the same ports for different purposes (though there is a way around it if necessary).

Source code availability

In the C++ version the source code for the library will be published on a server for teams to review and make comments. In the Java version the source code is included with each release. There is also a repository for teams to develop and share community projects for any language including LabVIEW. This is hosted at http://firstforge.wpi.edu. Team members may sign up for accounts and request projects to be shared by the entire *FIRST* community to be hosted. Currently we don't have the capacity to grant project requests for individual team robot programs.

Using the WPI Robotics Library User's Guide

This document is designed to help you use WPILib to program your robot. The general architecture of the WPI Robotics Library documentation is shown below.

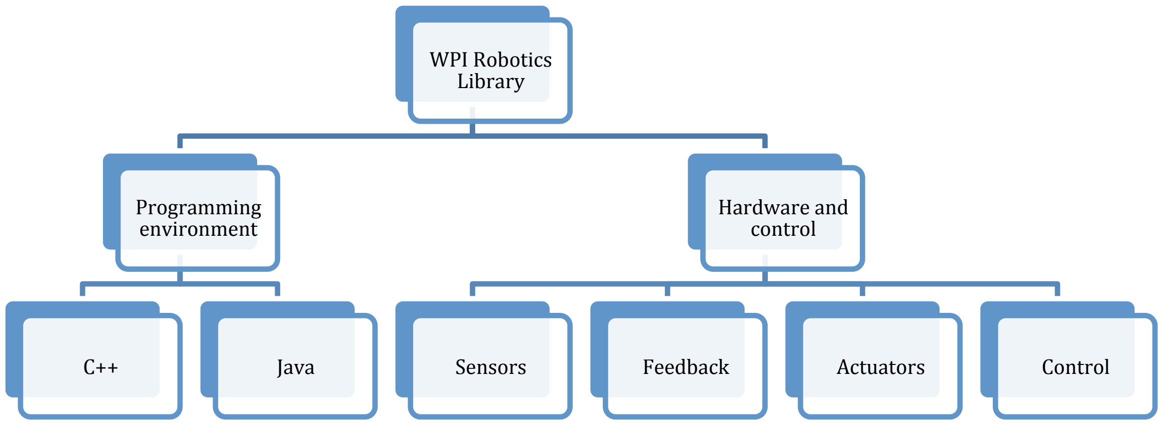


Figure 1: WPILib structure diagram

As shown by the diagram above, the WPI Robotics Library supports environments for both the C++ and Java programming languages. These environments and programming languages are discussed and explained in the "Getting Started With Java For FRC" and "Getting Started With C++ For FRC" documents. Both of these documents, along with other supportive materials, can be found online at http://first.wpi.edu in the FIRST Robotics Competition section.

The WPI Robotics Library User's Guide addresses the Hardware and Control branch as shown above. A more detailed view of what this involves is shown in the series of charts below.

The first primary section of the user's guide is the sensors section. This section discusses how to use the sensors provided in the FRC kit of parts, as well as a few other sensors commonly used on FRC robots. The structure of this section is shown in the chart below:

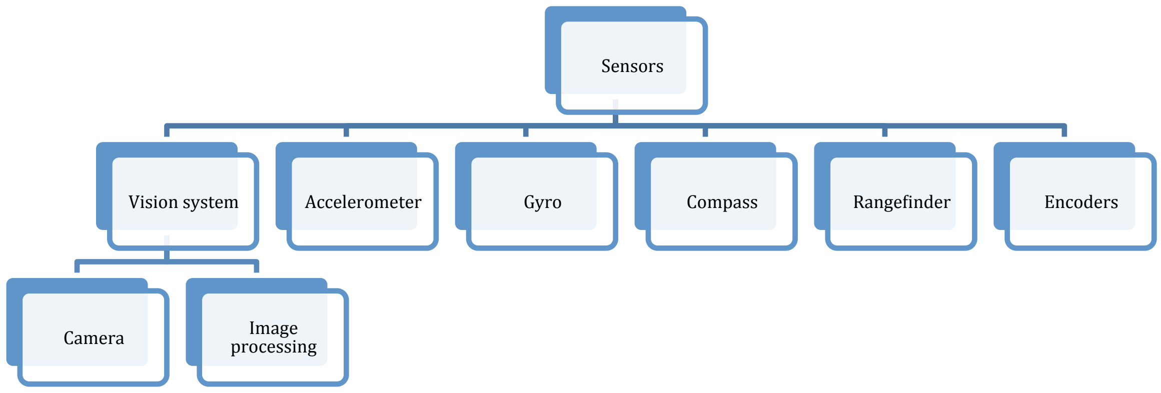


Figure 2: WPILib Sensors section organization

As shown in the sensors diagram above, each sensor subsection includes basic information about the sensor, any necessary calibration or settings, as well as an example of how to implement the sensors in your robot program. The camera section also includes information about image processing, color tracking, and other vision tasks commonly used with FRC robots.

The next primary section discusses actuators, such as motors and pneumatics, and is represented in the chart below:

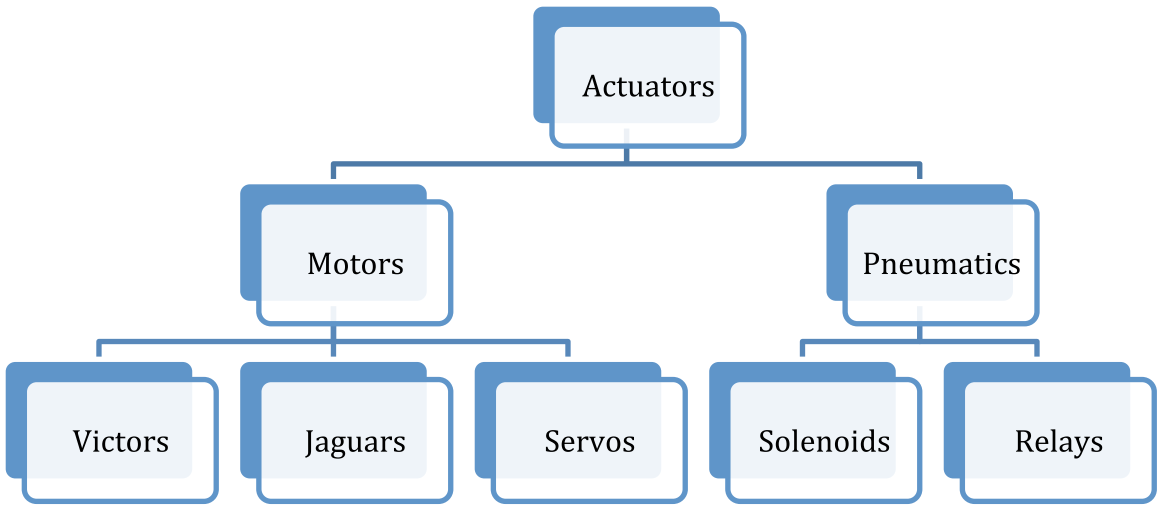


Figure 3: WPILib Actuators section organization

The actuator section describes different types of motor control and solenoid control, including the use of speed controllers, relays and solenoids.

The next section, feedback, is outlined in the chart below:

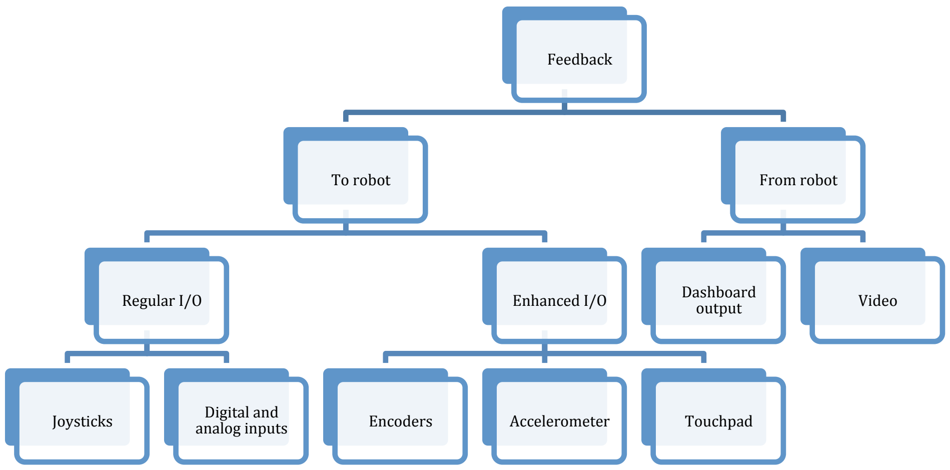


Figure 4: WPILib feedback section organization

The second primary section of the user's guide is the feedback section. This section talks about two different aspects: user feedback and response. This covers feedback/data that you can get from the driver station, including using buttons, lights, potentiometers and joysticks.

The miscellaneous section primarily discusses more advanced programming techniques used for control, i.e. PID control, multitasking (in C++), and other select topics. The structure of the control section is shown in the chart below:

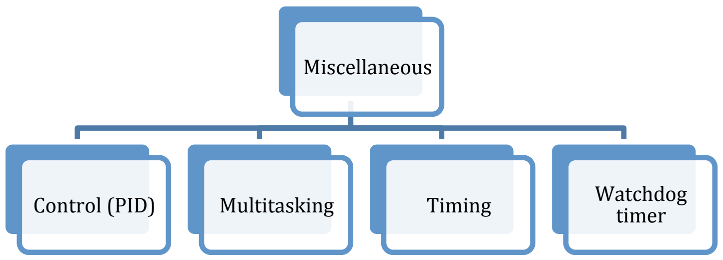


Figure 5: WPILib miscellaneous section organization

Choosing Between C++ and Java

C++ and Java are very similar languages; in fact Java has its roots in C++. If you can write WPILib C++ programs for your robot, then you can probably also write WPILib Java programs. There are, however, reasons for choosing one programming language over the other.

Language Differences

There is a detailed list of the differences between C++ and Java on Wikipedia available here: http://en.wikipedia.org/wiki/Comparison_of_Java_and_C++. Below is a summary of the differences that will most likely effect robot programs created with WPILib.

C++	Java
Memory allocated and freed manually.	Objects must be allocated manually, but are freed automatically when no references remain.
Pointers, references, and local instances of objects.	References to objects instead of pointers. All objects must be allocated with the new operator and are referenced using the dot (.) operator. (e.g. gyro.getAngle())
Header files and preprocessor used for including declarations in necessary parts of the program.	Header files are not necessary and references are automatically resolved as the program is built.
Implements multiple inheritance where a class can be derived from several other classes, combining the behavior of all the base classes.	Only single inheritance is supported, but interfaces are added to Java to get the most benefits that multiple inheritance provides.
Does not natively check for many common runtime errors.	Checks for array subscripts out of bounds, uninitialized references to objects and other runtime errors that might occur in program development.
Highest performance on the platform, because it compiles directly to machine code for the PowerPC processor in the cRIO.	Compiles to byte code for a virtual machine, and must be interpreted.

Table 1: Java/C++ Difference Summary

WPILib Differences

In order to streamline transitions between C++ and Java, all WPILib classes and methods have the same names in both languages. There are some minor differences between the language conventions and utility functions. These differences are detailed in the table below:

Item	C++	Java
Method naming convention	Upper case first letter and camel case after.	Lower case first letter and camel case thereafter.

	e.g. GetDistance()	e.g. getDistance()
Utility functions	Call function. e.g. Wait(1.0) will wait for one second.	Library functions are implemented as methods. e.g. Timer.delay(1.0) will wait for one second.

Table 2: Java/C++ Differences within WPILib

Our version of Java

The Java virtual machine and implementation used with WPILib is the Squawk platform based on the Java ME (micro edition) platform. Java ME is a simplified version of Java designed for the limitations of embedded devices. As a result, there are no user interface classes or other classes that are not meaningful in this environment. The most common Java platform is the Java Standard Edition (SE). Some of the SE features that are not included in our version of Java are described in the list below.

- Dynamic class loading is not supported for class loading or unloading.
- Reflection, a way of manipulating classes while the program is running, is also not supported.
- The Java compiler generates a series of byte codes for the virtual machine. When you create a program for the cRIO with Java ME, a step is automatically run after the program compiles (called pre-verification). This pre-verification pass simplifies the program loading process and reduces the size of the Java virtual machine (JVM).
- Finalization is not implemented, meaning the system will not automatically call the finalize() method of an unreferenced object. If you need to be sure code runs when a class is no longer referenced, you must explicitly call a method that cleans up.
- Java Native Interface (JNI) is not supported. This is a method of calling C programs from Java using a standard technique.
- Serialization and Remote Method Invocation (RMI) are not supported.
- The user interface APIs (Swing and AWT) are not implemented.
- Threads are supported, but thread groups are not.
- Java ME is based on an earlier version of Java SE (1.3), so it doesn't include newer Java features, such as generics, annotations and autoboxing.

Choosing a robot base

There are two choices of robot base class provided in WPILib each with advantages and disadvantages:

SimpleRobot	**Provides the easiest start to programming the robot. Your robot program overrides the operatorControl and autonomous methods that are called at the appropriate times as the competition is running.**
IterativeRobot	The IterativeRobot class has a number of methods that you override that are called periodically as the competition is running. Those methods advance the state of the robot with each call, reading sensors and setting values for the motors.

Each of these base classes are represented by sample programs in the C++ and Java development tools. Choosing a SimpleRobotTemplate, for example, will give you a starter program that uses the SimpleRobot base class.

SimpleRobot

The SimpleRobot base class is used in examples through this document and represents the easiest to understand way of programming your robot. You simply override the Autonomous and OperatorControl methods in your code. An example is shown here:

```java
package edu.wpi.first.wpilibj.templates;

import edu.wpi.first.wpilibj.*;

public class Sample extends SimpleRobot {

    private RobotDrive myRobot;      // robot drive system
    private Joystick stick;          // joystick for teleop control

    public Sample() {
        myRobot.setExpiration(0.1); // set the motor safety timeout
        stick = new Joystick(1);
    }

    protected void autonomous() {
        myRobot.setExpiration(2.5); // set MotorSafety expiration
        myRobot.drive(1.0, 0.0);    // drive forward full speed
        Timer.delay(2.0);           // wait 2 seconds while driving
        myRobot.drive(0.0, 0.0);    // stop robot
    }

    protected void operatorControl() {
        while (isEnabled()) {
            myRobot.arcade(stick);  // drive using arcade steering
        }
    }
};
```

This sample Java program simply drives forward for 2 seconds during the autonomous period then stops. In the teleop part of the match it drives using the joystick connected to driver station port 1. Notice that for the autonomous method, the robot advances forward and waits for each part to finish. Control is just turned over to the autonomous method and it handles everything.

The same is true during the teleop period of the match and the robot program loops, reading sensor values (in this case the joystick) and operates the motors.

Those methods are called once when the robot transitions from one phase of the game to the next.

IterativeRobot

The IterativeRobot class works differently than the SimpleRobot. It has a number of overridable methods that are called over and over while the robot is in one of three states: disabled, autonomous, or teleop. For each state there are three methods that are called, an init method, a periodic method and a continuous method.

Init methods (disabledInit, autonomousInit, teleopInit)

Called when the corresponding state is first entered. It is possible that the method will be called multiple times depending on the field controls. For example, in some games there is a period between the autonomous and teleop parts of the match were the robots are temporarily disabled while some scoring function happens. This is where you should put your initialization code.

Periodic methods (disabledPeriodic, autonomousPeriodic, teleopPeriodic)

These are called with each driver station update, approximately every 20 mS. The idea is to put code here that gets values from the driver station and updates the motors. You can read the joysticks and other driverstation inputs more often, but you'll only get the previous value until a new update is received. By synchronizing with the received updates your program will put less of a load on the cRIO CPU leaving more time for other tasks such as camera processing.

Continuous methods (disabledContinuous, autonomousContinuous, teleopContinuous)

These methods are called continuously during time the other methods are not being called. Using the continuous methods can easily load down the CPU and prevent other code from running properly, so should be used sparingly.

With the Iterative robot your program is organized such that during each call the state of the robot is advanced. For example, if the robot is to drive in a square pattern during the autonomous period, then during each autonomousPeriodic method call the program would keep track of which part of the square it is currently drawing and if it should advance to the next part.

Sensors

The WPI Robotics Library supports the sensors that are supplied in the FRC kit of parts, as well as many commonly used sensors available to *FIRST* teams through industrial and hobby robotics suppliers.

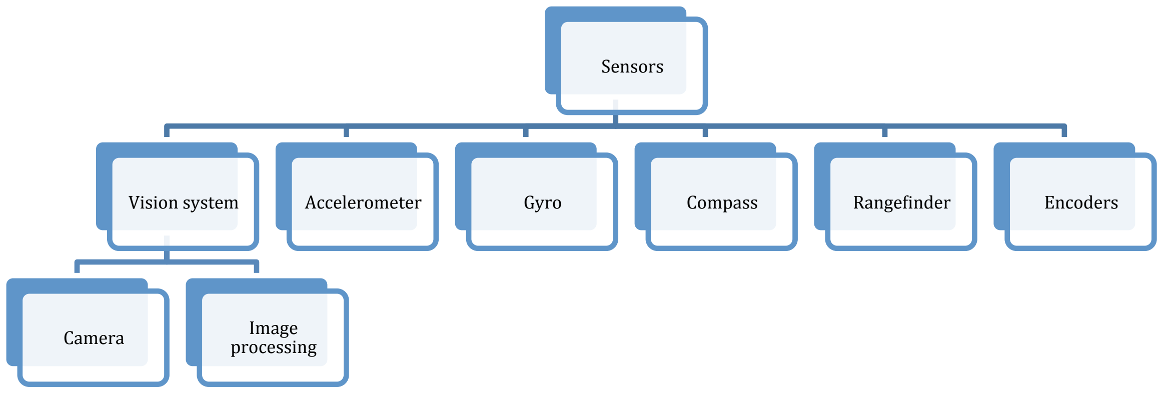


Figure 6: WPILib sensor section

Types of supported sensors

On the cRIO, the FPGA implements all the high-speed measurements through dedicated hardware ensuring accurate measurements no matter how many sensors and motors are connected to the robot. This is an improvement over previous systems, which required complex real-time software routines.

