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# Rolling Thunder

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# Rolling Thunder

**SUN Labs**

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A Major Qualifying Project

Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

In conjunction with SUN Microsystems

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

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Date: January16, 2009 Project Number: SMJ A081

Approved:

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Professor Susan Jarvis, Major Advisor

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Mr. Derek White, SUN Labs Liaison

*This report represents the work done at Sun Microsystems by our team (WPI undergraduate students) and Derek White (Staff Engineer at Sun Labs) submitted to the faculty as an evidence of a completion of a degree requirement.*

## Rolling Thunder Team

The contributions of each one of the members was required in order to complete this project. The amount of effort imparted into this project was equal from each one of the team members. This has been a great team and we are grateful for the opportunity to collaborate with Sun Microsystems, FIRST and Worcester Polytechnic Institute.

# Abstract

The purpose of this Major Qualifying Project is to assist SUN Microsystems with their current research project, called Rolling Thunder. The aim of this project is to integrate a JAVA platform inside an embedded control platform, the CompactRIO, which will be used as a robot controller in the next FIRST Robotic Competition. The CompactRIO, or CRIO, is a control/acquisition system containing a real-time processor that allows for rapid software development and an FPGA chip that can be programmed by the user for different applications. The main objective of the project is to be able to deploy a JAVA virtual machine, called Squawk, onto the CRIO, and use it to access the CRIO’s various peripherals including sensors, servos and actuators.

# Acknowledgements

We would like to extend our gratitude to the great team that made our Major Qualifying Project a positive and meaningful experience.

Professor Susan Jarvis, our advisor who gave us moral support and guidance throughout the project. Our weekly meetings with her led to great team organization and communication. Her contributions to this project led us to deliver an excellent and concise final presentation and written document.

Mr. Derek White, our Sun Liaison who introduced us to Sun Microsystems, The Squawk Project and our project objectives. Derek White has been the person that made this MQP possible in seven weeks. He helped us to understand the Squawk virtual machine and the defaults of its current stage, guided us in our daily work and pointed us in the correct direction to successfully accomplish our task.

Brad Miller, the Associate Director for the Robotics Resource Center at Worcester Polytechnic Institute, who assisted us with information regarding WPILib directions and supplied us hardware. Brad Miller provided us the CRIO system on which we implemented the Java virtual machine, helped us with the test and analysis of our test robot and arranged our final meeting with FIRST where we presented our final results.

Sun Microsystems, our corporate sponsor who in collaboration with Worcester polytechnic Institute gave us the opportunity to complete this project and provided us with the resources necessary.

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# 1. Introduction

The evolution of robotics has rapidly progressed to the point where "our robot creations are evolving similar to how life in earth evolved" [1]. Through robotics, engineers and scientist interested in mechanics, software and electronics get the chance to bring to the professional world their curiosities, making it the spark of science. Inspiring high school students in science and technology has been a common goal between schools and companies. This goal has been furthered by developing robotics competitions where the knowledge of those high school students in fields like software programming, electronics and mechanics is challenged.

FIRST, For Inspiration and Recognition of Science and Technology, is an association that was founded in 1989 by Dean Kamen, the inventor of the Segway Personal Transporter. The mission of FIRST is "to inspire young people to be science and technology leaders, by engaging them in exciting mentor-based programs that build science, engineering and technology skills, that inspire innovation, and that foster well-rounded life capabilities including self-confidence, communication, and leadership" [2]. Each year, the FIRST association organizes a robotic competition in which teams of high school students from around the world are challenged to develop robots which performs specific tasks. The teams are advised and mentored by professional engineers and institutions which sponsor them through these competitions. The Massachusetts Academy of Math Science and Worcester Polytechnic Institute are two institutions that in unison sponsor the FIRST team 190. This team is known for having some of the most innovative ideas in the league. Including students from MASS Academy, WPI and other regional high schools, this team is active all year offering over fifty demonstrations and hosting four tournaments every year [3].

FIRST has decided to use an acquisition and control platform called CompactRIO (CRIO) as its next-generation FIRST Robotics Competition (FRC) controller. This control platform will be used to program the target robot giving the students access to advanced control capabilities and superior performance [4]. Since the competition's rule is to build and program a robot in a time frame of six weeks using a standard "kit of parts", the students use a general purpose programming language which is suitable for rapidly developing application software. Historically, C has been the most common language used by FIRST participants. "C is a general purpose programming language which features economy of expression, modern control flow and data structures, and a rich set of operators" [5]. However as more powerful languages derivates of C have develop, FIRST directors are interested in providing the students with the possibility of using a simpler, more versatile, and more powerful language that is also a better match for the computer science curriculum in high schools. The Java programming language was an obvious candidate for this approach. Features of the Java programming language such as its virtual machine controlled environment, wide standard library and applications would be of great use when programming FRC robots [6].

Therefore, with the goal of making a transition from the C programming language to Java, Sun Microsystems, the developers of the Java programming language, sponsored and guided this Major Qualifying Project. To enable this transition for FIRST, our team wrote a code framework for the CRIO in the Java programming language. In order to use the Java programming language on the CRIO to control the target robot, a Java virtual machine, called Squawk, had to be ported. "Squawk is an open source research virtual machine for the Java language that examines better ways of building virtual machines"[7]. It is the virtual machine that will run the compiled Java code on the target robot.

During the seven weeks of research and work towards this project, our team received much guidance from the Squawk Project team members at Sun. This guidance helped us to further understand the functionalities of the Squawk virtual machine and the default behavior of its current stage. In the same manner, the WPI robotics resource center provided us the hardware required for this project and assisted us in the test and analysis of the Java implementation in the CRIO. Further explanations of how the Squawk Virtual Machine was ported to the CRIO and implementation details of how our team accomplished this goal are enclosed in this document.

# 2. Project Background

Sun Microsystems is a company that drives network participation through shared innovation, community development and open source leadership [7]. Since 1982 Sun has been providing a diversity of software, systems, services, and microelectronics that power everything from consumer electronics, to developer tools and the world's most powerful datacenters. One of Sun's core brands is the Java technology platform which is widely used in embedded devices, mobile phones and web servers. Since 1995 the Java technology revolution has been enabling developers to write applications once to run in any computer [8]. Subsequently the great success obtained by the Java platform consisting of three major parts: the Java programming language, the Java Virtual Machine (JVM), and several Java Application Programming Interfaces (APIs) induced Sun to license Java technology to all major hardware and software companies. For instance software operating systems like Microsoft Windows, Linux and Solaris use the Java Standard Edition platform for their implementations [9].

To foster the growth of Java, Sun Microsystems, a technology powerhouse, regularly provides students with resources like open source software, the Solaris platform, training and internships that help them to advance in their careers. Through Worcester Polytechnic Institute, Sun Microsystems this year (2008) sponsored and guided several Major Qualifying Project including our team. The purpose of the MQP is to combine the previous studies of each one of the team members, in order to solve problems or perform tasks similar to those encountered in professional life [12]. Our team consisting of Electrical and Computer Engineers students, had the opportunity to collaborate with Sun in their goal of making the transition from the C programming language to Java, helping those students in the FIRST Robotics Competition (FRC).

After the decision by FIRST to use the CompactRIO as their embedded control platform for the coming FRC, our team began researching and organizing our strategies to implement the Java programming language in the CRIO.  The National Instruments CRIO, is an advanced embedded control and data acquisition system designed for applications that require high performance and reliability. It combines an embedded real-time processor, a high-performance FPGA, and hot-swappable I/O modules.

The CRIO can be adapted to solve a wide variety of industry and application challenges. With its features such as its low cost and reliability, as well as with its suitability for real time embedded measurement and control application, the CRIO will give the students the opportunity to access advanced control capabilities and reach superior performance [4].

In order to start this project, the initial goals required to implement the Java programming language in the CRIO were determined by our Sun liaison. In the table below we show the list of the initial goals and further in section 6 we detail each goal and what changes were made through the project.

| |
|---|
| **Initial Steps** |
| Build Squawk on Windows |
| Native Windows Squawk |
| Report Issues |
| Install (VxWorks Workbench, WPIlib) on Windows |
| Discuss with Brad Miller (VxWorks Workbench, WPIlib, CRIO, Robots) |
| Get CRIO board (power and test) |
| Build and Run "Hello! World" program on CRIO |
| |
| **Squawk Running on CRIO** |
| How to compile Squawk with VxWorks/gcc compilers |
| Squawk build system should do a VxWorks build for CRIO |
| How to deploy Squawk code to CRIO, using FTP to CRIO file system |
| Run basic Squawk system in CRIO |
| |
| **Design Initial Robot APIs** |
| Review WPILib and SPOT documentation for basic APIS working with sensors, servos... |
| Propose Initial API to support in Java |
| Obtain feedback from SPOT team and Brad Miller |
| |
| **Implement Initial Robot APIs** |
| Look at Squawk FFI code  to call out C code from Java |
| Look at WPILib source that implements functionality |
| Either call out to WPILib functions or re-implement in Java |
| Generator  Script for FPGA package classes |
| |
| **Test** |
| Write simulation programs for the APIs |
| Write program for robot to do: control motors, react to sensor data, react to remote control |
| Get external tester |
| Hook up to real robot chassis and terrorize Sun Microsystems halls |
| |
| **Polish** |
| Make build and deployment scripts simple to use (preferably in Ant) |
| Create installation procedure |
| Document (Install, Build and Deployment) steps |
| Document new APIs |
| Clean example code |
| Publish source code, binaries, documents, examples, forums and wiki on java.net |
| Write and Present Project |

**Table 1: Rolling Thunder Initial Goals**

# 3. CompactRIO Overview

The FIRST Robotics Competition (FRC) plans to use a control/data acquisition system, called CompactRIO (CRIO), for its next generation competitions. The CRIO was created by National Instruments, a company which has been a major sponsoring body of the FRC providing funding for its creation and success. By supporting the students who are interested in technology and engineering, National Instrument hopes to help raise a future generation of engineers [4].

The control/data acquisition system, CRIO, is currently programmed using LabView, which is a data acquisition platform and development environment, or C programming language. The CRIO has a 400 MHz PowerPC processor power, 64MB of DRAM, and 128MB of non-volatile flash memory. It is relatively easy to program as the code can be debugged remotely from a workstation. Additionally it contains an industrial 400 MHz Freescale MPC5200 processor that executes the LabVIEW Real-Time applications using the Wind River VxWorks real-time operating system. It also has an FPGA programmable logic device that permits the implementation of custom timing, triggering, synchronization, control, and signal processing for the analog and digital I/O [4].

In order to provide a wireless networking configuration, an IEEE 802.11 ethernet bridge is available. The CRIO is also designed in such a way that it has a flexible input and output, with plug-ins for various sensors and I/O lines. “Digital sidecars”, which connect the digital I/O module in the CRIO, are also there to link the CRIO to devices like motor controllers that can be incorporated. In the same manner a driver station, which is the device that collects the position of Human Interface Devices (joysticks, switches, game pads, etc.) and sends them to the robot controller, can be connected to the CRIO. This connection provide the user with a control interface that has ethernet ports for a router, USB ports for joystick devices, and an LCD display. Furthermore the CRIO contains integrated plug-in and controller modules inside a metal chassis, which can be divided into three categories: the analog input module, the digital I/O module and the solenoid module.

## 3.1 Analog Input Module:

The analog bumper is the interface that plugs in to the Analog Input Module to provide analog inputs for the sensors. It is powered by a 12V input and 1A 5V switching power supply. The analog input module has 8 channels and a 12-bit resolution and accepts a +/- 10V input range. (*See Figure-1*).

## 3.2 Digital I/O Module:

The digital module has 32 channels of general purpose digital I/O. It operates on a 5V transistor logic level and can take up to 1A of current. A 37-pin connector contains all the I/O of the digital I/O module. (*See Figure-2*).

## 3.3 Solenoid Module:

The solenoid module contains eight 1A 12V solenoid outputs. A pneumatic bumper plugs into it making it able to control devices such as solenoids and pneumatics. It takes 12V and has two pin outputs.

**Figure-1: Analog Input Module and Bumper**
http://first.wpi.edu/FRC/analog.html

**Figure-2: Digital I/O Module**
http://first.wpi.edu/FRC/digital.html

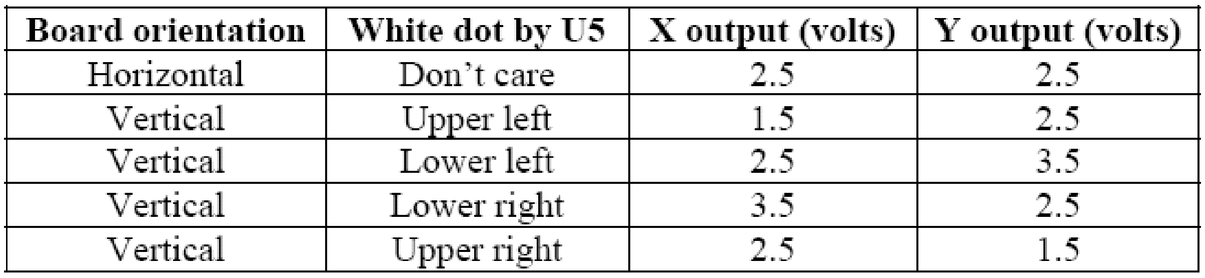
With the CRIO, the students will have the ability to build more advanced robots than previous FIRST controllers. They will have more control and be able to perform a large variety of autonomous tasks. Currently, the CRIO can only be programmed in C, C++, and LabVIEW. While the latter is particularly helpful to professionals, because it gives hardware simulation capabilities and has useful tools for debugging, it is not often a good match to the programming skills of high school students.

# 4. The CompactRIO Sensors

The CRIO that was used in the recent First Robotic Competition of 2008 came with several sensors. Three important sensors worth noting are: the dual-axis accelerometer, the yaw rate gyro, and the peak-detecting gear-tooth sensor. These sensors in particular are necessary to implement basic robotic motion control.

## 4.1 Dual-Axis Accelerometer:

The DAA measures static motion (i.e. gravity) and dynamic motion (i.e. vibration), providing 2-axis information. This sensor is used by robots in order to measure their acceleration by converting the mechanical motion into a relative electrical signal that can be used to control their velocity. The accelerometer is connected to two analog inputs in order to measure the acceleration in both the X-axis and Y-axis. This device draws approximately 3mA of current and has a resolution of 1,000 mV/g when fed with a 5V supply. (*See Figure-3*).



| Board orientation | White dot by U5 | X output (volts) | Y output (volts) |
|---|---|---|---|
| Horizontal | Don't care | 2.5 | 2.5 |
| Vertical | Upper left | 1.5 | 2.5 |
| Vertical | Lower left | 2.5 | 3.5 |
| Vertical | Lower right | 3.5 | 2.5 |
| Vertical | Upper right | 2.5 | 1.5 |

**Table-2: Dual Axis Accelerometer Table**
http://www.usfirst.org/uploadedFiles/Community/FRC/FRC_Documents_and_Updates/2008_Assets/Manual/2008_Sensor_Manual.pdf

## 4.2 Yaw Rate Gyro (GYRO)

Applications that have a gyro sensor typically use this device to detect rotation and return a value in degrees per second of rotation. The yaw rate gyro detects angular changes in the device it is attached to.  This device is usually mounted on the robot’s frame and has a driver that is programmed to resist any sudden changes in direction. Its function is mainly that of stabilizing the robot while it's being operated. The angle is measured from the top surface axis of the device when it is stable. A voltage is produced by the YRG that is proportional to the change in angular rate. This output can be used to control the robot platform and stabilize it. It operates under a 5V supply and is connected to two analog inputs in the robot. The sensor generates two outputs. The T output provides the “rotational velocity” and is measured in millivolts per degrees per second of rotation. The R output gives the relative temperature in millivolts per degree Kelvin (s*ee Figure-4*).