The library natively supports sensors in the categories shown below.

Category	Supported Sensors
Wheel/motor position measurement	Gear-tooth sensors, encoders, analog encoders, and potentiometers
Robot orientation	Compass, gyro, accelerometer, ultrasonic rangefinder
Generic pulse output	Counters

Table 3: List of Supported Sensors

There are many features in the WPI Robotics Library that make it easy to implement sensors that don't have prewritten classes. For example, general-purpose counters can measure period and count from any device generating output pulses. Another example is a generalized interrupt facility to catch high-speed events without polling and potentially missing them.

Digital I/O Subsystem

Below is a visual representation of the digital breakout board, and the digital I/O subsystem.

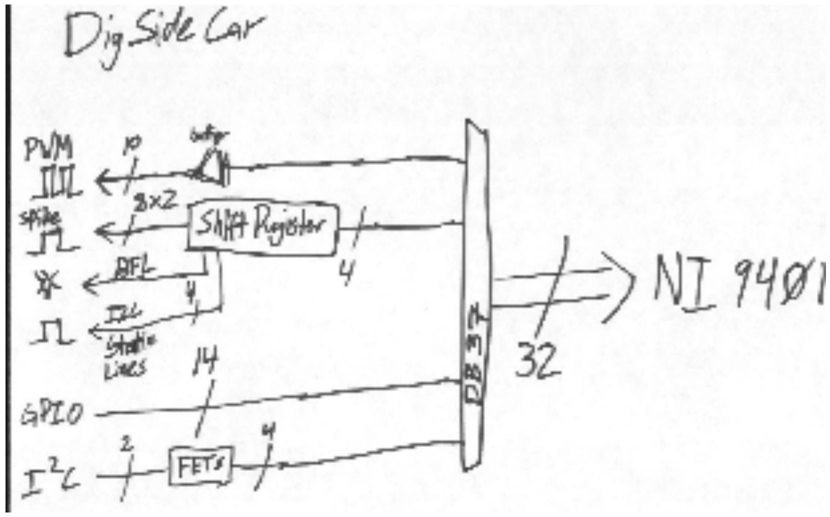


Figure 7: Digital I/O Subsystem Diagram

The NI 9401 digital I/O module provided in the kit has 32 general-purpose I/O lines (GPIO). The circuits in the digital breakout board, map these lines into 10 PWM outputs, 8 Relay outputs for driving Spike relays, the signal light output, an I2C port, and 14 bidirectional GPIO lines.

The basic update rate of the PWM lines is a multiple of approximately 5 ms. Jaguar speed controllers update at slightly over 5ms, Victors update at slightly over 10ms, and servos update at slightly over 20ms. Higher update rates are possible using the CAN bus and a community developed software available from http://firstforge.wpi.edu.

Digital Inputs

Digital inputs are often used for sensing switch values. The WPILib DigitalInput object is typically used to get the current state of the corresponding hardware line: 0 or 1. More complex uses of digital inputs, such as encoders or counters, are handled by using the more specific classes. Using these other supported device types (encoder, ultrasonic rangefinder, gear tooth sensor, etc.) doesn't require a digital input object to be created.

The digital input lines are shared from the 14 GPIO lines on each Digital Breakout Board. Creating an instance of a `DigitalInput` object will automatically set the direction of the line to input.

Digital input lines have pull-up resistors so an unconnected input will naturally be high. Therefor a switch is connected to the digital input it should connect to ground when closed. The open state of the switch will be 1 and the closed state will be 0.

In Java, digital input values are true for an open switch and false for a closed switch.

Digital Outputs

Digital outputs are typically used to run indicators or to interface with other electronics. The digital outputs share the 14 GPIO lines on each Digital Breakout Board. Creating an instance of a **`DigitalOutput`** object will automatically set the direction of the GPIO line to output. In C++, digital output values are 0 and 1 representing high (5V) and low (0V) signals. In Java, the digital output values are true (5V) and false (0V).

Accelerometer (2009 part)

A commonly used part (shown in the picture below) is a two-axis accelerometer. This device can provide acceleration data in the X and Y-axes relative to the circuit board. The WPI Robotics Library you treats it as two separate devices, one for the X-axis and the other for the Y-axis. The accelerometer can be used as a tilt sensor – by measuring the acceleration of gravity. In this case, turning the device on the side would indicate 1000 milliGs or one G.

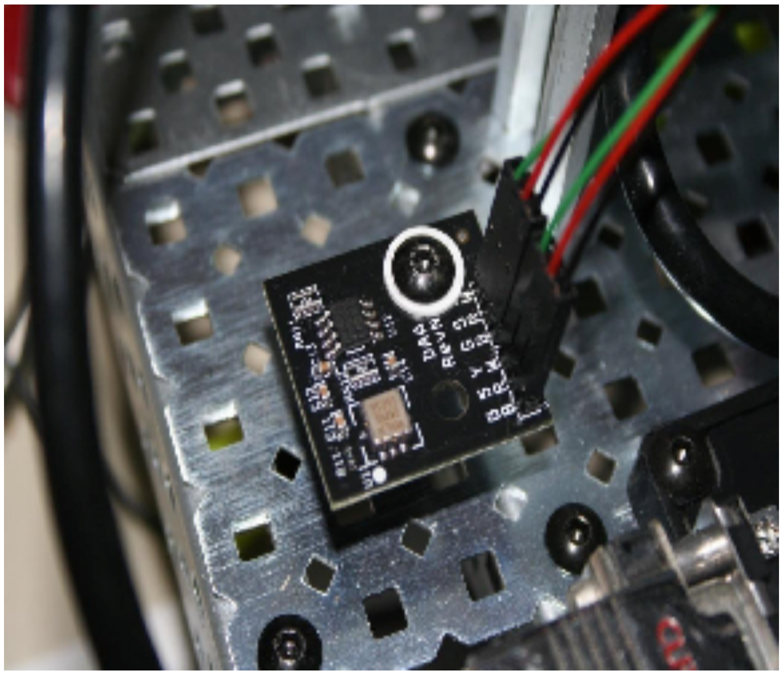


Figure 8: Example 2 -axis accelerometer board connected to a robot

Gyro

Gyros typically in the FIRST kit of parts are provided by Analog Devices, and are actually angular rate sensors. The output voltage is proportional to the rate of rotation of the axis normal to the top package surface of the gyro chip. The value is expressed in mV/°/second (degrees/second or rotation expressed as a voltage). By integrating (summing) the rate output over time, the system can derive the relative heading of the robot.

Another important specification for the gyro is its full-scale range. Gyros with high full-scale ranges can measure fast rotation without "pinning" the output. The scale is much larger so faster rotation rates can be read, but there is less resolution due to a much larger range of values spread over the same number of bits of digital to analog input. In selecting a gyro, you would ideally pick the one that had a full-scale range that matched the fastest rate of rotation your robot would experience. This would yield the highest accuracy possible, provided the robot never exceeded that range.

Using the Gyro class

The Gyro object should be created in the constructor of the `RobotBase` derived object. When the Gyro object is used, it will go through a calibration period to measure the offset of the rate output while the robot is at rest. This requires that the robot be stationary and the gyro is unusable until the calibration is complete.

Once initialized, the `GetAngle()` (or `getAngle()` in Java) method of the Gyro object will return the number of degrees of rotation (heading) as a positive or negative number relative to the robot's position during the calibration period. The zero heading can be reset at any time by calling the `Reset()` (`reset()` in Java) method on the Gyro object.

Setting the gyro sensitivity

The Gyro class defaults to the settings required for the 80°/sec gyro that was delivered by FIRST in the 2008 kit of parts.

To change gyro types call the `SetSensitivity(float sensitivity)` method (or `setSensitivity(double sensitivity)` in Java) and pass it the sensitivity in volts/°/sec. Take note that the units are typically specified in mV (volts / 1000) in the spec sheets. For example, a sensitivity of 12.5 mV/°/sec would require a `SetSensitivity()` (`setSensitivity()` in Java) parameter value of 0.0125.

The following example programs cause the robot to drive in a straight line using the gyro sensor in combination with the `RobotDrive` class. The `RobotDrive.Drive` method takes the speed and the turn rate as arguments; where both vary from -1.0 to 1.0. The gyro returns a value indicating the number of degrees positive or negative the robot deviated from its initial heading. As long as the robot continues to go straight, the heading will be zero. This example uses the gyro to keep the robot on course by modifying the turn parameter of the Drive method.

The angle is multiplied by a proportional scaling constant (Kp) to scale it for the speed of the robot drive. This factor is called the proportional constant or loop gain. Increasing Kp will cause the robot to correct more quickly (but too high and it will oscillate). Decreasing the value will cause the robot correct more slowly (possibly never reaching the desired heading). This is known as proportional control, and is discussed further in the PID control section of the advanced programming section.

```
class GyroSample : public SimpleRobot
{
   RobotDrive myRobot; // robot drive system
   Gyro gyro;
   static const float Kp = 0.03;

public:
   GyroSample():
      myRobot(1, 2),   // initialize the sensors in initialization list
      gyro(1)
   {
      myRobot.SetExpiration(0.1);
   }

   void Autonomous()
   {
      gyro.Reset();
      while (IsAutonomous())
      {
         float angle = gyro.GetAngle();   // get heading
         myRobot.Drive(-1.0, -angle * Kp); // turn to correct heading
         Wait(0.004);
      }
      myRobot.Drive(0.0, 0.0);   // stop robot
   }
};
```

Example 1:   A C++ program example to drive in a straight line using a gyro.

```
package edu.wpi.first.wpilibj.templates;

import edu.wpi.first.wpilibj.Gyro;
import edu.wpi.first.wpilibj.RobotDrive;
import edu.wpi.first.wpilibj.SimpleRobot;
import edu.wpi.first.wpilibj.Timer;

public class GyroSample extends SimpleRobot {

    private RobotDrive myRobot; // robot drive system
    private Gyro gyro;

    double Kp = 0.03;

    public GyroSample()
    {
        myRobot.setExpiration(0.1);
    }

    protected void Autonomous() {
        gyro.reset();
        while (isAutonomous()) {
        double angle = gyro.getAngle();    // get heading
            myRobot.drive(-1.0, -angle*Kp); // drive to heading
            Timer.delay(0.004);
        }
        myRobot.drive(0.0, 0.0);    // stop robot
    }
};
```

Example 2: Java program example to drive in a straight line using a gyro.

HiTechnicCompass

The compass uses the earth's magnetic field to determine the heading. This field is relatively weak causing the compass to be susceptible to interference from other magnetic fields such as those generated by the motors and electronics on your robot. If you decide to use a compass, be sure to mount it far away from interfering electronics and verify tits accuracy. Additionally, the compass connects to the I2C port on the digital I/O module. It is important to note that there is only one I2C port on each of these modules.

```
HiTechnicCompass compass(4);
compVal = compass.GetAngle();
```

Example 3: A C++ program to create a compass on the I2C port of the digital module plugged into slot 4.

Add java example here

Ultrasonic rangefinder

The WPI Robotics library supports the common Devantech SRF04 or Vex ultrasonic sensor. This sensor has two transducers, a speaker that sends a burst of ultrasonic sound, and a microphone that listens for the sound to be reflected off of a nearby object. It requires two connections to the cRIO, one that initiates the ping and the other that tells when the sound is received. The Ultrasonic object measures the time between the transmission and the reception of the echo. Below is a picture of the Devantech SRF04, with the connections labeled.

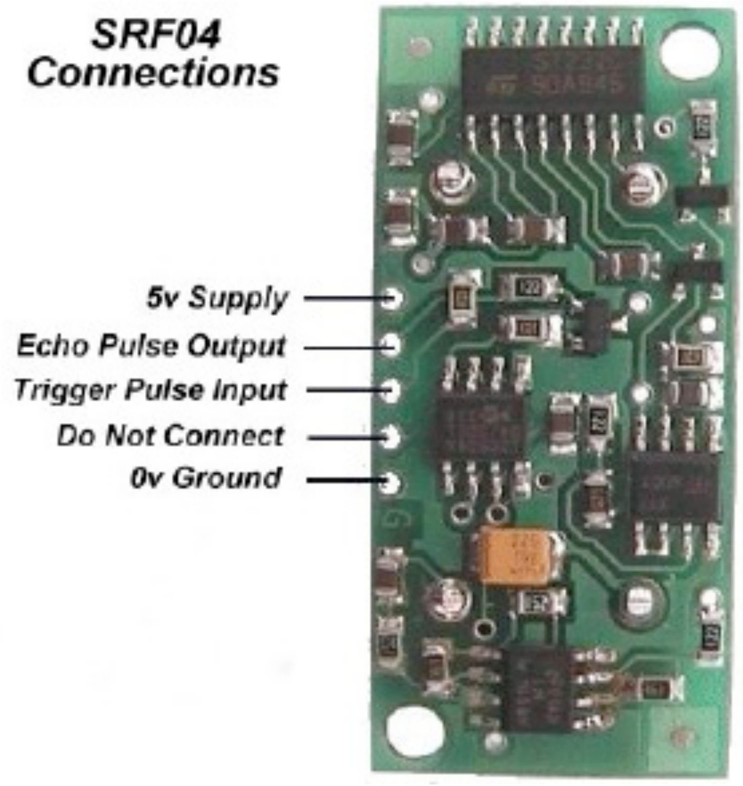


Figure 9: SRF04 Ultrasonic Rangefinder connections

Both the Echo Pulse Output and the Trigger Pulse Input have to be connected to digital I/O ports on a digital breakout board. When creating the Ultrasonic object, specify which ports it is connected to in the constructor, as shown in the examples below.

```
Ultrasonic ultra(ULTRASONIC_ECHO_PULSE_OUTPUT,
ULTRASONIC_TRIGGER_PULSE_INPUT);
```

Example 4: C++ example of creating an ultrasonic rangefinder object

```
Ultrasonic ultra = new Ultrasonic(ULTRASONIC_ECHO_PULSE_OUTPUT,
                                  ULTRASONIC_TRIGGER_PULSE_INPUT);
```

Example 5: Java example of creating an ultrasonic rangefinder object.

In this case, **`ULTRASONIC_ECHO_PULSE_OUTPUT`** and **`ULTRASONIC_TRIGGER_PULSE_INPUT`** are two constants that are defined to be the digital I/O port numbers.

Do not use the ultrasonic class for ultrasonic rangefinders that do not have these connections. Instead, use the appropriate class for the sensor, such as an **`AnalogChannel`** object for an ultrasonic sensor that returns the range as a voltage.

The following two examples read the range on an ultrasonic sensor connected to the output port ULTRASONIC_PING and the input port ULTRASONIC_ECHO.

```
Ultrasonic ultra(ULTRASONIC_PING, ULTRASONIC_ECHO);
ultra.SetAutomaticMode(true);
int range = ultra.GetRangeInches();
```

Example 6: C++ example of creating an ultrasonic sensor object in automatic mode and getting the range.

```
Ultrasonic ultra = new Ultrasonic(ULTRASONIC_PING, ULTRASONIC_ECHO);
ultra.setAutomaticMode(true);
int range = ultra.getRangeInches();
```

Example 7: Java example of creating an ultrasonic sensor object in automatic mode and getting the range.

Counter Subsystem

The counters subsystem represents an extensive set of digital signal measurement tools for interfacing with many sensors. There are several parts to the counter subsystem. Below is a schematic representing the counter subsystem.

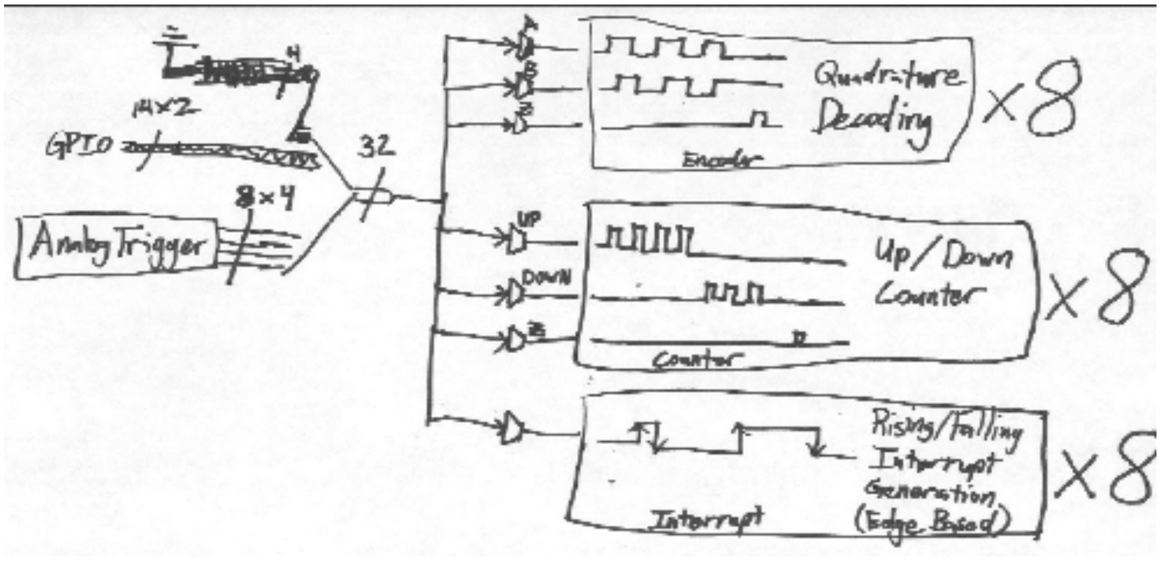


Figure 10: Schematic of the possible sources and counters in the Counter Subsystem in the cRIO.

Either analog triggers or digital inputs can trigger counters. The trigger source can either control up/down counters (Counter objects), quadrature encoders (Encoder objects), or interrupt generation. Analog triggers count each time an analog signal goes outside or inside of a set range of voltages.

Counter Objects

Counter objects are extremely flexible elements that can count input from either a digital input signal or an analog trigger. They can operate in a number of modes based on the type of input signal, some of which are used to implement other sensors in the WPI Robotics Library.

- Gear-tooth mode – enables up/down counting based on the width of an input pulse. This is used to implement the `GearTooth` object with direction sensing.
- Semi-period mode – counts the period of a portion of the input signal. This is used to measure the time of flight of the echo pulse in an ultrasonic sensor.
- Normal mode – can count edges of a signal in either up counting or down counting directions based on the input selected.

Encoders

Encoders are devices for measuring the rotation of a spinning shaft. Encoders are typically used to measure the distance a wheel has turned which can be translated into the distance the robot has traveled. The distance traveled over a measured period of time represents the speed of the robot, and is another common use for encoders. Encoders can also directly measure the rate of rotation by determining the time between pulses. The following table lists the WPILib supported encoder types:

Type	**Description**
Simple encoders (using the Counter class)	Single output encoders that provide a state change as the wheel is turned. With these encoders there is no way of detecting the direction of rotation. The Innovation First VEX encoder and the index outputs of a quadrature encoder are examples of this type of device.
Quadrature encoders (Encoder class)	Quadrature encoders have two outputs, typically referred to as the A channel and the B channel, and are is out of phase from each other. Looking at the relationship between the two inputs provides information about the direction the motor is turning. The relationship between the inputs is identified by locating the rising edge and falling edge signals. The quadrature encoder class can look at all edges and give an oversampled output with 4x accuracy.
Gear tooth sensor (GearTooth class)	The gear tooth sensor is typically supplied by FIRST as part of the FRC kit of parts. It is designed to monitor the rotation of a sprocket or gear. It uses a Hall-effect device to sense the teeth of the sprocket as they move past the sensor.

Table 4: Encoder types that are supported by WPILib

Gear Tooth Sensor

Gear tooth sensors are designed to be mounted adjacent to spinning ferrous gear or sprocket teeth and detect whenever a tooth passes. The gear tooth sensor is a Hall-effect device that uses a magnet and solid-state device that can measure changes in the field caused by the passing teeth.

The picture below shows a gear tooth sensor mounted on a VEX robot chassis measuring a metal gear rotation. Notice that a metal gear is attached to the plastic gear. The gear tooth sensor needs a ferrous material passing by it to detect rotation.

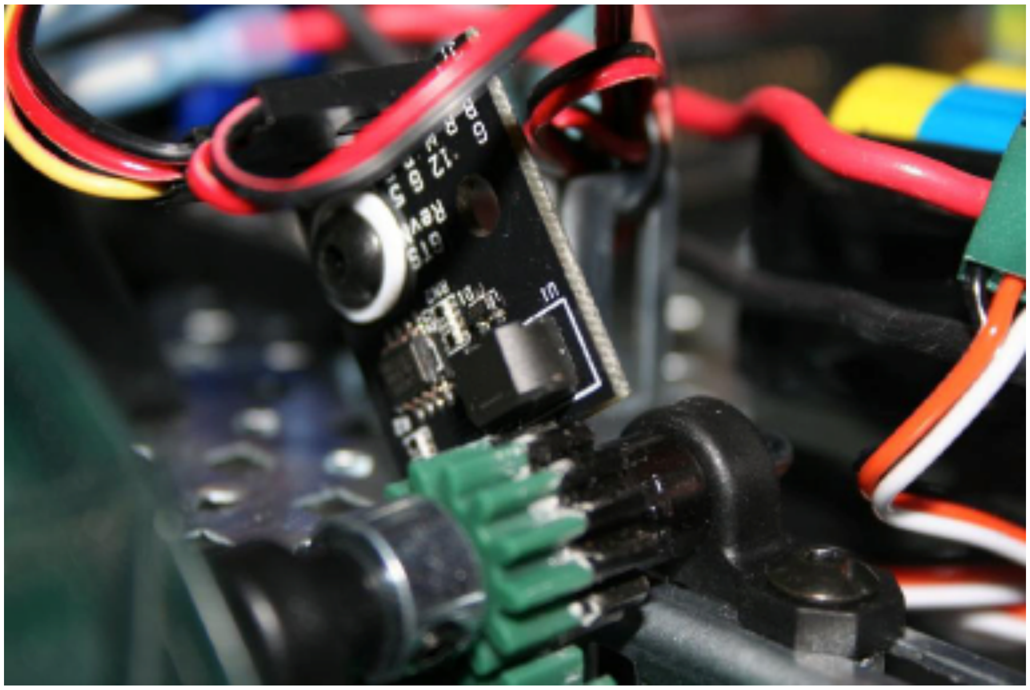


Figure 11: Gear tooth sensor with a ferrous gear cemented to the plastic Vex gear so the gear tooth senor would detect the rotation.

Encoders

Encoders typically have a rotating disk with slots that spin in front of a photo detector. As the slots pass the detector, pulses are generated on the output. The rate at which the slots pass the detector indicates the rotational speed of the shaft, and the number of slots that have passed the detector indicates the number of rotations.

Below is a picture of an encoder mounted on a VEX robot:

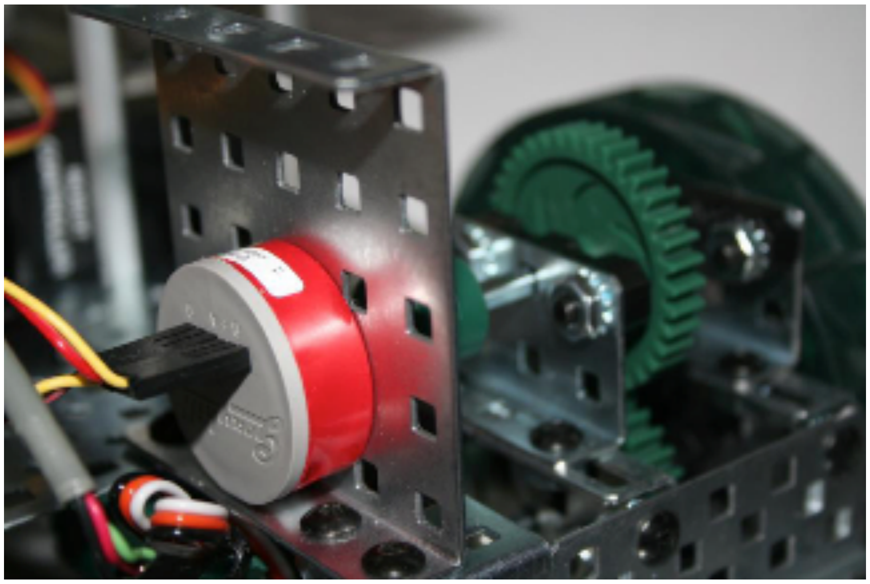


Figure 12: A Grayhill quadrature optical encoder. Note the two connectors, one for the A channel and one for the B channel.

Quadrature Encoders

Quadrature encoders are handled by the Encoder class. Using a quadrature encoder is done by connecting the A and B channels to two digital I/O ports and assigning them in the constructor for Encoder. A diagram of the output signals of a quadrature encoder is shown below.

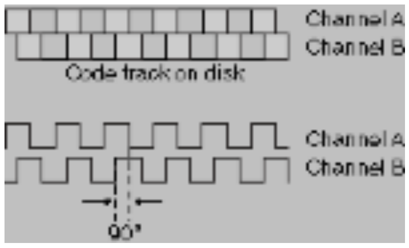


Figure 13: Quadrature encoder phase relationships between the two channels.

Some quadrature encoders have an extra index channel. This channel pulses once for each complete revolution of the encoder shaft. If counting the index channel is required for the application it can be done by connecting that channel to a simple Counter object which has no direction information.

There are four `QuadratureEncoder` modules in the cRIO's FPGA and 8 Counter modules that can operate as quadrature encoders. One of the differences between the encoder and counter hardware is that encoders can give an oversampled 4X count using all 4 edges of the input signal, but counters can only return a 1X or 2X result based on one of the input signals. If 1X or 2X is chosen in the Encoder constructor, a Counter module is used with lower oversampling. If 4X (default) is chosen, then one of the four FPGA encoders is used.

In the example below, **`1`** and **`2`** are the port numbers for the two digital inputs and **`true`** tells the encoder to not invert the counting direction. The sensed direction could depend on how the encoder is mounted relative to the shaft being measured. The `k4X` makes sure that an encoder module from the FPGA is used and 4X accuracy is obtained. To get the 4X value you should use the `GetRaw()` method on the encoder. `The Get()` method will always return the normalized value by dividing the actual count obtained by the 1X, 2X, or 4X multiplier.

```
   Encoder encoder(1, 2, true, k4X);
```

Example 8: C++ code creating an encoder on ports 1 and 2 with reverse sensing and 4X encoding.

```
Encoder encoder;
   encoder = new Encoder(1, 2, true, EncodingType.k4X);
```

Example 9: Java code craeating an encoder on ports 1 and 2 with reverse sensing and 4X encoding.

Analog Inputs

The NI 9201 Analog to Digital module has a number of features not available on simpler controllers. It will automatically sample the analog channels in a round-robin fashion, providing a combined sample rate of 500 ks/s (500,000 samples / second). These channels can be optionally oversampled and averaged to provide the value that is used by the program. There are raw integer and floating point voltage outputs available in addition to the averaged values. The diagram below outlines this process.

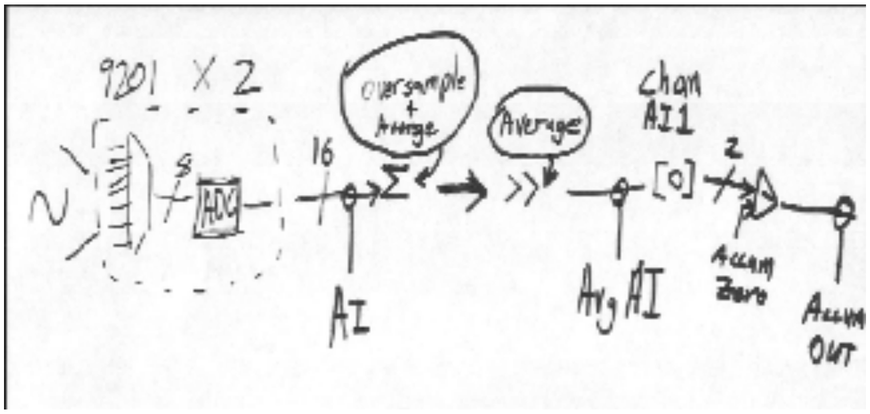


Figure 14: Analog Input System

When the system averages a number of samples, the division results in a fractional part of the answer that is lost in producing the integer valued result. Oversampling is a technique where extra samples are summed, but not divided down to produce the average. Suppose the system were oversampling by 16 times – that would mean that the values returned were actually 16 times the average. Using the oversampled value gives additional precision in the returned value. The oversample and average engine equations are shown below.

oversample bits

average bits

$$AvgAI = \frac{\sum_{0}^{2^M-1} \left(\sum_{0}^{2^N-1} (AI_x) \right)}{2^M}$$

$$f_{avg} = \frac{f_s}{2^{(M+N)}}$$

Figure 15: Oversample and Average Engine Equations

To set the number of oversampled and averaged values use the methods in the examples below:

```
void SetAverageBits(UINT32 bits);
UINT32 GetAverageBits();
void SetOversampleBits(UINT32 bits);
UINT32 GetOversampleBits();
```

Example 10: C++ methods for setting oversampling and averaging on an analog to digital converter.

```
void setAverageBits(int bits);
UINT32 getAverageBits();
void setOversampleBits(UINT32 bits);
UINT32 getOversampleBits();
```

Example 11: Java methods for setting oversampling and averaging on an analog to digital converter.

The number of averaged and oversampled values are always powers of two (number of bits of oversampling/averaging). Therefore the number of oversampled or averaged values is two bits, where 'bits' is passed to the methods: **`SetOversampleBits(bits)`** and **`SetAverageBits(bits).`** The actual rate that values are produced from the analog input channel is reduced by the number of averaged and oversampled values. For example, setting the number of oversampled bits to 4 and the average bits to 2 would reduce the number of delivered samples by 16x and 4x, or 64.

The sample rate is fixed per analog I/O module, so all the channels on a given module must sample at the same rate. However, the averaging and oversampling rates can be changed for each channel. The WPI Robotics Library will allow the sample rate to be changed once for a module. Changing it to a different value will result in a runtime error being generated. The use of some sensors (currently just the Gyro) will set the sample rate to a specific value for the module it is connected to.

Analog Triggers

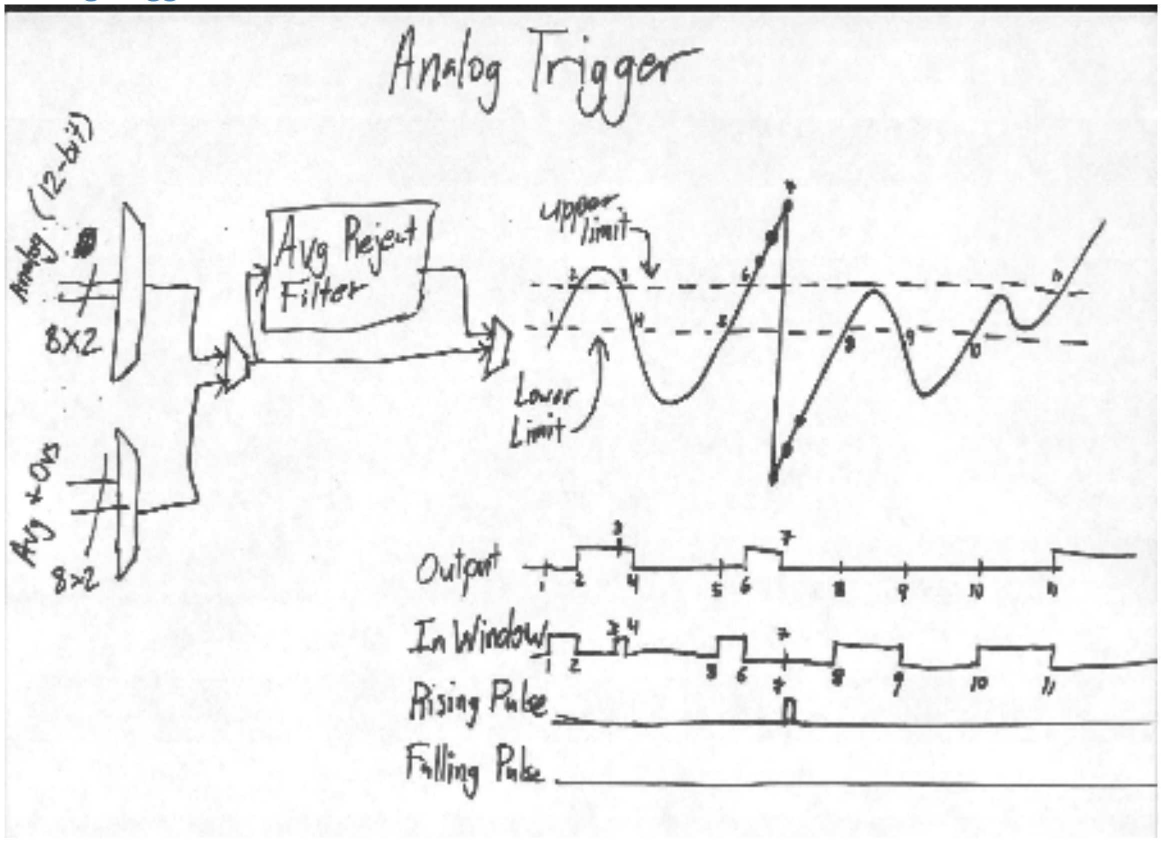


Figure 16: Analog Trigger

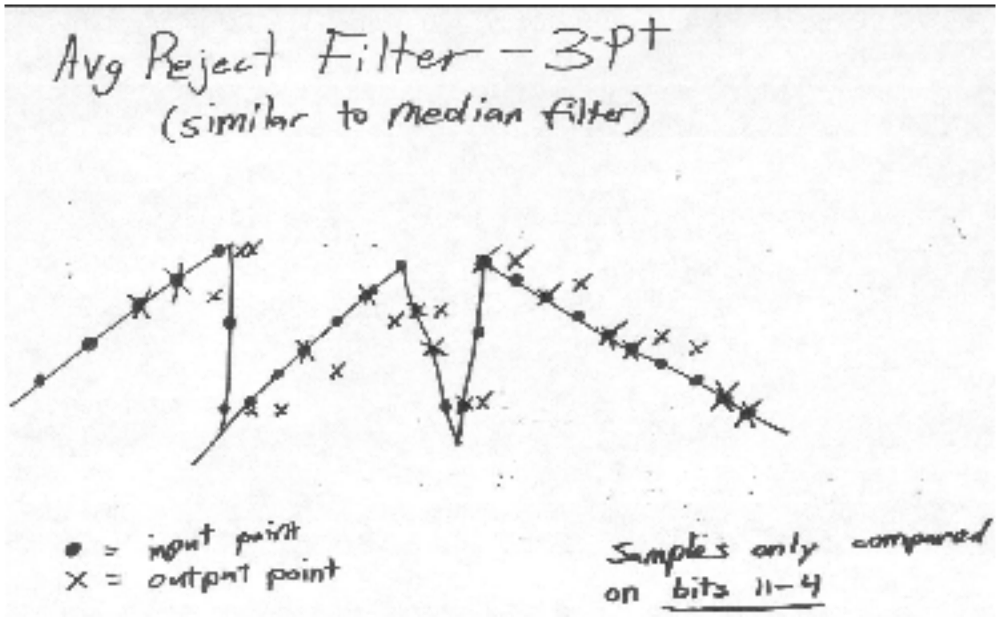

Avg Reject Filter – 3 pt
(similar to median filter)
● = input point
X = output point
Samples only compared on bits 11–4

Figure 17: 3 Point Average Reject Filter

Controlling Actuators

This section discusses the control of motors and pneumatics through speed controllers, relays, and WPILib methods. The overall structure of this section is shown in the chart below.