## 4.3 The Differential Peak-Detecting Gear Tooth Sensor

The gear tooth sensor is very important because it allows a direct calculation of the speed of the robot as it moves. This IC uses 12 DC volts and draws about 16mA in order to calculate and control the robot speed. When each ferrous tooth passes through the sensor, a pulse is generated and the sensor outputs a Pulse-Width Modulation signal with a distinct duty cycle, which is the ratio between the pulse duration and the pulse period. The speed of the robot can then be calculated and the result can be output through a port to the CRIO controller (s*ee Figure-5*).

Figure-3: Dual Axis Accelerometer
*http://www.usfirst.org/uploadedFiles/Community/FRC/FRC_Documents_and_Updates/2008_Assets/Manual/2008_Sensor_Manual.pdf*

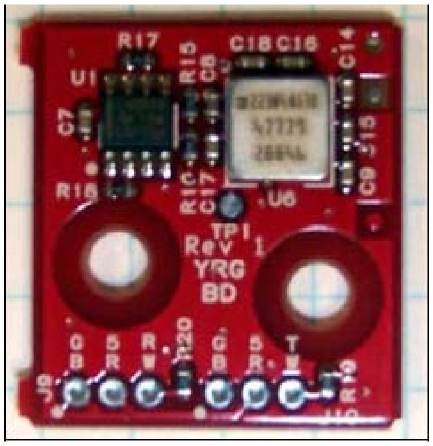


Figure-4: Yaw Rate Gyro
*http://www.usfirst.org/uploadedFiles/Community/FRC/FRC_Documents_and_Updates/2008_Assets/Manual/2008_Sensor_Manual.pdf*

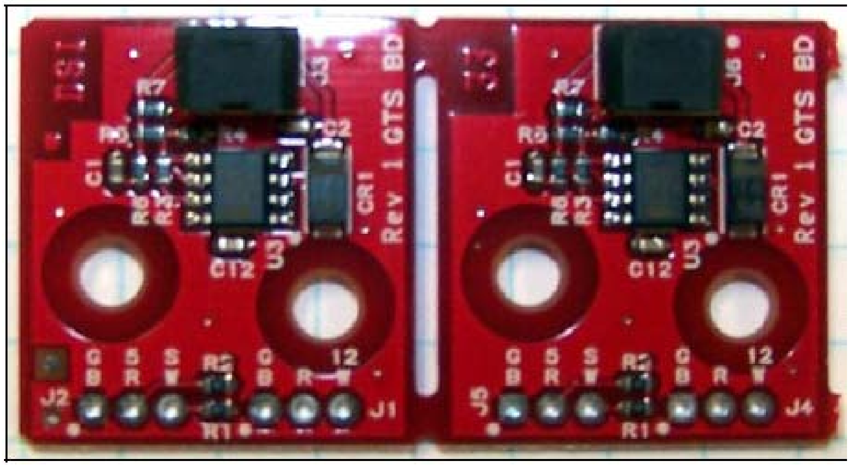


Figure-5: The Differential Peak- Detecting Gear Tooth Sensor
*http://www.usfirst.org/uploadedFiles/Community/FRC/FRC_Documents_and_Updates/2008_Assets/Manual/2008_Sensor_Manual.pdf*

# 5. Squawk

Sun Microsystems virtual machine, Squawk, is an open source virtual machine written in Java language for embedded systems and small devices. With its core mostly written in Java, Squawk provides ease of portability and seamless integration of virtual machine and application resources. As part of an ongoing research on Sun Microsystems Laboratories, Project Squawk's goals are to write as much of the virtual machine (VM) in Java as possible (Figure 6), targeting small resource constrained devices and enable Java for micro-embedded development.

In order to accomplish our task of implementing Java on the CRIO we made use of the Squawk virtual machine. It was an intriguing challenge at first while we tried to understand the Squawk architecture and its implementation. The Squawk architecture is mostly implemented in the language that it executes (Java). As illustrated in *Figure-6: the Standard Java Virtual Machine vs. the Squawk Virtual Machine* the objective behind the Squawk VM is to create a sufficiently small VM that can be store in embedded devices permitting faster start up time for the embedded application. This objective is to be accomplished by having a compact byte code instruction set, suites (collection of classes), a split VM architecture, isolates (mechanism by which an application is represented as an object) and several VM components.

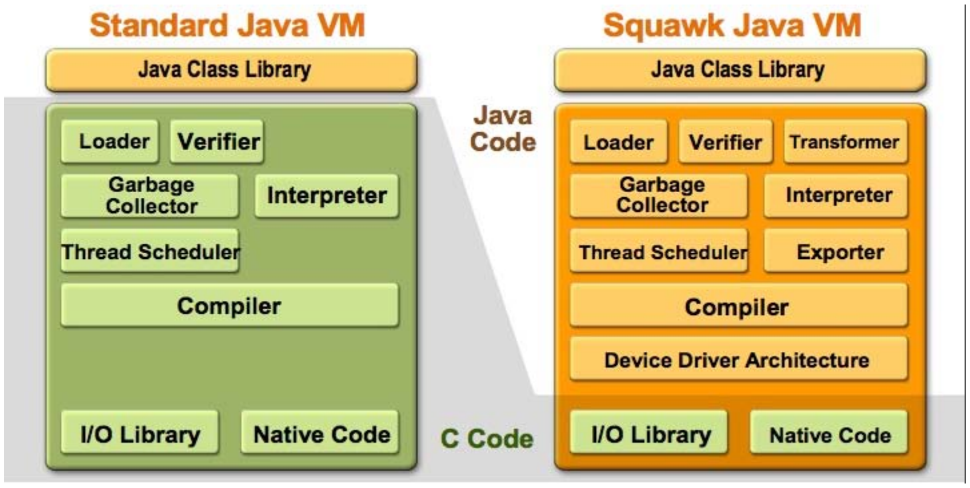


**Figure-6: the Standard Java Virtual Machine vs. the Squawk Virtual Machine**
http://research.sun.com/projects/squawk/

As we began porting the Squawk VM on the CRIO, we discovered that porting Squawk into a different platform had several difficulties which we later detail in our "*Porting Squawk to CRIO*" section. Through the solution of those difficulties and the completion of this project, our team served as a major contributor to the Project Squawk and their ongoing research.

# 6. WPILib

## 6.1 The Library

WPILib is a framework for programming FRC Robots which highly simplifies the programming task for the FRC teams. By using the WPILib the FIRST teams obtain support for common devices such as gyros, accelerometers and optical encoders and have the possibility of extending the framework with drivers of their own creation without modifying any program that uses WPILib. The WPILib framework is available for free to all FIRST teams and can be easily downloaded.

Another advantage to using WPILib is that it does not require the user to generate of all the complex math and calculations involved in devices like wheel encoders. This default code can be called whenever the user needs to access any of the peripherals or devices through simple function calls with variables that are passed as arguments. Additionally, WPILib is portable, meaning that it can be used on many controllers without the need to make any changes to it. It is compatible with FRC controllers that were used in the 2005 and 2006 competitions, as well as other controllers like the VEX, Robovation, or the CRIO. WPILib is structured so that it is modular, and therefore any type of devices can be added to it without modifying the existent source code. Additional advantages that the library gives are its simplicity and its extensibility. As complex as robotic may seem, any inexperienced user can program his/her robot by simply calling the desired modules which are are already programmed and this manipulating simple variables like direction, angle, or speed for instance and passing them through function calls as parameters. One last benefit that the library has is its broad-spectrum of capabilities. It contains all the common devices that one would see in a typical robots; things like gyros, encoders, counters, accelerometers, and cameras. All of these modules have their drivers written in separate classes so that the user can request them at his or her convenience.