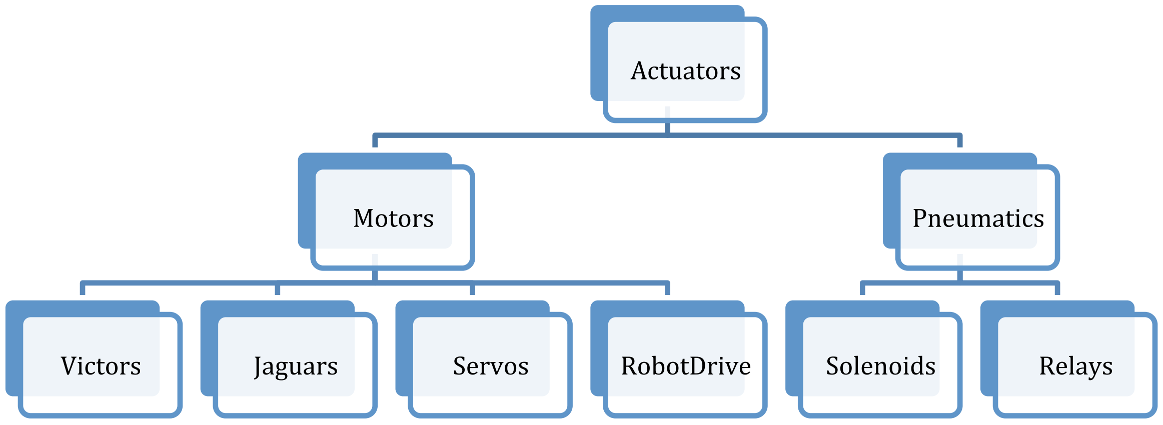


Figure 18: Actuator section organization

Motors

The WPI Robotics library has extensive support for motor control. There are a number of classes that represent different types of speed controllers and servos. The WPI Robotics Library currently supports two classes of speed controllers, PWM-based motor controllers (Jaguars or Victors) and servos, but is also designed to support non-PWM motor controllers that will be available in the future. In addition, while not actually an actuator, the RobotDrive class handles standard 2 motor, 4 motor, and Mecanum drive bases incorporating either Jaguar or Victor speed controllers.

Motor speed controllers take speed values in floating point numbers that range from -1.0 to +1.0. The value of -1.0 represents full speed in one direction, 1.0 represents full speed in the other direction, and 0.0 represents stopped. Motors can also be set to disabled, where the signal is no longer sent to the speed controller.

There are a number of motor controlling classes included in WPILib. These classes are given in the table below:

Type	Usage
PWM	Base class for all the pwm-based speed controllers and servos
Victor	Speed controller with a 10ms update rate, supplied by Innovation First, commonly used in robotics competitions.
Jaguar	Advanced speed controller used for 2009 and future FRC competitions with a 5ms update rate.
Servo	Class designed to control small hobby servos as typically supplied in the FIRST kit of parts.
RobotDrive	General purpose class for controlling a robot drive train with either 2 or 4 drive motors. It provides high level operations like turning. It does this by controlling all the robot drive motors in a coordinated way. It's useful for

	both autonomous and tele-operated driving.

Table 5: Types of motor control

PWM

The PWM class is the base class for devices that operate on PWM signals and is the connection to the PWM signal generation hardware in the cRIO. It is not intended to be used directly on a speed controller or servo. The PWM class has shared code for Victor, Jaguar, and Servo subclasses that set the update rate, deadband elimination, and profile shaping of the output signal.

SafePWM

The SafePWM class is a subclass of PWM that implements the RobotSafety interface and adds watchdog capability to each speed controller object.

Victor

The Victor class represents the Victor speed controllers provided by Innovation First. They have a minimum 10ms update period and only take a PWM control signal. The minimum and maximum values that will drive the Victor speed control vary from one unit to the next. You can fine-tune the values for a particular speed controller by using a simple program that steps the values up and down in single raw unit increments. You need the following values from a victor:

Value	Description
Max	The maximum value where the motors stop changing speed and the light on the Victor goes to full green.
DeadbandMax	The value where the motor just stops operating.
Center	The value that is in the center of the deadband that turns off the motors.
DeadbandMin	The value where the motor just starts running in the opposite direction.
Min	The minimum value (highest speed in opposite direction) where the motors stop changing speed.

Table 6: Necessary information about Victors

With these values, call the **`SetBounds`** method on the created Victor object.

```
void SetBounds(INT32 max,
                INT32 deadbandMax,
                INT32 center,
                INT32 deadbandMin,
                INT32 min);
```

Example 12: A C++ method for setting the bounds on a Victor object.

Jaguar

The Jaguar class supports the Texas Instruments Jaguar speed controller. It has a PWM update period of slightly greater than 5ms.

The input values for the Jaguar range from -1.0 to 1.0 for full speed in either direction with 0 representing stopped.

Use of limit switches

TODO

Example

TODO

Servo

The Servo class supports the Hitechnic servos supplied by *FIRST*. They have a 20ms update period and are controlled by PWM output signals.

The input values for the Servo range from 0.0 to 1.0 for full rotation in one direction to full rotation in the opposite direction. There is also a method to set the servo angle based on the (currently) fixed minimum and maximum angle values.

For example, the following code fragment rotates a servo through its full range in 10 steps:

```
Servo servo(3);
float servoRange = servo.GetMaxAngle() - servo.GetMinAngle();
for (float angle = servo.GetMinAngle();
       angle < servo.GetMaxAngle();
       angle += servoRange / 10.0)
{
   servo.SetAngle(angle);                    // set servo to angle
   Wait(1.0);                                // wait 1 second
}
```

Example 13: C++ example that rotates a servo through its full range in 10 steps.

RobotDrive

The **`RobotDrive`** class is designed to simplify the operation of the drive motors based on a model of the drive train configuration. The program describes the layout of the motors. Then the class can generate all the speed values to operate the motors for different configurations. For cases that fit the model, it provides a significant simplification to standard driving code. For more complex cases that aren't directly supported by the **`RobotDrive`** class it may be subclassed to add additional features or not used at all.

First, create a **`RobotDrive`** object specifying the left and right Jaguar motor controllers on the robot, as shown below.

```
RobotDrive drive(1, 2);      // left, right motors on ports 1,2
```

Example 14: Creating a Robot drive object in C or Java.

Or

```
RobotDrive drive(1, 2, 3, 4);   // four motor drive configuration
```

Example 15: Creating a robot drive object with 4 motors.

This sets up the class for a 2 motor configuration or a 4 motor configuration. There are additional methods that can be called to modify the behavior of the setup.

```
SetInvertedMotor(kFrontLeftMotor, true);
```

Example 16: Inverting the motor direction in C++.

This sets the operation of the front left motor to be inverted. This might be necessary depending on the setup of your drive train.

Once set up, there are methods that can help with driving the robot either from the Driver Station controls or through programmed operations. These methods are described in the table below.

Method	Description
`Drive(speed, turn)`	Designed to take speed and turn values ranging from -1.0 to 1.0. The speed values set the robot overall drive speed; with positive values representing forward and negative values representing backwards. The turn value tries to specify constant radius turns for any drive speed. Negative values represent left turns and the positive values represent right turns.
`TankDrive(leftStick, rightStick)`	Takes two joysticks and controls the robot with tank steering using the y-axis of each joystick. There are also methods that allow you to specify which axis is used from each stick.
`ArcadeDrive(stick)`	Takes a joystick and controls the robot with arcade (single stick) steering using the y-axis of the joystick for forward/backward speed and the x-axis of the joystick for turns. There are also other methods that allow you to specify different joystick axes.
`HolonomicDrive(magnitude, direction, rotation)`	Takes floating point values, the first two are a direction vector the robot should drive in. The third parameter, rotation, is the independent rate of rotation while the robot is driving. This is intended for robots with 4 Mecanum wheels independently controlled.
`SetLeftRightMotorSpeeds(leftSpeed, rightSpeed)`	Takes two values for the left and right motor speeds. As with all the other methods, this will control the motors as defined by the constructor.

Table 7: C++ options for driving a robot. The Java methods are the same except with leading lower case characters.

The `Drive` method of the `RobotDrive` class is designed to support feedback based driving. Suppose you want the robot to drive in a straight line despite physical variations in its mechanical design and external forces. There are a number of ways of solving this problem, but two examples are using gear tooth sensors or a gyro. In either case an error value (*desired* – *actual*) is generated that represents how far from straight the robot is currently tracking. This error value (positive for one direction and negative for the other) can be scaled and used directly with the turn argument of the Drive method. This causes the robot to turn back to straight with a correction that is proportional to the error – the larger the error, the greater the turn.

Using RobotDrive with Victor speed controllers

By default the RobotDrive class assumes that Jaguar speed controllers are used. To use Victor speed controllers, create the Victor objects then call the RobotDrive constructor passing it pointers or references to the Victor objects rather than port numbers.

Example TODO

Relays

The cRIO provides the connections necessary to wire IFI spikes via the relay outputs on the digital breakout board. The breakout board provides a total of sixteen outputs, eight forward and eight reverse. The forward output signal is sent over the pin farthest from the edge of the breakout board, labeled as output A, while the reverse signal output is sent over the center pin, labeled output B. The final pin is a ground connection.

When a Relay object is created in WPILib, its constructor is passed a channel and direction, or a slot, channel and direction. The slot is the slot number that the digital module is plugged into (the digital module being what the digital breakout board is connected to on the cRIO) – this parameter is not needed if only the first digital module is being used. The channel is the number of the connection being used on the digital breakout board. The direction can be `kBothDirections` (two direction solenoid), `kForwardOnly` (uses only the forward pin), or `kReverseOnly` (uses only the reverse pin). If a value is not input for direction, it defaults to `kBothDirections`. This determines which methods in the Relay class can be used with a particular instance of the object. The methods included in the relay class are shown in the table below.

Method	Description
`void Set(Value value)`	This method sets the the state of the relay – Valid inputs: All Directions: kOff – turns off the Relay kForwardOnly or kReverseOnly: kOn – turns on forward or reverse of relay, depending on direction kForwardOnly: kForward – set the relay to forward kReverseOnly: kReverse – set the relay to reverse
`void SetDirection(Direction direction)`	Sets the direction of the relay – Valid inputs: kBothDirections: Allows the relay to use both the forward and reverse pins on the channel kForwardOnly: Allows relay to use only the forward signal pin kReverseOnly: Allows relay to use only the reverse signal pin

Table 8: Relay class methods

In the example below, `m_relay` is initialized to be on channel 1. Since no direction is specified, the direction is set to the default value of `kBothDirections`. m_relay2 is initialized to channel 2, with a direction of `kForwardOnly`. In the following line, `m_relay` is set to the direction of `kReverseOnly`, and is then turned on, which results in the reverse output being turned on. `m_relay2` is then set to forward – since it is a forward only relay, this has the same effect as setting it to on. After that, `m_relay` is turned off, a command that turns off any active pins on the channel, regardless of direction.

```
Relay m_relay(1);
Relay m_relay2(2,Relay::kForwardOnly);

m_relay.SetDirection(Relay::kReverseOnly);
m_relay.Set(Relay::kOn);
m_relay2.Set(Relay::kForward);
m_relay.Set(Relay::kOff);
```

Example 17: C++ example of controlling relays using the Relay class.

Need Java example

Using the serial port

Need some examples and documentation

Using I2C

Need documentation and examples

Pneumatics

Controlling pneumatics with WPILib is quite simple. The two classes you will need are shown in the table below.

Class	Purpose
`Solenoid`	Can control pneumatic actuators directly without the need for an additional relay. (In the past a Spike relay was required along with a digital output port to control a pneumatics component.)
`Compressor`	Keeps the pneumatics system charged by using a pressure switch and software to turn the compressor on and off as needed.

Table 9: Classes for controlling pneumatics

Compressor

The Compressor class is designed to operate the FRC supplied compressor on the robot. A **`Compressor`** object is constructed with 2 input/output ports:

- The Digital output port connected to the Spike relay that controls the power to the compressor. (A digital output or Solenoid module port alone doesn't supply enough current to operate the compressor.)
- The Digital input port connected to the pressure switch that monitors the accumulator pressure.

The **`Compressor`** class will automatically create a task that runs in the background and twice a second and turns the compressor on or off based on the pressure switch value. If the system pressure is above the high set point, the compressor turns off. If the pressure is below the low set point, the compressor turns on.

To use the Compressor class create an instance of the Compressor object and use the **`Start()`** method. This is typically done in the constructor for your Robot Program. Once started, it will continue to run on its own with no further programming necessary. If you do have an application where the compressor should be turned off, possibly during some particular phase of the game play, you can stop and restart the compressor using the **`Stop()`** and **`Start()`** methods.

The compressor class will create instances of the **`DigitalInput`** and **`Relay`** objects internally to read the pressure switch and operate the Spike relay.

For example, suppose you had a compressor and a Spike relay connected to Relay port 2 and the pressure switch connected to digital input port 4. Both of these ports are connected to the primary digital input module. You could create and start the compressor running in the constructor of your **`RobotBase`** derived object using the following 2 lines of code:

```
Compressor *c = new Compressor(4, 2);
c->Start();
```

Example 18: Starting the compressor in a C++ program fragment.

Need java example

In the example above, the variable c is a pointer to a compressor object and the object is allocated using the **`new`** operator. If it were allocated as a local variable in the constructor, at the end of the constructor function its local variables would be deallocated and the compressor would stop operating.

C++ Object Life Span

You need the Compressor object to last the entire match. If you allocate it with **`new`**, the best practice is to store the pointer in a member variable, then **`delete`** it in the Robot's destructor, as shown in the example below:

```
class RobotDemo : public SimpleRobot
{
   Compressor *m_compressor;

public:
   RobotDemo()
   {
      m_compressor = new Compressor(4, 2);
      m_compressor->Start();
   }

   ~RobotDemo()
   {
      delete m_compressor;
   }
}
```

Example 19: Making the compressor run for the entire match in a C++ program.

Alternatively, you can declare it as a member object then initialize and **`Start()`** it in the Robot's constructor. In this case you need to use the constructor's "initialization list" to initialize the Compressor object. The C++ compiler will quietly give RobotDemo a destructor that deletes the Compressor object.

Solenoid

The Solenoid object controls the outputs of the NI 9472 Digital Output Module. It is designed to apply an input voltage to any of the 8 outputs. Each output can provide up to 1A of current. The module is designed to operate 12v pneumatic solenoids used on FIRST robots. This makes the use of relays unnecessary for pneumatic solenoids.

The NI 9472 Digital Output Module does not provide enough current to operate a motor or the compressor, so relays connected to Digital Breakout board digital outputs will still be required for those applications.

The port numbers on the Solenoid class range from 1-8 as printed on the pneumatics breakout board.

The NI 9472 indicator lights are numbered 0-7 for the 8 ports, which is different numbering than used by the class or the pneumatic bumper case silkscreening.

Setting the output values of the Solenoid objects to true or false will turn the outputs on and off respectively. The following code fragment will create 8 Solenoid objects, initialize each to true (on), and then turn them off, one per second. Then it turns them each back on, one per second, and deletes the objects. You can observe the operation of the Solenoid class by looking at the indicator lights on the 9472 module.

```
Solenoid *s[8];
for (int i = 0; i < 8; i++)
   s[i] = new Solenoid(i + 1); // allocate the Solenoid objects
for (int i = 0; i < 8; i++)
{
   s[i]->Set(true);          // turn them all on
}
Wait(1.0);
for (int i = 0; i < 8; i++)
{
   s[i]->Set(false);         // turn them each off in turn
   Wait(1.0);
}
for (int i = 0; i < 8; i++)
{
   s[i]->Set(true);          // turn them back on in turn
   Wait(1.0);
   delete s[i];              // delete the objects
}
```

Example 20: Controlling Solenoids in a C++ program fragment.

Need Java example

Getting Feedback from the Driver Station

The driver station is constantly communicating with the robot controller. You can read the driver station values of the attached joysticks, digital inputs, analog inputs, and write to the digital outputs. In addition there is Enhanced I/O provided through the Cypress module. The DriverStation class has methods for reading and writing everything connected to it, including joysticks. There is another object, Joystick that provides a more convenient set of methods for dealing with joysticks and other HID controllers connected to the USB ports. The general relationships of feedback from the driver station are shown in the chart below. The enhanced I/O is provided through an additional class called **`DriverStationEnhancedIO`**. This class has methods for reading and writing all the I/O options on the Cypress module as well as configuring it.

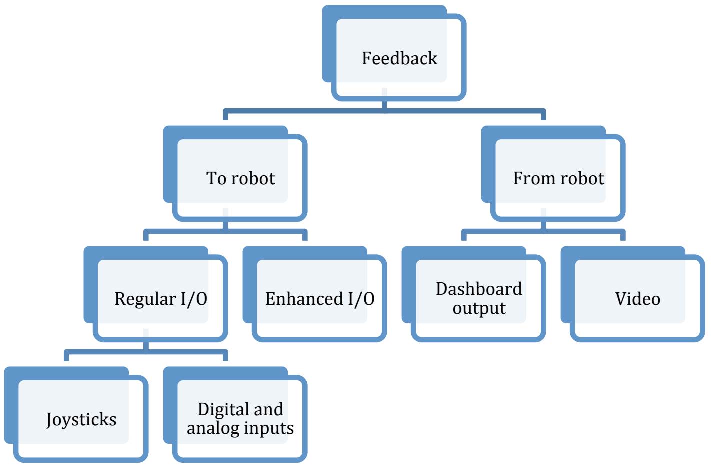


Figure 19: Feedback section organization

Getting Data from the Digital and Analog Ports

Building a driver station with just joysticks is simple and easy to do, especially with the range of HID USB devices supported by the Microsoft Windows based driver station. Custom interfaces can be constructed and implemented using the digital and analog I/O on the driver station. Switches can be connected to the digital inputs, the digital outputs can drive indicators, and the analog inputs can read various sensors, like potentiometers. Here are some examples of custom interfaces that are possible:

- Set of switches to set various autonomous modes and options
- Potentiometers on a model of an arm to control the actual arm on the robot
- Rotary switches with a different resistor at each position to generate unique voltage to effectively add more switch inputs
- Three pushbutton switches to set an elevator to one of three heights automatically

These custom interfaces often give the robot better control than is available from a standard joystick or controller.

You can read/write the driver station analog and digital I/O using the following DriverStation methods:

Method	Description
`float GetAnalogIn(UINT32 channel)`	Read an analog input value connected to port channel
`bool GetDigitalIn(UINT32 channel)`	Read a digital input value connected to port channel
`void SetDigitalOut(UINT32 channel, bool value)`	Write a digital output value on port channel
`bool GetDigitalOut(UINT32 channel)`	Read the currently set digital output value on port channel

Table 10: Using the driver station analog and digital I/O

Other Driver Station Features

The Driver Station is constantly communicating with the Field Management System (FMS) and provides additional status information through that connection:

Method	Description
`bool IsDisabled()`	Robot state
`bool IsAutonomous();`	Field state (autonomous vs. teleop)
`bool IsOperatorControl();`	Field state
`UINT32 GetPacketNumber();`	Sequence number of the current driver station received data packet
`Alliance GetAlliance();`	Alliance (red, blue) for the match
`UINT32 GetLocation();`	Starting field position of the robot (1, 2, or 3)
`float GetBatteryVoltage();`	Battery voltage on the robot

Table 11: Communicating with the FMS

Joysticks

The standard input device supported by the WPI Robotics Library is a USB joystick. The 2009 kit joystick comes equipped with eleven digital input buttons and three analog axes, and interfaces with the robot through the Joystick class. The Joystick class itself supports five analog and twelve digital inputs – which allows for joysticks with more capabilities.

The joystick must be connected to one of the four available USB ports on the driver station. The startup routine will read whatever position the joysticks are in as the center position, therefore, when the station is turned on the joysticks must be at their center position. The constructor takes either the port number the joystick is plugged into, followed by the number of axes and then the number of buttons, or just the port number from the driver's station. The former is primarily for use in sub-classing (For example, to create a class or a non-kit joystick), and the latter for a standard kit joystick.

The following example would create a default joystick called driveJoy on USB port 1 of the driver station. Something like a Microsoft Sidewinder joystick (which has five analog axes and eight buttons) – which would be a good candidate for a subclass of Joystick.

```
Joystick driveJoy(1);
Joystick opJoy(2,5,8);
```

Example 21: Creating a default Joystick object.

There are two methods to access the axes of the joystick. Each input axis is labeled as the X, Y, Z, Throttle, or Twist axis. For the kit joystick, the applicable axis are labeled correctly; a non-kit joystick will require testing to determine which axes correspond to which degrees of freedom.

Each of these axes has an associated accessor; the X axis from driveJoy in the above example could be read by calling `driveJoy.GetX()`; the twist and throttle axes are accessed by `driveJoy.GetTwist()` and `driveJoy.GetThrottle()`, respectively.

Alternatively, the axes can be accessed via the the `GetAxis()` and `GetRawAxis()` methods. `GetAxis()` takes an AxisType – `kXAxis`, `kYAxis`, `kZAxis`, `kTwistAxis`, or `kThrottleAxis` – and returns that axis' value. `GetRawAxis()` takes a number (1-6) and returns the value of the axis associated with that number. These numbers are reconfigurable and are generally used with custom control systems, since the other two methods reliably return the same data for a given axis.

There are three ways to access the top button (defaulted to button 2) and trigger (button 1). The first is to use their respective accessor methods – `GetTop()` and `GetTrigger()`, which return a true or false value based on whether the button is currently being pressed. A second method is to call GetButton(), which takes a ButtonType which can be either `kTopButton` or `kTriggerButton`. The last method is one that allows access to the state of every button on the joystick – `GetRawButton()`. This method takes a number corresponding to a button on the joystick (see diagram below), and return the state of that button.

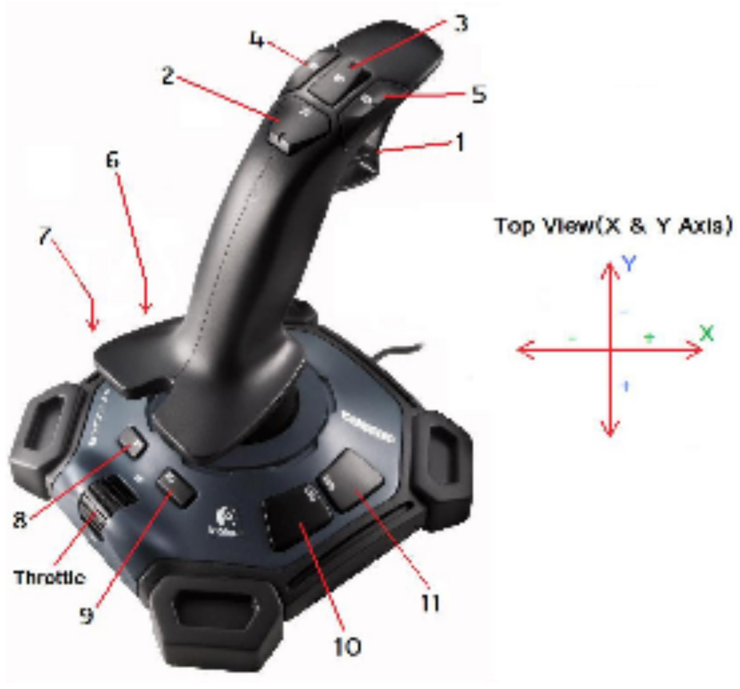


Figure 20: Diagram of a USB joystick

In addition to the standard method of accessing the Cartesian coordinates (x and y axes) of the joystick's position, WPILib also has the ability to return the position of the joystick as a magnitude and direction. To access the magnitude, the **`GetMagnitude()`** method can be called, and to access the direction, either **`GetDirectionDegrees()`** or **`GetDirectionRadians()`** can be called. (See the example below)

```
Joystick driveJoy(1);
Jaguar leftControl(1);
Jaguar rightControl(2);

if(driveJoy.GetTrigger())              //If the trigger is pressed
{
   //Have the left motor get input from Y axis
   //and the right motor get input from X axis
   leftControl.Set(driveJoy.GetY());
   rightControl.Set(driveJoy.GetAxis(kXAxis));
}
else if(driveJoy.GetRawButton(2))   //If button number 2 pressed (top)
{
   //Have both right and left motors get input
   //from the throttle axis
   leftControl.Set(driveJoy.GetThrottle());
   rightControl.Set(driveJoy.GetAxis(kThrottleAxis));
}
//If button number 4 is pressed
else if(driveJoy.GetRawButton(4))     //If button number 4 is pressed
{
   //Have the left motor get input from the
   //magnitude of the joystick's position
   leftControl.Set(driveJoy.GetMagnitude());
}
```

Example 22: Using buttons to determine how to interpret the joystick inputs.

Enhanced I/O through the Cypress Module

There are additional I/O options available through the Cypress module extended I/O class. The module contains:

- An accelerometer
- Analog inputs
- Analog outputs
- A button
- A status LED
- Digital inputs
- Digital outputs
- PWM outputs
- Fixed digital output
- Encoder inputs with index
- Touch sensor
- PWM outputs

All these are accessible through the DriverStationEnhancedIO class. The class is a singleton, i.e. there is never more than a single instance of it in the system. You can get a reference to the class through the DriverStation object as shown:

```
DriverStationEnhancedIO &dseio =
DriverStation.GetInstance().GetEnhancedIO();
```

Example 23: Getting a reference to the DriverStationEnhancedIO object in C++

```
DriverStationEnhancedIO dseio =
DriverStation.getInstance().getEnhancedIO();
```

Example 24: Getting a reference to the DriverStationEnhancedIO object in Java

Once you have a reference to the DriverStationEnhancedIO object you can call any of the methods that are available. For example, reading the touchpad slider is done with the following method (assuming you already have an instance as described above).

```
double slider = dseio.GetTouchSlider();
```

Example 25: Getting the value of the touchpad slider on the Cypress module in C++

```
double slider = dseio.getTouchSlider();
```

Example 26: Getting the value of the touchpad slider on the Cypress module in Java

Configuring the Enhanced I/O

The enhanced I/O features of the Cypress module can be configured either:

- in your C++ or Java program
- using the driver station I/O configuration screen

Either way that the configuration is set, the driver station records the configuration and remembers the settings. Whenever the dashboard starts up it first reads the configuration file, then the program settings are applied. This makes it convenient to set up the dashboard using the control panel. *However programs counting on settings made on a specific dashboard won't work if the dashboard is swapped for another one.*

Enhanced I/O data

The Enhanced I/O module has a very powerful and expanded set of capabilities beyond just simple analog and digital I/O. Here are some of the available options:

Function	Information
Accelerometer	Returns acceleration in Gs
Analog inputs	Analog inputs using a 3.3V reference either as a voltage or in ratiometric form
Analog outputs	2 channels (either A01 or A02) of analog output. About 0-3V and about 100uA of drive current
Button state	Get the state of either the button on the board or 5 additional configurable buttons
LED output	Set the state of any of 8 LEDs

Digital input	Read digital input values for switches, etc.
Digital output	Set digital output lines
PWM outputs	2 pairs of I/O lines capable of PWM output. There is a PWM generator for each pair. Pairs have common periods but independent duty cycles.
Quadrature encoder input	There are 2 signed 16 bit 4X quadrature encoder inputs with optional index functionality.
Capacitive touch slider	There is a touch sensitive capacitive slider on the board. Returns value between 0-1 with -1 indicating no touch.

Sending data to the dashboard

Often it is desirable to get feedback from the robot back to the drivers. The communications protocol between the robot and the driver station includes provisions for sending program specific data. The program at the driver station that receives the data is called the dashboard.

There are two sets of classes for sending data to the dashboard:

- SmartDashboard – automatically sends data and dynamically constructs a dashboard program based on a Java program running on the driver station of other dashboard computer.
- Orignal Dashboard class – based on a LabVIEW dashboard application that bundles values into "clusters" on the robot side to match the data formats on the dashboard side of the connection.

SmartDashboard

The SmartDashboard is new for 2011 and is by far the easiest way to display values on the driver station or the dashboard computer. It replaces having to print values and having to scroll through them trying to find where changes occurred.

The SmartDashboard (beta 1, 2011 season) uses a number of static methods on the SmartDashboard to log data by name from the robot to the dashboard program running at the driver station. A user interface is automatically generated based on the data that is sent from the robot program and values are updated as they change. Every time the robot sends a value using the SmartDashboard.log() method, the corresponding value is updated in the dashboard user interface (shown below).

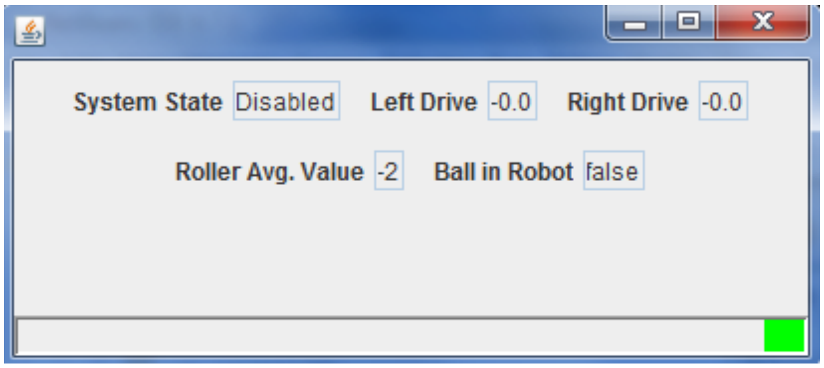

System State: Disabled
Left Drive: -0.0
Right Drive: -0.0
Roller Avg. Value: -2
Ball in Robot: false

Figure 21: Automatically generated dashboard user interface from logging methods called in the robot program

Programming the robot to send values is simply done by first calling SmartDashboard.init() then calling SmartDashboard.log() for each value that should get displayed on the dashboard program. Here are some program fragments that demonstrate initializing and logging strings to the SmartDashboard. The first argument to log is the value to be shown and the second argument is the log variable name.

```
    public void robotInit() {
        SmartDashboard.init();
        SmartDashboard.log("Initializing...", "System State");
    }

    public void disabledInit() {
        SmartDashboard.log("Disabled", "System State");
    }

    public void autonomousInit() {
        SmartDashboard.log("Auto", "System State");
    }

    public void teleopInit() {
        SmartDashboard.log("Teleop", "System State");
    }
```

In the previous example you can see the printing various strings to “System State” variable name. These will all be displayed to the same field as shown in the screen dump above. Below are some examples of logging additional values to the dashboard:

```
    public void teleopPeriodic() {
        driveline.tankDrive(leftJoystick, rightJoystick);
        SmartDashboard.log(leftJoystick.getY(), "Left Drive");
        SmartDashboard.log(rightJoystick.getY(), "Right Drive");
        SmartDashboard.log(collector.getAverageValue(),
                           "Roller Avg. Value");

        int logReturnCode = SmartDashboard.log(ballInRobot.get(),
                                               "Ball in Robot");

        if(logReturnCode != SmartDashboard.SUCCESS)
            System.out.println("Err: " +
                    SmartDashboard.diagnoseErrorCode(logReturnCode));
    }
```

In this example you can see the use of the return value from the log method to verify that the value was correctly sent to the dashboard from the robot. It is possible that if values are logged faster than they can be sent to the dashboard, some values might be ignored and not displayed properly. The log method will return an error in this case.

2010 Dashboard class

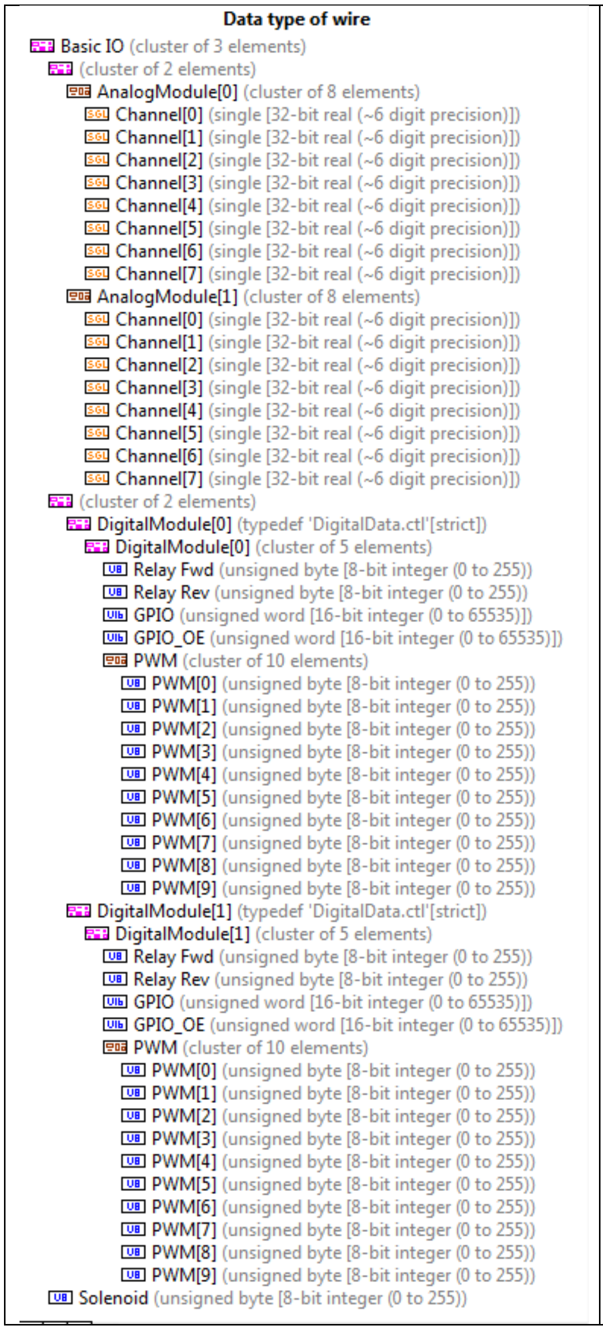
A default dashboard program is supplied with the driver station. The default dashboard program displays:

- Analog port values
- Digital I/O port values
- Solenoids
- Relays
- Camera tracking data

The data values are sent in groups called Clusters to correspond to the clusters on the LabVIEW dashboard program. The data is sent in two groups, high priority and low priority. The high priority data is sent first, then errors, then low priority data. On any given update only the high priority data might get transmitted, but on subsequent updates it might all get through. In the default dashboard the camera data is sent as high priority and the port data is sent as low priority.

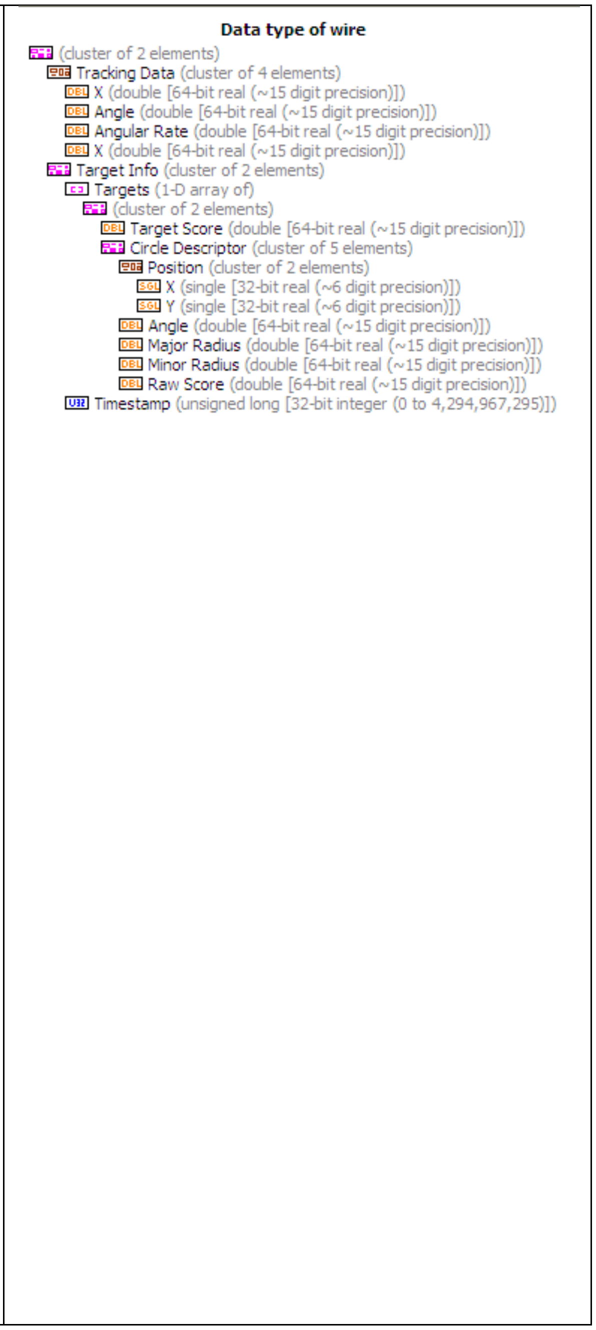
Adding dashboard data to your robot program

There is a sample program called **`DashboardDataExample`** included with the Workbench and NetBeans distributions. Look at those samples to get an idea of how to add custom data to your programs. The data structures being sent correspond to the LabVIEW dashboard client program at the driver station. Looking at the data model while looking at the sample program will make it clear as to how to customize the dashboard or write your own. The left structure is the I/O port data and the right structure is the camera tracking data.