Currently, the students participating in the competitions have a graphical development environment called easyC that they use in order to program the robots in C code and through which all of the WPILib classes are linked. For our project, we made use of the WPILib framework for the implementation of our robot. However, since we needed to program the CRIO in Java, we proceeded to translating and implementing the code of the library from C++ to Java. Further details of this implementation can be found in our "*WPILib Implementation*" section.

## 6.2 Architecture

The CRIO contains two microcontrollers. The first is basically a read-only device, and it stores the code written by FIRST that runs when the user program is linked to the manual controller. This master microcontroller deals mainly with communication issues with the CRIO and controls the main motors when not operated by the user interface. For example, it makes sure that all the motors are running at start-up and are disabled when the reset switch is triggered.

The second microcontroller is a user processor that processes the code that is implemented by the student programmers. It is connected to the master processor via a serial bus so that the speed of the motors is communicated from the user processor through the PWM outputs to the master processor periodically, at very short intervals. Also, information about the state of all the IO ports is transmitted but this time from the master processor back to the user processor in order for the user to have enough information to program the output port properly.

The architecture of the WPILib library can be broken down into several layers:

- **IFI base code** – the code developed by FIRST that runs on the master processor at startup.
- **WPILib timer and interrupt handling** – drivers in the library that handle complex functions for things such as timers for the controller and the interrupt service routine.
- **WPILib device drivers** - the classes mentioned above, containing code for important device drivers. A list of some of these drivers is presented below.
- **User written drivers** - files added by the user to control new devices and modules added to the robot.
- **User applications –** the program written by the user in order to run the robot and make it perform desired tasks.

The order of these four layers matches the order with which each one is executed by the master and user processor after the programs are compiled and linked to the CRIO.

## 6.3 Common devices included in WPILib

A list of common devices enclosed in the library is shown below:

**Gear Tooth Sensor –** Refer to “The CompactRIO Sensors” section of the report.

**Ultrasonic Rangefinder –** Made of two transducers, a speaker that sends ultrasonic pings and a microphone that received the echoed ping. The driver measures the time it takes for the ping to travel from the transmitter to the receiver and converts this to distance (in different units).

**Accelerometer** - Refer to “The CompactRIO Sensors” section of the report.

**Gyro** - Refer to “The CompactRIO Sensors” section of the report.

**Compass** – a device that returns a measurement in degrees, from 0 to 360°. It helps navigate the robot by showing the direction that it's facing with a magnetic field sensor that can detect the Earth's magnetic field.

**Compressor and Pressure Switch –** The pressure switch is connected to the pressure side of the circuit designed for the pneumatics and controls the pressure of the system through a polling algorithm. When this one is low, the switch is closed and a relay port is turned on indicating the state of the system pressure.

**Camera** – this device is initialized with the necessary parameters to indicate what object is to be tracked. It's then used to track this object down as it moved by following it and returning data packets showing its position and size.

**Encoders –** These devices measures the rotation of the shafts that are spinning when the robot is moving. Usually, these devices are called when the distance the robot travels need to be calculated. The device measures the number of rotations of the shafts to calculate the distance that the wheels have traveled. This distance is then divided by the period to give us the speed.

In conclusion, WPILib will be used as a backbone to our project. The different drivers mentioned above will be used, but this time, some of them will be rewritten in Java so that our end product is a system that is mostly written in the Java language. In the next section, a detailed report of all the steps that have been taken to complete the project are listed and explained. In this section, the reader will learn how we have designed the robot APIs to support Java and how these were implemented.

# 7. Design Implementation

In order to assure an organized and concise implementation of tasks, at the beginning of our project we developed a design approach implementation plan. The design implementation plan was a compilation of the initial goals specified by our sponsor liaison, the requirements specified by our advisor and the team's personal objectives.

Our first steps towards this plan were to analyze the initial goals specified by our sponsor liaison (*See Table-2)* and to make a SourceForge account. SourceForge is a source code repository where large amount of source code can be kept. In our SourceForge account we kept track of the project goals, saved the project documents and created a wiki (a collection of webpages) with resources used during the project implementation. As we started implementing our project tasks and subsequently populating our SourceForge account, we realized that some of the initial goals specified by our sponsor liasion either needed to be modified or were not going to be possible to accomplish. Within the limited time frame of the project, alternative approaches sometimes permitted us to save time and deliver a better result. For instance, for the goals specified in Initial Steps in *Table-2*, we decided to eliminate the Native Windows Squawk goal, which consisted in making Squawk run on windows without using another JVM as a proxy for network and file I/O, due to its complexity and lack of specific value towards the end product of this project. For the Implement Initial Robot APIs section, we couldn't accomplish the Generator Script for FPGA package classes goal due to time constraint. In the same manner for the Polish section we couldn't accomplish the following goals: publish source code, binaries, documents, examples, forums and wiki on java.net and make build and deployment scripts simple to use (preferably in Ant) due to time constraints.

| |
|---|
| **Initial Steps** |
| Build Squawk on Windows |
| Native Windows Squawk |
| Report Issues |
| Install (VxWorks Workbench, WPIlib) on Windows |
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| Review WPILib and SPOT documentation for basic APIS working with sensors, servos... |
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| Document (Install, Build and Deployment) steps |
| Document new APIs |
| Clean example code |
| Publish source code, binaries, documents, examples, forums and wiki on java.net |
| Write and Present Project |

**Table 3: Rolling Thunder Initial Goals**

After we realized what goals were going to be accomplish under our time constraint and capabilities we created *Table-3*. In *Table-3* we documented the alternatives, like the order of implementation, and the additional steps that were required to deliver a better result.

Besides the project initial goals specified by our sponsor liaison we also had to achieve our advisor's requirements, which assured the successful completion of this Major Qualifying Project. Our advisor's requirements included: weekly meetings, where revisions and final documentations of the project needed to be made.  These requirements were added to our design implementation plan and managed trough our SourceForge account. During the weekly meeting held by our advisor we discussed the current state of the project and the team perspectives, toward the project, sponsor liaison and each team member. In the same manner a revision of the project documentation was sent by e-mail to the advisor and the team members; this was followed by feedback that help us towards the completion of this document.

Finally our design approach was complete after the team personal objectives were included. Our team objectives consisted in permanent communication, active and positive collaboration and consistent focus on final goals. To assure that these objectives were met, we: maintained consistent meetings with our sponsor liaison, scheduled lunch meetings for the team members outside of the work environment, discussed topics or addressed questions related to the project as a group exercise towards the end of the week and avoided project work during weekends. The structure of our design approach implementation plan was respected and followed by each one of the team members. Accordingly our project had a successful outcome representing a positive experience for each one of the team members.

| |
|---|
| **Initial Steps** |
| Build Squawk on Windows |
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| **Squawk Running on CRIO** |
| How to compile Squawk with VxWorks/gcc compilers |
| Squawk build system should do a VxWorks build for CRIO |
| 1. Add VxWorks compiler |
| 2. Fix VxWorks Platform Specifics |
| How to deploy Squawk code to CRIO, using FTP to CRIO file system |
| 1. Using WindRiver Workbench |
| 2. Via FTP |
| Run basic Squawk system in CRIO |
| |
| **Design Initial Robot APIs** |
| Obtain feedback from SPOT team and Brad Miller |
| Propose Initial API to support in Java |
| 1. Verbatim copy from C++ code |
| Review WPILib and SPOT documentation for basic APIS working with sensors, servos... |
| |
| **Implement Initial Robot APIs** |
| Port WPILib |
| Look at Squawk FFI code to call out C code from Java |
| Update WPILIbJ code to match WPILibC code |
| ChipObject Java Components |
| |
| **Test** |
| Get external tester |
| Get SimpleRobot to Run |
| Get InteractiveRobot to run |
| Write simulation programs for the APIs |
| Write program for robot to do: control motors, react to sensor data, react to remote control |
| Hook up to real robot chassis and terrorize Sun Microsystems halls |
| |
| **Polish** |
| Clean example code |
| Create installation procedure |
| Document new APIs |
| OTA Deployment |
| Document (Install, Build and Deployment) steps |
| Write and Present Project |

**Table 4: Rolling Thunder Revised Goals**

## 7.1 Goals

Understanding the concepts of each goal was the most important part of our design implementation plan. This guaranteed a correct implementation and helped us when explaining to others the detailed purpose of our project.