Data type of wire

```
Basic IO (cluster of 3 elements)
  (cluster of 2 elements)
    AnalogModule[0] (cluster of 8 elements)
      Channel[0] (single [32-bit real (~6 digit precision)])
      Channel[1] (single [32-bit real (~6 digit precision)])
      Channel[2] (single [32-bit real (~6 digit precision)])
      Channel[3] (single [32-bit real (~6 digit precision)])
      Channel[4] (single [32-bit real (~6 digit precision)])
      Channel[5] (single [32-bit real (~6 digit precision)])
      Channel[6] (single [32-bit real (~6 digit precision)])
      Channel[7] (single [32-bit real (~6 digit precision)])
    AnalogModule[1] (cluster of 8 elements)
      Channel[0] (single [32-bit real (~6 digit precision)])
      Channel[1] (single [32-bit real (~6 digit precision)])
      Channel[2] (single [32-bit real (~6 digit precision)])
      Channel[3] (single [32-bit real (~6 digit precision)])
      Channel[4] (single [32-bit real (~6 digit precision)])
      Channel[5] (single [32-bit real (~6 digit precision)])
      Channel[6] (single [32-bit real (~6 digit precision)])
      Channel[7] (single [32-bit real (~6 digit precision)])
  (cluster of 2 elements)
    DigitalModule[0] (typedef 'DigitalData.ctl'[strict])
      DigitalModule[0] (cluster of 5 elements)
        Relay Fwd (unsigned byte [8-bit integer (0 to 255)])
        Relay Rev (unsigned byte [8-bit integer (0 to 255)])
        GPIO (unsigned word [16-bit integer (0 to 65535)])
        GPIO_OE (unsigned word [16-bit integer (0 to 65535)])
        PWM (cluster of 10 elements)
          PWM[0] (unsigned byte [8-bit integer (0 to 255)])
          PWM[1] (unsigned byte [8-bit integer (0 to 255)])
          PWM[2] (unsigned byte [8-bit integer (0 to 255)])
          PWM[3] (unsigned byte [8-bit integer (0 to 255)])
          PWM[4] (unsigned byte [8-bit integer (0 to 255)])
          PWM[5] (unsigned byte [8-bit integer (0 to 255)])
          PWM[6] (unsigned byte [8-bit integer (0 to 255)])
          PWM[7] (unsigned byte [8-bit integer (0 to 255)])
          PWM[8] (unsigned byte [8-bit integer (0 to 255)])
          PWM[9] (unsigned byte [8-bit integer (0 to 255)])
    DigitalModule[1] (typedef 'DigitalData.ctl'[strict])
      DigitalModule[1] (cluster of 5 elements)
        Relay Fwd (unsigned byte [8-bit integer (0 to 255)])
        Relay Rev (unsigned byte [8-bit integer (0 to 255)])
        GPIO (unsigned word [16-bit integer (0 to 65535)])
        GPIO_OE (unsigned word [16-bit integer (0 to 65535)])
        PWM (cluster of 10 elements)
          PWM[0] (unsigned byte [8-bit integer (0 to 255)])
          PWM[1] (unsigned byte [8-bit integer (0 to 255)])
          PWM[2] (unsigned byte [8-bit integer (0 to 255)])
          PWM[3] (unsigned byte [8-bit integer (0 to 255)])
          PWM[4] (unsigned byte [8-bit integer (0 to 255)])
          PWM[5] (unsigned byte [8-bit integer (0 to 255)])
          PWM[6] (unsigned byte [8-bit integer (0 to 255)])
          PWM[7] (unsigned byte [8-bit integer (0 to 255)])
          PWM[8] (unsigned byte [8-bit integer (0 to 255)])
          PWM[9] (unsigned byte [8-bit integer (0 to 255)])
  Solenoid (unsigned byte [8-bit integer (0 to 255)])
```



Data type of wire

```
(cluster of 2 elements)
  Tracking Data (cluster of 4 elements)
    X (double [64-bit real (~15 digit precision)])
    Angle (double [64-bit real (~15 digit precision)])
    Angular Rate (double [64-bit real (~15 digit precision)])
    X (double [64-bit real (~15 digit precision)])
  Target Info (cluster of 2 elements)
    Targets (1-D array of)
      (cluster of 2 elements)
        Target Score (double [64-bit real (~15 digit precision)])
        Circle Descriptor (cluster of 5 elements)
          Position (cluster of 2 elements)
            X (single [32-bit real (~6 digit precision)])
            Y (single [32-bit real (~6 digit precision)])
          Angle (double [64-bit real (~15 digit precision)])
          Major Radius (double [64-bit real (~15 digit precision)])
          Minor Radius (double [64-bit real (~15 digit precision)])
          Raw Score (double [64-bit real (~15 digit precision)])
    Timestamp (unsigned long [32-bit integer (0 to 4,294,967,295)])
```

2010 Camera and Image Processing

New for 2010 there is a new API to access the camera and the related image processing classes. Java implements the new API and the C++ library includes both the new and the old APIs. Access to the camera and all the image types are now objects and can be accessed using methods on the appropriate object type.

Using the camera

The camera is accessed through the `AxisCamera` class. It is a singleton, meaning that you can get an instance of the `AxisCamera` using the static method `GetInstance()` in C++ or getInstance() in Java. Methods on the camera object can be used to set various parameters on the camera to programmatically control its operation.

Typically your robot program would retrieve image from the camera and process them. Here is a portion of a program that retrieves images and performs some processing on them.

```
HSLImage image;

// Create and set up a camera instance
AxisCamera &camera = AxisCamera::getInstance();
camera.writeResolution(k160x120);
camera.writeBrightness(0);
Wait(3.0);

// loop getting images from the camera and finding targets
while (IsOperatorControl())
{
   // Get a camera image
   camera.GetImage(image.image);
   // do something with image here
       .
       .
       .
}
```

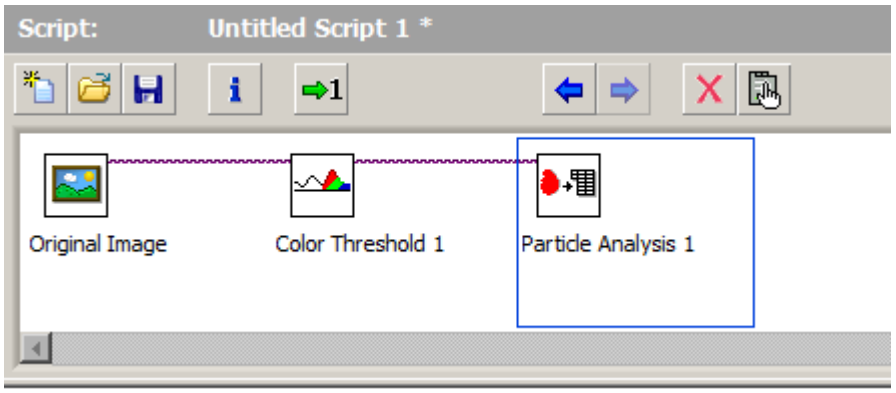
Example 27: A C++ program that sets up the camera, gets images, and processes them. Notice how the HSLImage object is used with the camera.

The camera supports video back to the dashboard. When your dashboard program does a network connection to the `PCVideoServer` object on the robot, a stream of JPEG images will be sent back to the dashboard. The sample LabVIEW dashboard application will make connections to the video server and you will be able to see what the robot camera is seeing in real-time as it is driving in your lab or in competition. Once you retrieve an instance of the camera the server will be automatically available for video back to the dashboard. You don't have to write any code to enable this.

Working with images

There are a number of image classes that represent the types of images that are supported by the NI IMAQ (Image Acquisition) library. For each image type there are methods that can be called to do various operations on the image. Cascading these image operations together is the way to do more complex operations such as target recognition.

A good way to prototype image processing code is to use the NI Vision Assistant that is included with the FRC Software DVD. Images taken with the FRC camera can be saved to disk. Then using the Vision Assistant you can try different operations with varying parameters you set and will show the result of each operation. You can cascade a number of image operations together and see the result of them combined. Once it is working on a number of test images then it is easy to write the corresponding code and add it to your robot program. Here is an example of cascading a Color Threshold and a Particle Analysis:



All of the sample images shown in this section were produced using the Vision Assistant.

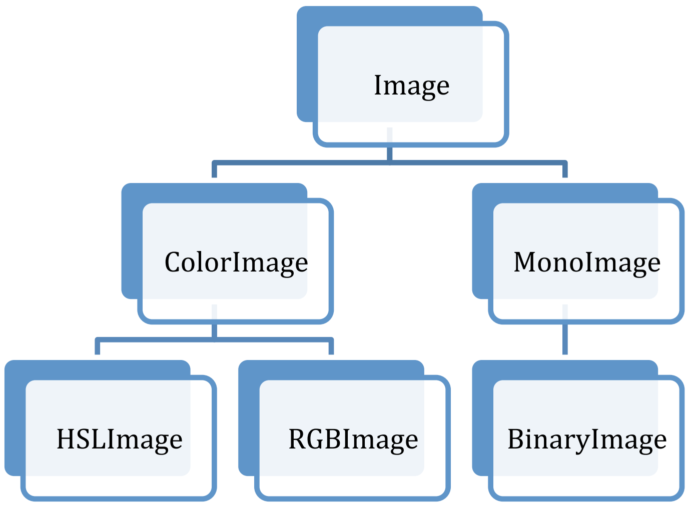
Use of image memory

In Java images are stored using C++ data structures and only pointers are manipulated, all the actual processing is done at the C/C++ level for optimum performance. For example, a threshold operation on a color image it is actually performed by C code and the image itself is stored as a C data structure. This is to prevent unnecessary copies from C/C++ to Java for large image structures.

In C++ the actual IMAQ image is stored as a member of the corresponding image object. Whenever new images are produced as a result of an operation, for example, returning a `BinaryImage` as the result of a threshold operation, a pointer (`BinaryImage`*) is returned from the C++ method**. It is the responsibility of the caller to free the newly allocated image when finished with it**. Be sure to delete the image objects when you are finished using them. See the example programs supplied with the C++ FRC Toolkit for more information.

Image types

There are a number of image types available, each used for a different purpose.



This shows the hierarchy diagram of the types of images and the class relationships between them.

`Image` is the base class for all other image types. If provides height and width accessor methods that work across all image types.

`ColorImage` is the basic color image type and can either be a `HSLImage` or an `RGBImage` representing the two most commonly used image formats. ColorImage objects have three planes each representing some part of the total image. In an `RGBImage`, the three planes represent the red, green, and blue values that make up the total picture.

`MonoImage` objects represent a single color. `BinaryImage` objects have a single bit for each pixel. They are often the result of a color or edge detection operation on a `ColorImage`. For example looking for objects of a particular color might use a threshold operation on a `ColorImage` resulting in a `BinaryImage` with each set pixel corresponding to a pixel in the ColorImage.

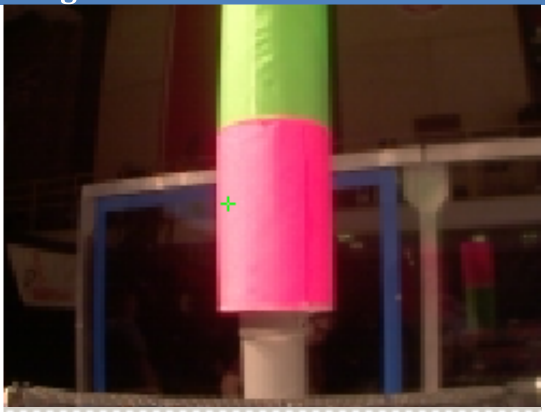
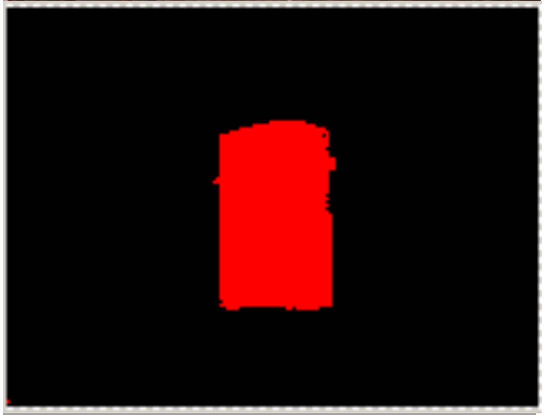
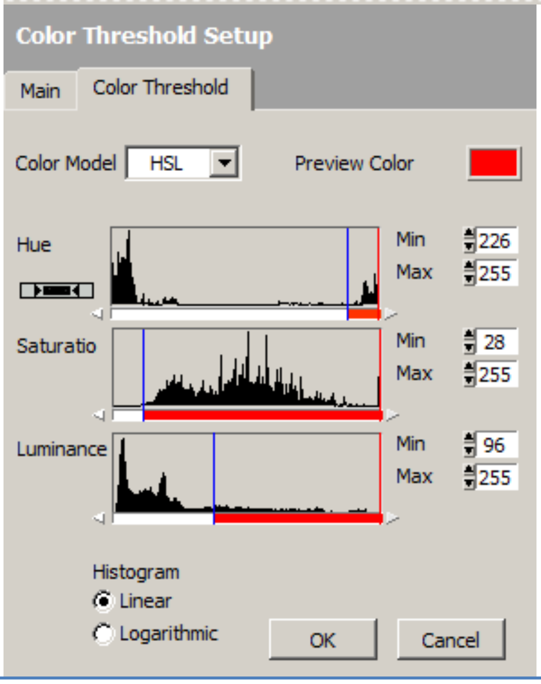
Common ColorImage operations

Once you have a `ColorImage` (either `HSLImage` or `RGBImage`) there are a number of operations that can be done it. Most of these operations results in a new image of the same size.

Threshold detection

Threshold detection takes a three ranges corresponding to the three color planes in the image type. A `BinaryImage` is returned where each pixel that is on in the `BinaryImage` corresponds to a pixel in the `ColorImage` that was within the threshold range.

Locating color targets from the 2009 Lunacy game consists of finding the pink and green targets and making sure they were one over the other in the right order. Using a threshold operation to detect only the pink portion of the image is done using a set of values that correspond to the pink color found on the targets. The result is a bitmap (`BinaryImage`) that represents the pixel locations in the original images that represent the matching colors.

Image	ColorImage operation
	This is the original image taken using the FRC camera.
	This is the resultant bitmap with just the pixels that matched the pink threshold values.
 Color Threshold Setup Main / Color Threshold Color Model: HSL Preview Color 🟥 Hue Min 226 Max 255 Saturatio Min 28 Max 255 Luminance Min 96 Max 255 Histogram: [✓ Linear] Logarithmic OK Cancel	One of the easiest ways to determine the threshold values is using the Vision assistant. You can tune the 6 color parameters to find a set that results in the best discrimination of the image being tested. Then those parameters can be copied into your program to do the detection in the robot. Here you can see graphs that represent the values of Hue, Saturation, and Luminance in the original color image and the min-max values that are the parameters to the threshold operation. You can manipulate the values to see the effectiveness of the parameters changing.

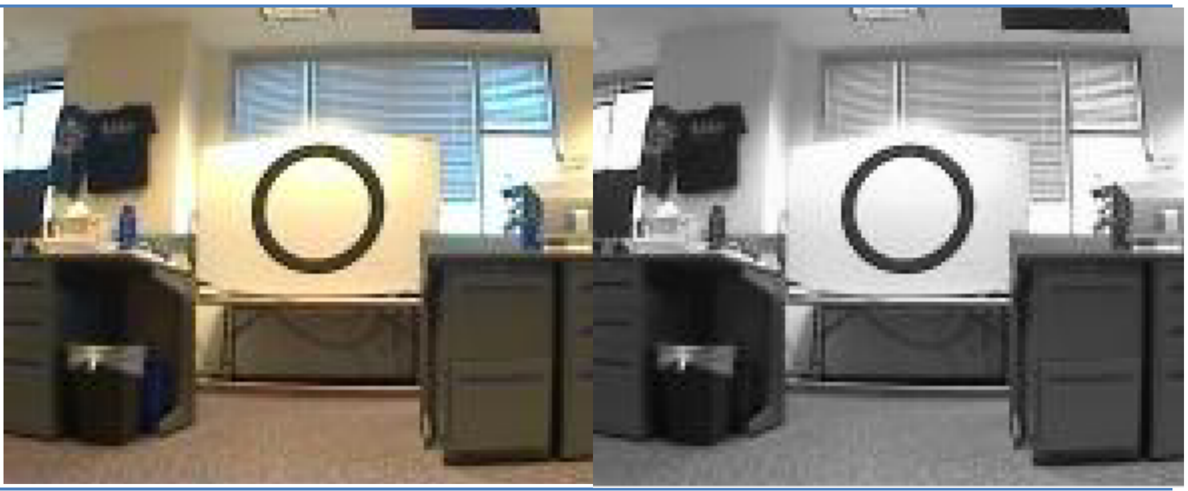
The code to do this threshold operation is shown below:

```
Threshold pinkThreshold(226, 255, 28, 255, 96, 255);
HSLImage *targetImage = new HSLImage("/testImage.png"); // create image
BinaryImage *pinkPixels = targetImage->thresholdHSL(pinkThreshold);
```

This code produces a `BinaryImage` object using the threshold ranges shown. You can see how the values are taken from the Vision Assistant window above.

Plane extraction and replacement

There are a number of methods that will extract a single plane from a color image. The meaning of the plane will depend on the type of the image. For example in a RGB (red-green-blue) image the second plane is the green plane and represents all the green values. In an HSL image, the second plane is the saturation value for the image. You can extract any type of plane from any type of image. For example, if you have an RGBImage object, you can still extract the luminance plane by calling the `GetLuminancePlane()` method in C++ or the `getLuminancePlane()` method in Java.

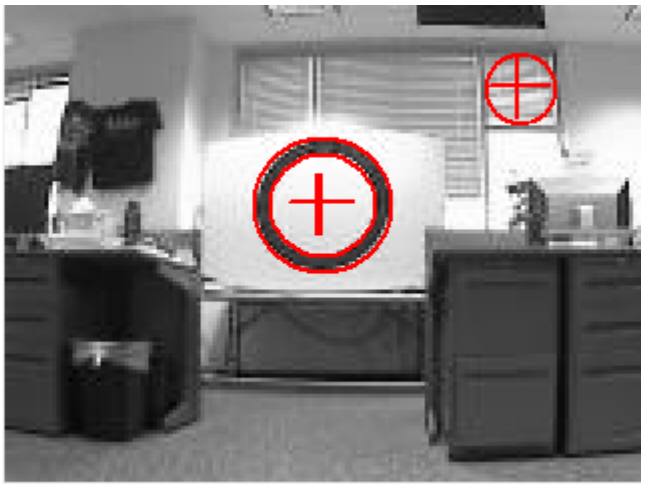


Above are two images, the first a color image taken with the camera on the robot as recorded by the driver station. The second image was produced by extracting the luminance plane from the first image leaving only greyscale.

Ellipse detection

Ellipse detection is one type of shape detection available for use with the camera. Ellipse detection is a single IMAQ library call even though internally it does many steps to find ellipses. This method is available on `MonoImage` objects. Detecting ellipses from camera images that are color (either `RBGImage` or `HSLImage`) require extraction of a single plane. Typically the luminance plane is used since it makes the detection less effected by color changes.

Ellipse detection is very flexible and has a number of options that you might want to use to change the effectiveness of the detection.



The image above shows the previous image with the detected images shown in red.

You should refer to the sample programs included with C++ and Java and the National Instruments Vision library documentation for more information. An example of ellipse detection in C++ and Java are shown here:

```
ColorImage *image;
     .
     .
     .
MonoImage  *luminancePlane = image->getLuminancePlane();
vector<EllipseMatch> *results =
   luminancePlane->DetectEllipses(&ellipseDescriptor,
                                  &curveOptions,
                                  NULL,
                                  NULL);
printf("Found %d ellipses\n", results->size());
delete luminancePlane;
```

Example 28: Ellipse detection taken from one of the C++ sample programs provided with the C++ FRC toolkit. The luminance plane is extracted from the ColorImage producing a MonoImage. The results of DetectEllipses is a vector of EllipseMatch structures with each one representing one detected ellipse.

<java example of ellipse detection here>

Miscellaneous

This section discusses more advanced control of your robot, such as with PID programming. The structure of this section is outlined in the chart below.

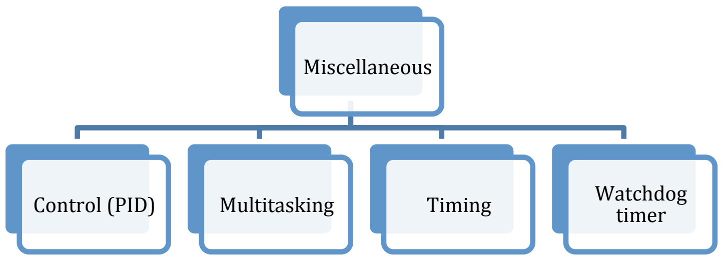


Figure 22: Miscellaneous section organization

PID Programming

PID controllers are a powerful and widely used implementation of closed loop control. The `PIDController` class allows for a PID control loop to be created easily, and runs the control loop in a separate thread at consistent intervals. The `PIDController` automatically checks a `PIDSource` for feedback and writes to a `PIDOutput` every loop. Sensors suitable for use with `PIDController` in WPILib are already subclasses of `PIDSource`. Additional sensors and custom feedback methods are supported through creating new subclasses of `PIDSource`. Jaguars and Victors are already configured as subclasses of `PIDOutput`, and custom outputs may also be created by sub-classing `PIDOutput`.

The following example shows how to create a `PIDController` to set the position of a turret to a position related to the x-axis on a joystick. This turret uses a single motor on a Jaguar, and a potentiometer for angle feedback. As the joystick X value changes, the motor should drive to a position related to that new value. The `PIDController` class will ensure that the motion is smooth and stops at the right point.

A potentiometer that turns with the turret will provide feedback of the turret angle. The potentiometer is connected to an analog input and will return values ranging from 0-5V from full clockwise to full counterclockwise motion of the turret. The joystick X-axis returns values from -1.0 to 1.0 for full left to full right. We need to scale the joystick values to match the 0-5V values from the potentiometer. This can be done with the following expression:

```
(turretStick.GetX() + 1.0) * 2.5
```

Example 29: Example of scaling Joysticks in C++.

The scaled value can then be used to change the setpoint of the control loop as the joystick is moved.

The 0.1, 0.001, and 0.0 values are the Proportional, Integral, and Differential coefficients respectively. The `AnalogChannel` object is already a subclass of

`PIDSource` and returns the voltage as the control value and the Jaguar object is a subclass of `PIDOutput`.

```
Joystick turretStick(1);
Jaguar turretMotor(1);
AnalogChannel turretPot(1);
PIDController turretControl(0.1, 0.001, 0.0, &turretPot, &turretMotor);

turretControl.Enable();  // start calculating PIDOutput values

while(IsOperator())
{
    turretControl.SetSetpoint((turretStick.GetX() + 1.0) * 2.5);
    Wait(.02);      // wait for new joystick values
}
```

Example 30: Using the `PIDController` object.

The `PIDController` object will automatically (in the background):

- Read the `PIDSource` object (in this case the turretPot analog input)
- Compute the new result value
- Set the `PIDOutput` object (in this case the turretMotor)

This will be repeated periodically in the background by the `PIDController`. The default repeat rate is 50ms although this can be changed by adding a parameter with the time to the end of the `PIDController` argument list. See the reference document for details.

Multitasking (C++)

There are a number of classes in the C++ version of WPILib to aid in creating programs that use concurrent programming techniques. The underlying operating system, VxWorks has a full support for multitasking, but the classes simplify programming for the more common cases.

Creating tasks

A task is a thread of execution in a program that runs concurrently with other tasks in a program. Each task has a number of attributes including a name and priority. Tasks share memory with each other. To create a task you write a function that should is the starting point for that thread of execution. Using the Task class you can run that function as a separate task. Creating an instance of Task looks like this:

```
Task myTask(“taskname”, (FUNCPTR) functionToStart);
```

The task name will be seen in the task list in Workbench when you are debugging the program. The functionToStart is the name of a function to run when the task is started. FUNCPTR is a typedef that defines the type (signature) of the function. The task is started using the `Start()` method.

```
myTask.Start();
```

Once started, the function will run asynchronously along with the other tasks in the system.

Synchronizing tasks

Starting tasks is easy – and for many cases that's all that's required. A good example is the Compressor class. The compressor class creates a task that simply loops checking the pressure switch and operating the compressor relay. It doesn't interact with other tasks and doesn't really share data with the rest of the program.

The difficulties with multitasking come in when there is data that's shared between two tasks. If one task is writing to the data and gets half of it written, then the reader task starts up, it will find inconsistent data. Only half of the data will have been changed and that can cause very hard to track down problems in your code. An example is the Camera class. It's reading camera images in one task and your program is consuming them in a different task. If the consumer tries to read an image while the camera is writing it, half the image will be new and the other half will be old. Not a good situation!

VxWorks provides a facility to help this called a Semaphore. Semaphores let you synchronize access to data ensuring that only one task will have access to it at a time. You lock the block of data, read or write it, then unlock it. While it's locked, any other task trying to access it will have to wait until it's unlocked. WPILib has a class called Synchronized that simplifies the use of semaphores for this purpose. It is modeled after the Java style of synchronization.

The model for synchronizing data access is to first create a semaphore that will be used. Here is an example from the `AnalogModule` class in WPILib.

```
static SEM_ID m_registerWindowSemaphore;
```

Then to protect access to data using the semaphore, create a new block with a `Synchronized` object on the first line.

```
INT16 AnalogModule::GetValue(UINT32 channel)
{
   INT16 value;
   CheckAnalogChannel(channel);

   tAI::tReadSelect readSelect;
   readSelect.Channel = channel - 1;
   readSelect.Module = SlotToIndex(m_slot);
   readSelect.Averaged = false;

   {
      Synchronized sync(m_registerWindowSemaphore);
      m_module->writeReadSelect(readSelect, &status);
      m_module->strobeLatchOutput(&status);
      value = (INT16) m_module->readOutput(&status);
   }

   wpi_assertCleanStatus(status);
   return value;
}
```

This will “take” the semaphore, declaring that this piece of code *owns* the associated data. Access the data inside the block, and when the block exits, the synchronized object will be automatically freed by C++ and the semaphore will be released allowing access from other parts of your code.

You should use the same semaphore in all the places where you write code that access that protected data.

Timers

Timers provide a means of timing events in your program. For example, your program can start a timer, wait for an even to happen, then read the timer value as a way of determine the elapsed time. The Timer class can get the time value as well as start, stop, and reset the current time associated with that timer.

Notification

There is a facility in WPILib to let you do regular timed operations. The `Notifier` class will run a function that you write after a period of time or at regular intervals. The function runs as a separate task and is started with optional context information. An example is the `PIDController` class which requires calculations to be done on a regular basis. It creates a `Notifier` object using the function to be called.

```
m_controlLoop = new Notifier(PIDController::CallCalculate, this);
```

Then when it is time to start the function running, in this case `CallCalculate` from the `PIDController` class, it does it using the `StartPeriodic()` method.

```
m_controlLoop->StartPeriodic(m_period);
```

The `CallCalculate` method will be called every `m_period` seconds (typically the period is a fraction of a second). You can also have single instance notification – the notifier function is only called one time after the interval, using the `StartSingle()` method. Periodic notification can also be stopped by calling the `Stop()` method on the Notifier.

Watchdog timer

It is possible for a program to fail in such a way that the actuators are running with no program control. A robot can start driving at high speed, the program crashes, and the robot continues to drive breaking the robot or injuring nearby people. To help programmers ensure safety of their robots WPILib as a number of features to prevent this runaway condition based around the concept of a “watchdog timer”. The idea is that while the program is working, your code constantly calls a method on a watchdog object (feeds the watchdog). As soon as you stop feeding the watchdog, such as when the program crashes or gets into an unforeseen state, the system automatically stops all the motors. There is an expiration timer that controls the length of time by which the watchdog must be fed. The features in the library to help prevent this condition are:

1. System watchdog timer – the system has a built in watchdog timer that looks for communications with the driver station. If there is no communication for a preset amount of time, the system watchdog error is signaled and the motors are stopped. This is built into the system and cannot be turned off.
2. Motor safety timers – each motor and RobotDrive object has a timer built in. As long as values are supplied to these objects they keep running. If a period of time goes by where no values are supplied, that motor or object is stopped. In this case the other motors that are receiving values keep running. The motor safety feature is automatically enabled for the RobotDrive class and disabled by default on all other actuators. You must explicitly enable the motor safety feature on individual motors not created by the RobotDrive class in order for them to work. Each timer has its own settable expiration timer.
3. User watchdog timer – the user program can have its own watchdog timer that keeps the motor running as long as the feed method is called. This watchdog is completely optional and can be enabled and disabled under

program control. When the user watchdog isn't fed, then all motors stop. There is no fine control over specific motors as in with motor safety timers. The user watchdog has a single expiration timer for all motors.

Note: *The user watchdog timer is being replaced with the MotorSafety interface. MotorSafety is the preferred way to provide safe operation of motors on your robot. By default, the user watchdog is disabled (changed from 2010) and the MotorSafety timeouts are enabled by default on the RobotDrive object and not enabled by default on Victors and Jaguars.*

Motor Safety Timers

There are a number of methods on the RobotDrive, Jaguar, and Victor objects that implement the MotorSafety interface. Below is an example of using MotorSafety on a RobotDrive object. The example is a Java program, the C++ program would be similar.

```
    public void autonomous() {
        getWatchdog().setEnabled(false);
        drive.setExpiration(5.0);
        drive.setSafetyEnabled(true);
        drive.drive(1, 0);
        Timer.delay(3);
        drive.drive(-1, 0);
        Timer.delay(3);
        drive.drive(0, 0);
    }
```

In this example, the user watchdog is first disabled (default in the final version of WPILib). The expiration time is set for the RobotDrive object and the safety feature is enabled. This will stop the motors from running after 5 seconds of not sending a value to the motors. In this case, the values are updated every three seconds and they continue to operate. The same methods are also available on Victor and Jaguar objects.

System Architecture

This section describes how the system is put together and how the libraries interact with the base hardware. It should give you better insight as to how the whole system works and its capabilities.

Digital Sources

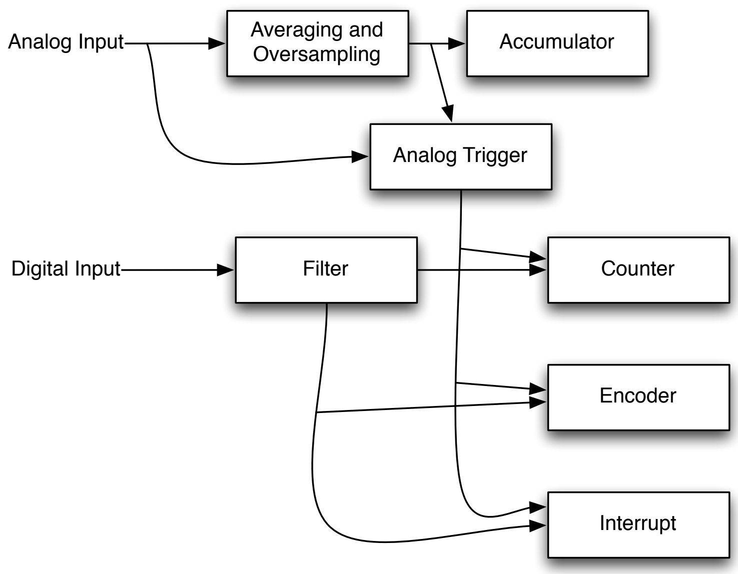


Figure 23: Digital source breakdown

Digital Filter

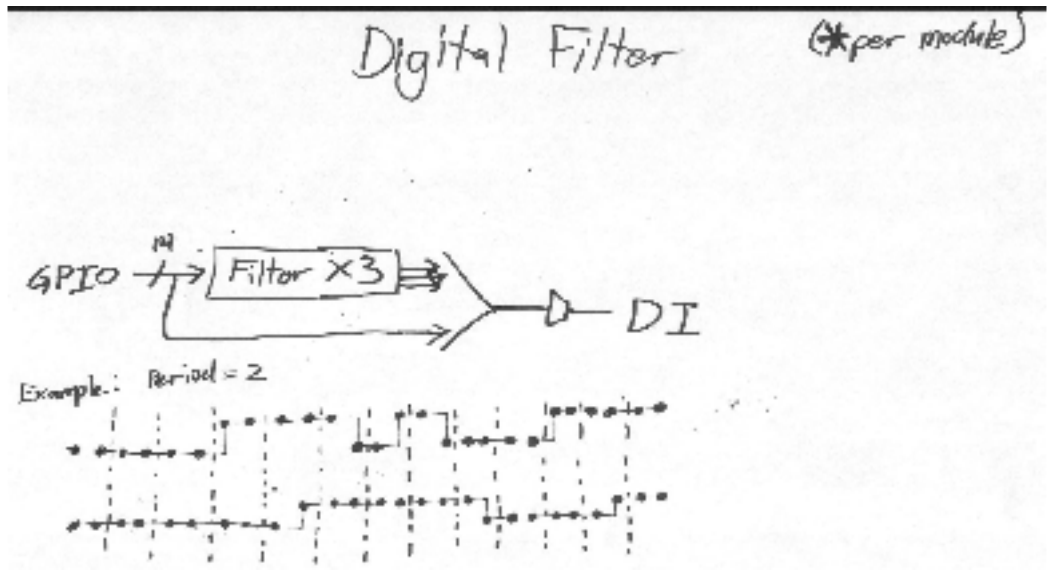


Figure 24: Digital filter diagram and example

Contributing to the WPI Robotics Library

TODO: fill In this sction

Appendix A: 2009 Camera and Vision

Note: The 2009 Camera and Vision code is still supplied in the library but has been deprecated in favor of the newer object oriented interface to the camera and image types.

Camera

The camera provided in the 2009 kit is the Axis 206. The C camera API provides initialization, control and image acquisition functionality. Image appearance properties are configured when the camera is started. Camera sensor properties can be configured with a separate call to the camera, which should occur before camera startup. The API also provides a way to update sensor properties using a text file on the cRIO. PcVideoServer.cpp provides a C++ API that serves images to the dashboard running on a PC. There is a sample dashboard application as part of the LabVIEW distribution that can interface with C and C++ programs.