The Initial Step section of our goals table 3 was summarized into: *Run Java Connected Limited Device (CLDC) and Information Module Profile (IMP) on CRIO.* Through this goal we provided Java 2 Platform Mobile Edition application environment for the CRIO, which is a device that does not provide rich graphical display capabilities and is limited in other ways. Subsequently we summarized the other sections of our goals table into: *Port WPILib into Java*, *Obtain access to sensors and servos*, *Remote Debugging of Java code* and *OTA deployment* and *Documentation*.

*Port WPILib into Java*, purpose was to translate the C++ WPILib code into Java code. For this goal we copied the code of the WPILib classes without changes and followed by correcting problems encountered, such as the concept of pointers in Java and C++.

*Obtain access to sensors and servos*, consisted on writing some test code and was accomplished after we port Squawk on the CRIO and fixed some WPIlib functions.

*Remote Debugging of Java code* and *OTA deployment* consisted on writing test code for our target robot and was accomplished when we could command the robot wireless.

*Documentation*, consisted on documenting our research and implementation procedures during this project. This final goal was accomplished after the completion of this document and the presentation given to Sun Microsystems, in their location at Burlington, MA and FIRST, in their headquarters at Manchester, NH.

# 8. Implementing WPILib

In order to ease the startup time for FIRST robot development, WPI provides a library of common robot features, dubbed WPILib.  This library, written in C++, consists of two key sections.  First, WPILib contains a set of classes representing the base functionality of a robot for a FIRST competition.  These classes provide the interface with the competition field controllers, which indicate to the robot whether it should be disabled, running autonomously, or running with team control.  Second, the library provides a suite of classes for common devices attached to a robot.  These devices include servos, analog and digital sensors, such as potentiometers and switches, and motors.  With these components provided, teams are not required to reproduce the common code that controls these devices, allowing them more time to write the code for their robot's functionality.

Following the same methodology, we wanted to provide an equivalent library of common code in Java, which we call WPILibJ (appending the 'J' for Java).  In order to simplify the C++ to Java transition, we opted to exactly mirror the class structure.  This means that all of our library's classes, and the functions they provide, have exactly the same names and parameters as the functions in the C++ library.  The justification for this decision was two-fold: first, teams using the C++ version of WPILib can switch to Java with almost no changes to their code; and second, our team was able to simplify development of our new library.

The actual implementation process was simple, yet time consuming.  Since C++ and Java have a similar syntax, the majority of the code could be copied without changes.  Our choice of common function names simplified matters further: we were relieved of the task of renaming the functions that the existing C++ code called after we copied it. The copied code provided the skeleton for our updated code, requiring only minor changes, instead of a full rewrite. With nearly 10,000 lines of code, this was an immense time saver. *Table-4* contains the full list of converted classes and their individual line counts.

| **Class Name** | **Line Count** | **Class Name** | **Line Count** |
|---|---|---|---|
| Accelerometer | 91 | HiTechnicCompass | 60 |
| AnalogChannel | 190 | I2C | 134 |
| AnalogModule | 452 | ICounter | 74 |
| AnalogTrigger | 144 | InterruptableSensorBase | 69 |
| AnalogTriggerOutput | 113 | IterativeRobot | 283 |
| communication/FRCControl | 61 | Jaguar | 66 |
| communication/FRCControlData | 146 | Joystick | 224 |
| Compressor | 126 | Module | 26 |
| Counter | 350 | Notifiable | 5 |
| DigitalInput | 148 | Notifier | 225 |
| DigitalModule | 266 | PID | 93 |
| DigitalOutput | 75 | PIDController | 219 |
| DigitalSource | 16 | PIDOutput | 10 |
| DriverStation | 325 | PIDSource | 10 |
| Encoder | 189 | PWM | 261 |
| fpga/tAI | 258 | Relay | 148 |
| fpga/tAlarm | 56 | Resource | 102 |
| fpga/tAnalogTrigger | 163 | RobotBase | 116 |
| fpga/tCounter | 350 | RobotDrive | 382 |
| fpga/tDIO | 382 | SensorBase | 221 |
| fpga/tDMA | 307 | Servo | 108 |
| fpga/tDMAChannelDescriptor | 23 | SimpleRobot | 83 |
| fpga/tDMAManager | 59 | Solenoid | 88 |
| fpga/tEncoder | 285 | SpeedController | 7 |
| fpga/tGlobal | 71 | tests/AITest | 25 |
| fpga/tInterrupt | 132 | tests/DIOTest | 109 |
| fpga/tInterruptHandler | 6 | tests/JoyTest | 69 |
| fpga/tInterruptManager | 63 | tests/RobotTest | 50 |
| fpga/tSolenoid | 43 | Timer | 127 |
| fpga/tSPI | 337 | TimerEventHandler | 6 |
| fpga/tSystem | 57 | Ultrasonic | 246 |
| fpga/tWatchdog | 135 | util/UncleanStatusException | 35 |
| GearTooth | 89 | Utility | 43 |
| GenericHID | 52 | Victor | 83 |
| Gyro | 128 | Watchdog | 128 |
| **Total** | | | **9623** |

**Table 5: WPILibJ Captions and Line Counts**

## 8.1 Implementation Challenges

Our implementation of the WPILibJ code was not without its difficulties. Although Java and C++ share syntax, they vary greatly in semantics. A key omission from Java is the concept of a pointer. Both C++ and Java create instances of classes by allocating a block of data on the heap, though they differ in how that instance is accessed. In C++, this data is always in the same location in memory, so a pointer containing the address of the data is used. In Java, the garbage collector is free to move the object around to optimize memory, and is accessed with an equivalent object that hides this relocation. Also of note is that C++ allows pointers to the primitive data types, such as integers and doubles, whereas Java does not.

The complication here was caused by the original C++ code which made extensive use of pointers. We had to track down each of these pointers and replace them with the appropriate Java code. For usages within the code, there was usually a way to simply remove the pointer concept and use the objects directly. More complex was the use of pointers as function parameters. A major reason for this in C++ is to allow a function to modify the values of its parameters, especially if it needs to return multiple values (for instance, a string and its length). Java has no support for this feature, greatly complicating the conversion from C++.

The other major impediment was the Chip Object classes used in C++. These classes represented external devices that were implemented using LabView. Only the interfaces to these classes were available to us, so our first attempt at dealing with these was to use Java Native Access (JNA) code to directly call the C++ functions. Initially, this seemed to work fine. We were able to call the constructor of a class, and access some static functions it exposed. This model was shattered once we tried to use instance functions. Without an easy way to use classes in the JNA code, we were simply treating the pointer to the class instance we received from the

C++ code as an integer.  This was fine for referencing the instance itself, but was unsuited for calling instance functions.  C++ uses a different mechanism for calling instance functions than we expected.  We believed that the C++ compiler would rewrite the function call so that a hidden first parameter would be the instance of the class on which the function was invoked. Unfortunately, this was not the case; we were unable to determine the correct calling convention, and were forced to try an alternate solution.