Camera task management

A stand-alone task, called *FRC_Camera*, is responsible for initializing the camera and acquiring images. It continuously runs alongside your program acquiring images. It needs to be started in the robot code if the camera is to be used. Normally the task is left running, but if desired it may be stopped. The activity of image acquisition may also be controlled, for example if you only want to use the camera in Autonomous mode, you may either call *StopCameraTask()* to end the task or call *StopImageAcquisition()* to leave the task running but not reading images from the camera.

Camera sensor property configuration

ConfigureCamera () sends a string to the camera that updates sensor properties. GetCameraSetting () queries the camera sensor properties. The properties that may be updated are listed below along with their out-of-the-box defaults:

- brightness =50
- whitebalance=auto
- exposure=auto
- exposurepriority=auto
- colorlevel=99
- sharpness=0

GetImageSetting() queries the camera image appearance properties (see the Camera Initialization section below). Examples of property configuration and query calls are below:

```
// set a property
ConfigureCamera("whitebalance=fixedfluor1");

// query a sensorproperty
char responseString[1024];          // create string
bzero (responseString, 1024);       // initialize string
if (GetCameraSetting("whitebalance",responseString)=-1) {
    printf("no response from camera \n);
} else {printf("whitebalance: %s \n",responseString);}

// query an appearance property
if (GetImageSetting("resolution",responseString)=-1) {
    printf("no response from camera \n);
} else {printf("resolution: %s \n",responseString);}
```

Example 31: The example program CameraDemo.cpp will configure properties in a variety of ways and take snapshots that may be FTP'd from the cRIO for analysis.

Sensor property configuration using a text file

The utility *ProcessFile()* sets obtain camera sensor configuration specified from a file called "cameraConfig.txt" on the cRIO. *ProcessFile()* is called the first time with 0 lineNumber to get the number of lines to read. On subsequent calls each lineNumber is requested to get one camera parameter. There should be one property=value entry on each line, i.e. "exposure=auto"   A sample cameraConfig.txt file is included with the CameraDemo project. This file must be placed on the root directory of the cRIO. Below is an example file:

```
#######################
! lines starting with ! or # or comments
! this a sample configuration file
! only sensor properties may be set using this file
! - set appearance properties when StartCameraTask() is called
#######################
exposure=auto
colorlevel=99
```

Simple Camera initialization

StartCameraTask() initializes the camera to serve MJPEG images using the following camera appearance defaults:

- Frame Rate = 10 frames / sec
- Compression = 0
- Resolution = 160x120
- Rotation = 0

```
if (StartCameraTask() == -1) {
   dprintf( LOG_ERROR, "Failed to spawn camera task; Error code %s",
         GetErrorText(GetLastError()) );
}
```

Example 32: C++ program showing how to initialize the camera.

Configurable Camera initialization

Image processing places a load on the cRIO which may or may not interfere with your other robot code. Depending on needed speed and accuracy of image processing, it is useful to configure the camera for performance. The highest frame rates may acquire images faster than your processing code can process them, especially with higher resolution images. If your camera mount is upside down or sideways, adjusting the Image Rotation in the start task command will compensate and images will look the same as if the camera was mounted right side up. Once the camera is initialized, it begins saving images to an area of memory accessible by other programs. The images are saved both in the raw (JPEG) format and in a decoded format (Image) used by the NI image processing functions. An example is shown below.

```
int frameRate = 15;                 // valid values 0 - 30
int compression = 0;                // valid values 0 – 100
ImageSize resolution = k160x120;      // k160x120, k320x240, k640x480
ImageRotation rot = ROT_180;            // ROT_0, ROT_180

StartCameraTask(frameRate, compression, resolution, rot);
```

Example 33: C++ program showing how to save images.

Image Acquisition

Images of types IMAQ_IMAGE_HSL, IMAQ_IMAGE_RGB, and IMAQ_IMAGE_U8 (gray scale) may be acquired from the camera. To obtain an image for processing, first create the image structure and then call GetImage() to get the image and the time that it was received from the camera:

```
double timestamp;               // timestamp of image returned
Image* cameraImage = frcCreateImage(IMAQ_IMAGE_HSL);
if (!cameraImage)  { printf("error: %s", GetErrorText(GetLastError()) };

if ( !GetImage(cameraImage, &timestamp) )  {
   printf("error: %s", GetErrorText(GetLastError()) };
```

Example 34: Getting images from the camera.

`GetImage()` reads the most recent image, regardless of whether it has been previously accessed. Your code can check the timestamp to see if it's an image you already processed.

Alternatively, **`GetImageBlocking()`** will wait until a new image is available if the current one has already been served. To prevent excessive blocking time, the call will return unsuccessfully if a new image is not available in 0.5 second. This is shown in the example below.

```
Image* cameraImage = frcCreateImage(IMAQ_IMAGE_HSL);
double timestamp;            // timestamp of image returned
double lastImageTimestamp;  // timestamp of last image, to ensure image is
new

int success = GetImageBlocking(cameraImage, &timestamp,
lastImageTimestamp);
```

Example 35: Getting images from the camera.

Camera Metrics

Various camera instrumentation counters used internally may be accessed that may be useful for camera performance analysis and error detection. Here is a list of the metrics:

CAM_STARTS, CAM_STOPS, CAM_NUM_IMAGE, CAM_BUFFERS_WRITTEN, CAM_BLOCKING_COUNT, CAM_SOCKET_OPEN, CAM_SOCKET_INIT_ATTEMPTS, CAM_BLOCKING_TIMEOUT, CAM_GETIMAGE_SUCCESS, CAM_GETIMAGE_FAILURE, CAM_STALE_IMAGE, CAM_GETIMAGE_BEFORE_INIT, CAM_GETIMAGE_BEFORE_AVAILABLE, CAM_READ_JPEG_FAILURE, CAM_PC_SOCKET_OPEN, CAM_PC_SENDIMGAGE_SUCCESS, CAM_PC_SENDIMAGE_FAILURE, CAM_PID_SIGNAL_ERR, CAM_BAD_IMAGE_SIZE, CAM_HEADER_ERROR

The following example call gets the number of images served by the camera:

```
int result = GetCameraMetric(CAM_NUM_IMAGE);
```

Example 36: Retrieving the image number.

Images to PC

The class PCVideoServer, when instantiated, creates a separate task that sends images to the PC for display on a dashboard application. The sample program DashboardDemo shows an example of use.

```
StartCameraTask();       // Initialize the camera
PCVideoServer pc;        // The constructor starts the image server task
pc.Stop();              // Stop image server task
pc.Start();             // Restart task and serve images again
```

Example 37: Sending images to the PC dashboard program.

To use this code with the LabVIEW dashboard, the PC must be configured as IP address 10.x.x.6 to correspond with the cRIO address 10.x.x.2.

Vision / Image Processing

Access to National Instrument's nivison library for machine vision enables automated image processing for color identification, tracking and analysis. The VisionAPI.cpp file provides open source C wrappers to a subset of the proprietary library. The full specification for the simplified FRC Vision programming interface is in the FRC Vision API Specification document, which is in the *WindRiver\docs\extensions\FRC* directory of the Wind River installation with this document. The FRC Vision interface also includes high level calls for color tracking (TrackingAPI.cpp). Programmers may also call directly into the low level library by including nivision.h and using calls documented in the NI Vision for LabWindows/CVI User Manual.

Naming conventions for the vision processing wrappers are slightly different from the rest of WPILib. C routines prefixed with "imaq" belong to NI's LabVIEW/CVI vision library. Routines prefixed with "frc" are simplified interfaces to the vision library provided by BAE Systems for FIRST Robotics Competition use.

Sample programs provided include SimpleTracker, which in autonomous mode tracks a color and drives toward it, VisionServoDemo, which also tracks a color with a two-servo gimbal. VisionDemo demonstrates other capabilities including storing a

JPEG image to the cRIO, and DashboardDemo sends images to the PC Dashboard application.

Image files may be read and written to the cRIO non-volatile memory. File types supported are PNG, JPEG, JPEG2000, TIFF, AIDB, and BMP. Images may also be obtained from the Axis 206 camera. Using the FRC Vision API, images may be copied, cropped, or scaled larger/smaller. The intensity measurement functions available include calculating a histogram for color or intensity and obtaining values by pixel. Contrast may be improved by equalizing the image. Specific color planes may be extracted. Thresholding and filtering based on color and intensity characteristics are used to separate particles that meet specified criteria. These particles may then be analyzed to find the characteristics.

Color Tracking

High level calls provide color tracking capability without having to call directly into the image processing routines. You can either specify a hue range and light setting, or pick specific ranges for hue, saturation and luminance for target detection.

Example 1: Using Defaults

Call GetTrackingData() with a color and type of lighting to obtain default ranges that can be used in the call to FindColor(). The ParticleAnalysisReport returned by FindColor() specifies details of the largest particle of the targeted color.

```
TrackingThreshold tdata = GetTrackingData(BLUE, FLUORESCENT);
ParticleAnalysisReport par;

if (FindColor(IMAQ_HSL, &tdata.hue, &tdata.saturation,
                &tdata.luminance, &par)
{
   printf("color found at x = %i, y = %i",
      par.center_mass_x_normalized, par.center_mass_y_normalized);
   printf("color as percent of image: %d",
      par.particleToImagePercent);
}
```

Example 38: Color tracking example.

The normalized center of mass of the target color is a range from −1.0 to 1.0, regardless of image size. This value may be used to drive the robot toward a target.

Example 2: Using Specified Ranges

To manage your own values for the color and light ranges, you simply create Range objects as shown in the example below.

```
    Range hue, sat, lum;

    hue.minValue = 140;   // Hue
    hue.maxValue = 155;
    sat.minValue = 100;   // Saturation
    sat.maxValue = 255;
    lum.minValue = 40; // Luminance
    lum.maxValue = 255;

    FindColor(IMAQ_HSL, &hue, &sat, &lum, &par);
```

Example 39: Using specified ranges of colors to limit the found color values.

Tracking also works using the Red, Green, Blue (RGB) color space, however HSL gives more consistent results for a given target.

Example 3: Using Return Values

Here is an example program that enables the robot to drive towards a green target. When it is too close or too far, the robot stops driving. Steering like this is quite simple as shown in the example below.

The following declarations in the class are used for the example:

```
  RobotDrive *myRobot
  Range greenHue, greenSat, greenLum;
```

Example 40: C++ program declarations.

This is the initialization of the RobotDrive object, the camera and the colors for tracking the target. It would typically go in the RobotBase derived constructor.

```
if (StartCameraTask() == -1) {
    printf( "Failed to spawn camera task; Error code %s",
         GetErrorText(GetLastError()) );
}
myRobot = new RobotDrive(1, 2);

// values for tracking a target - may need tweaking in your environment
greenHue.minValue = 65; greenHue.maxValue = 80;
greenSat.minValue = 100; greenSat.maxValue = 255;
greenLum.minValue = 100; greenLum.maxValue = 255;
```

Example 41: C++ program showing the use of return values.

Here is the code that actually drives the robot in the autonomous period. The code checks if the color was found in the scene and that it was not too big (close) and not too small (far). If it is within the limits, the robot is driven forward full speed (1.0), and with a turn rate determined by the **`center_mass_x_normalized`** value of the particle analysis report.

The **`center_mass_x_normalized`** value is 0.0 if the object is in the center of the frame; otherwise it varies between -1.0 and 1.0 depending on how far off to the sides it is. That is the same range as the Drive method uses for the turn value. If the robot is correcting in the wrong direction then simply negate the turn value.

Example 4: Two Color Tracking

An example of tracking a two color target is in the demo project TwoColorTrackDemo. The file Target.cpp in this project provides an API for searching for this type of target. The example below first creates tracking data:

```
while (IsAutonomous())
{
   if ( FindColor(IMAQ_HSL, &greenHue, &greenSat, &greenLum, &par)
      && par.particleToImagePercent < MAX_PARTICLE_TO_IMAGE_PERCENT
      && par.particleToImagePercent > MIN_PARTICLE_TO_IMAGE_PERCENT )
   {
      myRobot->Drive(1.0, (float)par.center_mass_x_normalized);
   }
   else myRobot->Drive(0.0, 0.0);
   Wait(0.05);
}
myRobot->Drive(0.0, 0.0);
```

Example 42: Autonomous color tracking and driving the robot towards the target.

```
   // PINK
         sprintf (td1.name, "PINK");
         td1.hue.minValue = 220;
         td1.hue.maxValue = 255;
         td1.saturation.minValue = 75;
         td1.saturation.maxValue = 255;
         td1.luminance.minValue = 85;
         td1.luminance.maxValue = 255;
   // GREEN
         sprintf (td2.name, "GREEN");
         td2.hue.minValue = 55;
         td2.hue.maxValue = 125;
         td2.saturation.minValue = 58;
         td2.saturation.maxValue = 255;
         td2.luminance.minValue = 92;
         td2.luminance.maxValue = 255;
```

Example 43: Typical color values for the green and pink targets.

Call FindTwoColors() with the two sets of tracking data and an orientation (ABOVE, BELOW, RIGHT, LEFT) to obtain two ParticleAnalysisReports which have details of a two-color target.

Note: The FindTwoColors API code is in the demo project, not in the WPILib project

```
// find a two color target
if (FindTwoColors(td1, td2, ABOVE, &par1, &par) {
  // Average the two particle centers to get center x & y of combined
target
   horizontalDestination = (par1.center_mass_x_normalized +
                  par2.center_mass_x_normalized) / 2;
   verticalDestination = (par1.center_mass_y_normalized +
                      par2.center_mass_y_normalized) / 2;
{
```

Example 44: Finding a 2 color target.

To obtain the center of the combined target, average the x and y values. As before, use the normalized values to work within a range of -1.0 to +1.0. Use the *center_mass_x* and *center_mass_y* values if the exact pixel position is desired.

Several parameters for adjusting the search criteria are provided in the Target.h header file (again, provided in the TwoColorTrackDemo project, not WPILib). The initial settings for all of these parameters are very open to maximize target recognition. Depending on your test results you may want to adjust these, but remember that the lighting conditions at the event may give different results. These parameters include:

- **FRC_MINIMUM_PIXELS_FOR_TARGET** – (default 5) Make this larger to prevent extra processing of very small targets.
- **FRC_ALIGNMENT_SCALE** – (default 3.0) scaling factor to determine alignment. To ensure one target is exactly above the other, use a smaller number. However, light shining directly on the target causes significant variation, so this parameter is best left fairly high.
- **FRC_MAX_IMAGE_SEPARATION** (default 20) Number of pixels that can exist separating the two colors. Best number varies with image resolution. It would normally be very low but is set to a higher number to allow for glare or incomplete recognition of the color.
- **FRC_SIZE_FACTOR** (default 3) Size difference between the two particles. With this setting, one particle can be three times the size of the other.
- **FRC_MAX_HITS** (default 10) Number of particles of each color to analyze. Normally the target would be found in the first (largest) particles. Reduce this to increase performance, Increase it to maximize the chance of detecting a target on the other side of the field.
- **FRC_COLOR_TO_IMAGE_PERCENT** (default 0.001) One color particle must be at least this percent of the image.

Smart Dashboard

The Smart Dashboard is a program with library additions display robot data on a connected laptop in real time as the values change. There are two parts to the Smart Dashboard:

1. The library additions that send data updates using the log methods of the Smart Dashboard object (available in C++ and Java).
2. The Smart Dashboard viewer that runs on your driver station or dashboard computer that gets receives the data value updates and displays them along with the data value name.

WPILib SmartDashboard class

The SmartDashboard class has a very simple interface – it provides a number of logging methods for sending data of various types from the robot program to the dashboard program. The logging methods each take a data value name used to identify the data value and the value itself. There is no need to set up anything in advance, just start using the logging methods the same as you would print values to the console.

SmartDashboard data viewer

The data viewer program receives updates as data is logged on the robot program and displays the most recent value for the data. Each time a previously unseen data value is received, a new display object is created on the screen and the value is shown. As new values are received, the corresponding data values are updated. The layout of the data values in the SmartDashboard viewer is automatic, but you can customize it by dragging the display widgets anywhere in the window. You can then save the layout and reload it again later to get the same layout back again.

The SmartDashboard viewer is an open source project and is written entirely in Java making the viewer portable and able to run on Windows, Mac OS X or Linux.

Currently there are a few different display types available with more on the way. Each type of display object has a set of properties that can be modified by right-clicking on the object and setting the appropriate values for the properties listed. In addition there is a display object for the camera data stream generated by the PC video server on the cRIO. This can be positioned anywhere on the screen along with the other data value display elements.

Sample Program

```
package edu.wpi.first.wpilibj.templates;

import edu.wpi.first.wpilibj.DriverStation;
import edu.wpi.first.wpilibj.RobotDrive;
import edu.wpi.first.wpilibj.SimpleRobot;
import edu.wpi.first.wpilibj.SmartDashboard;
import edu.wpi.first.wpilibj.Timer;

public class SampleDashboard extends SimpleRobot {

    RobotDrive drive = new RobotDrive(1, 2);
    int status = SmartDashboard.log("Program starting up", "Status");

    public SampleDashboard() {
        logStuff();
    }

    public void autonomous() {
        drive.setSafetyEnabled(false);
        for (int i = 0; i < 10; i++) {
            SmartDashboard.log(i + " through the loop", "Status");
            logStuff();
            drive.drive(1, 0);
            Timer.delay(4);
            drive.drive(0, 0);
            Timer.delay(2);
        }
    }

    public void operatorControl() {
        while (isOperatorControl() && isEnabled())
            logStuff();
    }

    private void logStuff() {
        DriverStation ds = DriverStation.getInstance();
        SmartDashboard.log(ds.getPacketNumber(), "Packet number");
        SmartDashboard.log(ds.getBatteryVoltage(), "Battery voltage");
        SmartDashboard.log(ds.getLocation(), "Location");
        SmartDashboard.log(ds.getAlliance().value, "Alliance");
    }
}
```

Example 45: Sample Java program that uses the SmartDashboard class for logging various robot values while the program is running.