The solution we decided on worked, if inelegantly.  Since we were unable to call instance functions from JNA, and could not use the functions directly, we needed an interoperability layer.  Our choice for this was C code: C functions are easily callable from JNA and can be made to work with C++ classes.  Before the arduous process of creating a "glue" layer, we coded a few of the functions we expected to need as a trial.  We created a wrapper for the constructor, returning an integer to represent the new instance, and created a mirror of the function we wanted to access in C using the calling convention we described above (passing the class object as the first parameter to the function).  The C function is responsible for converting the variable types and rewriting the calling convention to match C++.  Our JNA code then invokes the C function in the standard fashion.  Our first attempts worked correctly, meaning we could continue making our glue layer.  For 17 different classes with several functions each, doing this by hand would be a waste of our time.  We opted to optimize the process by creating a PHP script that could read the C++ class interfaces and generate the matching C and Java code (see Appendix 1 for the script).

*Techno-babble:  Our C functions are technically not C functions.  In actuality, they are C++ functions that have been declared with extern "C", making them accessible from pure C code.  Although we didn't need pure C code to call them, this simplified access from our JNA calls.*

# 9. Porting Squawk to the CRIO

Porting Squawk to the CRIO was the primary objective of this project. As the implementation progressed, VxWorks, the operating system of the CRIO, presented increasingly complicated problems. Beginning this task, we knew that VxWorks is POSIX compliant, and Squawk had existing, though limited, support for POSIX systems.

VxWorks is a real-time operating system designed for use in embedded systems. For this project, we used VxWorks version 5.5. For development, we used the Wind River Workbench, which is built on the Eclipse IDE for portability. Most VxWorks programs are developed in C++, which is not supported in Eclipse, hence the need for Wind River Workbench.

VxWorks complies with the POSIX (Portable Operating System Interface) standards produced by IEEE and recognized by ISO and ANSI. These standards are used in order to define a common Application Programming Interface (API) for any operating system. Since 1988, POSIX, also known as IEEE 1003, standards have been representing the Single UNIX Specification group of standards for computer operating systems. POSIX compliance generally simplifies the task of porting applications to other platforms, since covered functionality can be assumed to be equivalent. For example, the POSIX standards cover memory allocation, time functions, and multi-threading (although other techniques exist).

GCC, the GNU Compiler Collection, is a set of compilers for various programming languages. GCC is commonly used as the standard compiler for all UNIX-like operating systems. The GCC tool chain also includes utilities, such as GDB, the GNU Debugger, and cross-compilers. GCC is also the name used for the GNU C Compiler. Although GCC is typically intended to compile an application for the same platform as the one hosting the tools, our variant would also build applications for VxWorks under a Windows or UNIX host.

The first step was to build Squawk natively on Windows. Accordingly to the instructions on the java.net (Sun Microsystems) webpage, we proceeded by first installing the specific software needed, continued by getting Squawk and building it on Windows.

## 9.1 Building Squawk on Windows

Before we could build Squawk on Windows, we needed several tools to be installed. First, we needed a Subversion client, in order to retrieve the Squawk source from the repository. The recommended client for Windows is TortoiseSVN, which is both freely available and well supported. We also needed to install a version of Microsoft Visual C++. Visual C++ is an IDE provided by Microsoft for the development of Windows applications. We had several choices for the version we would install: Microsoft Visual Studio 2005 (or later), Microsoft Visual C++ 2005 (or later), or Microsoft Visual C++ 2005 Express Edition (or later). The only parts of Visual C++ required were the compilers and the header files, so the free Express Edition was sufficient. Finally, we needed a version of the Java 2 Standard Edition Development Kit 5.0. The Java Runtime Environment (JRE) was required to run the build tools provided with Squawk, which are written in Java, while the Java Development Kit (JDK) was required to compile the Java portions of Squawk. One vital note here is that the JDK must be version 5.0; 1.4 and earlier, or 6.0 and later, do not work (which we learned from experience).

After the installation of the software required, we could begin building the Windows version of Squawk. There are actually two versions of Squawk for Windows: a “hosted” version, which uses the existing JRE as a proxy for file and network operations, and a “native” version, which is responsible for its own. Native Squawk on Windows was incomplete, and it was decided that our effort was better utilized elsewhere. We were able to build the hosted version easily, following the directions provided on java.net. We used the hosted version of Squawk for Windows throughout the project.

## 9.2 Moving to the CRIO

Beginning the development for the CRIO was less complicated. The only software we needed to add was the Wind River Workbench, which provided the compilers we would use. Continuing from here, the development process should have been simple: add information to the Squawk builder for VxWorks, compile the code, and run. Unfortunately, the process was not nearly this easy.

The first obstacle to implementation was the Squawk builder. In order to compile for VxWorks, we needed to make changes to the builder. Some research into the builder revealed that we would need to add two classes: a Platform class, providing the paths to the tools and information about file formats (such as the executable extension), and a Compiler class, containing the specific instructions to compile the code. These classes were a simple addition; from here, things became more complex. We needed a way to hijack the platform detection code to force a build for VxWorks. The builder normally detects the host operating system and compiles for the same platform; we added a command line option to build for VxWorks. In order to save a step in the build process, we also specified that VxWorks uses a big endian file format (the default is little endian).

With the updates to the Squawk builder, we moved on to the compilation step. We expected this process to have several errors, indicating which files would need updates for

VxWorks. With the expectation of failure, we initiated the build, and were stunned at the result. Instead of the few errors we were expecting, the build process failed on the first step; GCC had failed to locate any of the header files for the POSIX-compliant functions. At this point, we very nearly panicked. The missing headers included the one for memory allocation, and without that, it would be nearly impossible to get Squawk working. The solution (and the cause) was simple: VxWorks may provide POSIX-compliant functions, but its authors had no desire to follow the naming conventions for the header files. As a result, we spent multiple days locating the correct header files for functions that should have existed elsewhere.

With the missing header files resolved, we attempted the build again, which, again, failed. This time, we were missing functions entirely. Some of these were hidden away in different headers, some were just unavailable, and some were, considerately, defined in header files and never implemented, making them useless. In the first case, we had to track down more rogue header files. In the second and third, we had to implement these functions by hand, typically using VxWorks specific functions. These took nearly as long to resolve as the missing headers, despite being far fewer. With these fixed, we could try the build again.

This time, much to our surprise, the build succeeded. From here, we took the executable and the Squawk libraries and deployed them to the CRIO. Using the Wind River Workbench, we were able to launch Squawk on the CRIO. Rather miraculously, the code ran, so we attempted the built-in test suite for Squawk. This required a small change to our startup code, and after recompiling, nothing was working anymore. We spent two days stepping through lines of code in the debugger looking for the source of the problem. We finally discovered the source, which was a common beginner mistake: there was a pointer to uninitialized memory in the code we had written. After that was corrected, we successfully ran the Squawk test suite.

# 10. Test and Analysis

After we ported Squawk to the CRIO and had a fully functioning JVM to execute our Java code, the next step was to carry out a set of tests in order to make sure that the CRIO was working harmoniously with our new WPILibJ. Since we didn't have a robot at the time we reached this step in our project, we borrowed a digital sidecar from Professor Brad Miller. With our limited knowledge of its interface, we opted to perform some basic tests with this hardware alone. We wanted to reduce the glitches before we had access to an actual robot from the Robotics department at WPI. The digital sidecar had several capabilities that allowed us to test parts of our code. For example, it had general purpose I/O pins that we could program using the *DigitalModule* class from WPILib. In the same way, we were able to control other peripherals like the Pulse Width Modulator (PWM) and relay pins, as we will explain later.

Since we were lacking actual robot hardware, we combined a servo from Professor Miller and a few Lego bricks that belonged to Derek White's son. We assembled this handful of parts into a makeshift test apparatus. We attached a motor to one of the relay ports, a push-button to a digital input port, and a servo to one of the PWM ports.

After we set up the hardware, we created a test framework in C++ containing a set of tests on the C++ implementation of WPILib. These tests allowed us to see how the classes in the library interacted with each other, since the C++ library was already functional. This gave us the baseline results which we would later compare to our Java library tests. In *Appendix 2-1* we have attached the C++ code that we wrote in order to test some of the functionalities that WPILib provided.

The C++ tests for the WPILib functionalities showed that our digital I/O and relay pins were working, but our PWM pins (and the attached servo) were not. To make the PWM work, we had to disable both the system timer and user Watchdog timers. These timers are generally used to halt the system when no driver station is connected to the CRIO. This would not be a problem in a real robot, because the driver station would be provided. We instantiated a servo object in our test code and called the appropriate functions to rotate our servo from one side (0°) to the opposite (180°). The code for our servo tests is included in *Appendix 2-2.*

In our servo test code we first, tested to see what would happen if we set the angle to a value above the maximum angle or below the minimum one with two new methods, ServoTest_MoveAboveMax(void) and ServoTest_MoveBelowMin(void). After that, the angle was set to the middle position with the function ServoTest_MoveMid(void). We found a bug in WPILib here. The servos were only programmed to move either to the maximum or to the minimum angle. We modified the library and test it again. This enabled our mid-range test to pass.

After gathering results from our C++ tests, the test suite was re-implemented in Java and, excitingly, our results were the same. In addition to all these tests, the analog input module was tested to make sure that the Java Analog Module class was also working. The code we wrote for this purpose is contained in *Appendix 2-3*.

Our test simply creates an analog module and reads the voltage on channel 1. We simulated an actual input by attaching a spare line from our power supply. We ran this test, and the same voltage appeared in the console output. This was the only hardware change we made; the digital sidecar and its associated test hardware remained exactly the same as with the C++

test code attached in *Appendix 2-4*. The code checked operation of the digital I/O pins by toggling pin one and reading it from pin two (an external wire connected these). We monitored the output pin with an oscilloscope as well, partially for visual confirmation and partially to verify that the code wasn’t caching the input values.

# 11. Suggestions

Since our project has been an innovation of the Java language in the CRIO platform, many challenges were encounter with unknown solutions. As we worked on this project we collected a set of solutions for these problems that subsequently became suggestions for future developers.

Our first suggestion is to implement the Java debugger on the CRIO platform. After translating the C++ code into Java, we obtained an enormous amount of code with several errors. Due to the fact that we didn’t have the Java debugger implemented locally on the CRIO we had to use numerous System.out.println() calls to implement debugging print-outs, which was very time consuming. Another suggestion that ties along to this problem is the need to improve WPILib. Translating the C++ code in the WPILib to Java was one of our hardest tasks. The reason was WPILib lack of flexibility for translation. Finally in order to save time and assure efficiency the Java programs should be run at startup instead of having to use WindRiver to start Java. Using the WindRiver interface to start Java creates unnecessary delay in the process.

## Conclusion

Over the course of this project, we gained a considerable amount of knowledge about Java and its virtual machine Squawk, the acquisition and control system CRIO, interfacing to the hardware components provided (oscilloscope, digital sidecar, driver station, joystick, wireless routers, etc.) and using multiple software applications. By the end of the seven week period that we had to complete our Major Qualifying Project, we were able to implement a fully functioning robot that was completely programmed in Java. This accomplishment is likely to have a large influence on the FIRST robotic competitions starting from 2010. The organization seemed very interested in our end product after a meeting we held with several of its members in Manchester, New Hampshire in October 2008. The impression at the end of the meeting was that FIRST was interested in possibly making a shift from C++ to Java for their 2010 competitions. With this movement, the high school students who learn Java in their computer science curriculum will have a chance to expand their programming skills even further outside of their classes and use them in debugging and building a more versatile and easier to control robot. With a simpler and more user-friendly environment like Squawk, the students' interest in such a youth-serving organization like FIRST might increase, especially for those who could be held back because of their lack of knowledge in C++.

In fact, the satisfaction we felt after observing our test robot perform simple test programs that we wrote could not be described. A dusty FIRST robot from the 2005 FRC was taken from one of the corners in the Robotics laboratory of WPI and reanimated in Java. We exhausted virtually all the possible tasks it could perform through Java test functions that we created to make sure it was operational. We made its arm move from the bottom up and rotated it shoulders using a “voodoo arm” that was attached to the driver station. We also made it move in all possible directions thanks to its omni-directional wheels using a joystick that was part of the driver station.  The whole floor shook in excitement at the sight of the WPI 2k5 running in Java. The joy of seeing this baby run down the floor and terrorize everybody near it was shared by all team members.

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# Appendixes

# Appendix 1: PHP Code for ChipObject Generator

### File One of Three: “genchipwrapper.php”

```php
<?php

// TODO: Should probably allow these as command line parameters
$CODIR = './ChipObject/';
$WRAPDIR = './';
$JAVADIR = './fpga/';

define('DEBUG', false);
define('VERBOSE', false);

function debugprint($str) {
    if(DEBUG) echo "$str";
}

function verboseprint($str) {
    if(VERBOSE) echo "$str";
}

// Useful string helpers:
function strstart($str, $start) {
    return substr($str, 0, strlen($start)) == $start;
}

function strend($str, $end) {
    return substr($str, -strlen($end)) == $end;
}

// Constants (using them as enums)
define('VIS_PUBLIC', 1);
define('VIS_PROTECTED', 2);
define('VIS_PRIVATE', 3);

// being lazy:
function visibility() {
    global $visibility; // Never mind that $visibility isn't defined until later.
    switch($visibility) {
        case VIS_PUBLIC: return 'public';
        case VIS_PROTECTED: return 'protected';
        case VIS_PRIVATE: return 'private';
    }
}

function FixNITypes($string) {
    $niTypes = array(
        'tNIRIO_i64' => 'long',
        'tNIRIO_i32' => 'int',
        'tNIRIO_i16' => 'short',
        'NIRIO_i8' => 'char',
        'tNIRIO_u64' => 'unsigned long',
        'tNIRIO_u32' => 'unsigned int',
        'tNIRIO_u16' => 'unsigned short',
        'tNIRIO_u8' => 'unsigned char',
    );

    return str_replace(array_keys($niTypes), array_values($niTypes),
$string);
}

function CParamAction($param) {
    global $pparams, $cparams, $longhandler, $paramname;
    if($pparams != '')
        $pparams .= ', ';
    if($cparams != '')
        $cparams .= ', ';

    verboseprint("For parameter $param:\n");

    $valid = true;
    $status = false;
    $cast = '';

    $words = split(' ', $param);
    for($w = 0; $w < count($words) - 1; $w++) {
        switch($words[$w]) {
            case 'const':
            case 'unsigned':
            case 'signed':
            case 'char':
            case 'short':
            case 'int':
            case 'float':
            case 'bool':
                $cast .= $words[$w] . ' ';
                verboseprint("Appending {$words[$w]} to cast\n");
                break;
            case 'long':
                if($words[$w+1] == 'long') {
                    $longhandler = true;
                    $cast .= 'long long ';
                    $w++;
                } else {
                    $cast .= 'long ';
                }
                break;
            case 'tRioStatusCode':
                $status = true;
                verboseprint("This is the status parameter.\n");
                break;
            default:
                $valid = false;
                $cast .= $words[$w] . ' ';
                print("Error parsing parameter: Unknown keyword
'{$words[$w]}'\n");
                break;
        }
    }

    $cast = trim($cast);
    $paramname = $status ? 'status' : $words[count($words) - 1];
    if(strstart($paramname, '*')) {          // Special case for pointers
        $paramname = substr($paramname, 1);
        $cast .= '*';
    } elseif(strstart($paramname, '&')) {    // Special case for references
        $paramname = substr($paramname, 1);
    }

    if($longhandler) {
        $pparams .= "int {$paramname}_MSW, int {$paramname}_LSW";
        $cparams .= $paramname;
    } else {
        $pparams .= ($status ? 'int* ' : 'int ') . $paramname;
        $cparams .= ($cast == '' ? '' : "($cast)") . $paramname;
    }

    return $valid;
}

function JParamAction($param) {
    global $pparams, $cparams, $longhandler, $paramname, $paramcount;
    verboseprint("For parameter $param:\n");

    $valid = true;
    $status = false;
    $cast = '';

    $words = split(' ', $param);
    for($w = 0; $w < count($words) - 1; $w++) {
        switch($words[$w]) {
            case 'const':
                $words[$w] = 'final';
                break;
            case 'unsigned':
            case 'signed':
                if($w < count($words) - 2) {
                    verboseprint("Removing unneeded '{$words[$w]}'\n");
                    $words[$w] = '';
                    break;
                } else {
                    $words[$w] = 'int';
                }
                // NOTE: Intended fallthrough here.
            case 'short':
            case 'int':
            case 'float':
                verboseprint("Type {$words[$w]} okay as-is\n");
                break;
            case 'bool':
                $words[$w] = 'boolean';
                verboseprint("Fix bool to boolean\n");
                break;
            case 'char':
                $words[$w] = 'byte';
```

```
                    verboseprint("Fix char to byte\n");
                    break;
                case 'long':
                    if($words[$w+1] == 'long') {
                        $words[$w+1] = '';
                        $longhandler = true;
                        $w++;
                    } else {
                        $words[$w] = 'int';
                    }
                    break;
                case 'tRioStatusCode':
                    $status = true;
                    verboseprint("This is the status parameter.\n");
                    return true;
                default:
                    $valid = false;
                    print("Error parsing parameter: Unknown keyword
'{$words[$w]}'\n");
                    break;
            }
        }

        if($pparams != '')
            $pparams .= ', ';
        if($cparams != '')
            $cparams .= ', ';

        $paramcount++;

        // Test:
        $paramname = $words[count($words) - 1];

        $paramtype = implode(' ', array_slice(array_filter($words), 0, -1)); // join
the parts of the array that aren't the parameter name (there should only be one, I think.)

        if(strstart($paramname, '*')) {           // Special case for pointers
            $paramname = substr($paramname, 1);
            // TODO: Need to handle this probably
        } elseif(strstart($paramname, '&')) {     // Special case for references
            $paramname = substr($paramname, 1);
        }

        $pparams .= "{$paramtype} {$paramname}";
        if($longhandler) {
            $cparams .= "{$paramname}_MSW, {$paramname}_LSW";
            $paramcount++;
        } elseif($paramtype == 'float') {
            $cparams .= "Float.floatToIntBits({$paramname})";
        } elseif($paramtype == 'boolean') {
            $cparams .= "{$paramname} ? 1 : 0";
        } else {
            $cparams .= $paramname;
        }

        return $valid;
    }
```

```
// Step 0: Setup:
if(!strend($CODIR, '/') && !strend($CODIR, '\\'))
    $CODIR .= '/';
if(!is_dir($CODIR))
    die("Can't read sources from {$CODIR}: No directory with this name
exists.");

if(!strend($WRAPDIR, '/') && !strend($WRAPDIR, '\\'))
    $WRAPDIR .= '/';
if(!file_exists($WRAPDIR))
    mkdir($WRAPDIR);
elseif(!is_dir($WRAPDIR))
    die("Can't put generated C objects in {$WRAPDIR}: There is a file with
this name, but it is not a directory.");

if(!strend($JAVADIR, '/') && !strend($JAVADIR, '\\'))
    $JAVADIR .= '/';
if(!file_exists($JAVADIR))
    mkdir($JAVADIR);
elseif(!is_dir($JAVADIR))
    die("Can't put generated Java objects in {$JAVADIR}: There is a file with
this name, but it is not a directory.");

// Step 1: Get the listing of C++ Header Files
echo "I'm going to read in the available ChipObject C++ classes.\n";
echo "I'll assume they live in ./ChipObject/\n";

$dir = dir('ChipObject');
$files = array();

while(($file = $dir->read()) !== false) {
    debugprint("Examining file {$file}");
    // tSystem is special.  Skip it.
    if(is_file($CODIR . $file) && strstart($file, 't') && strend($file, '.h')
&& $file != 'tSystem.h') {
        $files[] = $file;
        debugprint(" - valid!\n");
    } else {
        debugprint(" - not valid.\n");
    }
}

echo "Okay, I have your list.  I found " . count($files) . " files that look
like proper C++ headers.\n";

foreach($files as $file) {
    // Step 2: Extract class name, full namespace, constructor, methods (and visibility)
    echo "==========================================\n";
    echo "Analyzing $file...\n";

    $fp = fopen($CODIR . $file, 'r');
    $classname = substr($file, 0, -2);

    $linenum = 1;  // Mostly for debugging and/or errors
    // Things to load from the parsing nightmare loop
    $namespace = '';
    $visibility = VIS_PUBLIC;
    $ctors = array();
    $protos = array(); // like public void DoSomething(int param1, char* param2);
    $vars = array(); // like public static const char kNumSystems;
    $supressingBlock = 0;

    while(!feof($fp)) {
        $line = trim(fgets($fp)); // I don't care about whitespace here.

        if($supressingBlock > 0 && strstart($line, '}')) {
            $supressingBlock--;
        }

        // COMMENTS
        if(strstart($line, '//')) {
            verboseprint("Line $linenum is a comment -- skipping\n");
        } elseif(strstart($line, '/*')) {
            verboseprint("Line $linenum is a block comment -- skipping\n");
        // PREPROCESSOR INSTRUCTIONS
        } elseif(strstart($line, '#include')) {
            verboseprint("Line $linenum is an include -- skipping\n");
        } elseif(strstart($line, '#define')) {
            verboseprint("Line $linenum is a macro definition -- do I need
this?\n");
        } elseif(strstart($line, '#if') || strstart($line, '#endif')) {
            verboseprint("Line $linenum is a conditional compilation line --
skipping\n");
        // NAMESPACES
        } elseif(strstart($line, 'namespace')) {
            verboseprint("Line $linenum is a namespace directive -- recording
namespace\n");
            if($namespace != '')
                $namespace .= '::';
            $namespace .= substr($line, 10);
        // WHITESPACE
        } elseif($line == '') {
            verboseprint("Line $linenum is blank\n");
        // BLOCKS
        } elseif(strstart($line, '{')) {
            verboseprint("Line $linenum begins a block\n");
        } elseif(strstart($line, '}')) {
            verboseprint("Line $linenum ends a block\n");
        } elseif(strstart($line, 'class')) {
            // TODO: need to figure out base classes.
            verboseprint("Line $linenum is the class definition.\n");
        } elseif(strstart($line, 'union')) {
            verboseprint("Line $linenum begins a union -- I'm going to skip
over this.\n");
            $supressingBlock++;
        } elseif(strstart($line, 'struct')) {
            verboseprint("Line $linenum begins a struct -- I'm going to skip
over this.\n");
            $supressingBlock++;
        } elseif(strstart($line, 'typedef')) {
            verboseprint("Line $linenum begins a typedef -- I'm not going to
copy this for you.\n");
        // VISIBILITY
        } elseif(strstart($line, 'public:') && !$supressingBlock) {
            verboseprint("Line $linenum -- switching visibility to
PUBLIC\n");
            $visibility = VIS_PUBLIC;
        } elseif(strstart($line, 'protected:') && !$supressingBlock) {
            verboseprint("Line $linenum -- switching visibility to
PROTECTED\n");
            $visibility = VIS_PROTECTED;
        } elseif(strstart($line, 'private:') && !$supressingBlock) {
            verboseprint("Line $linenum -- switching visibility to
PRIVATE\n");
            $visibility = VIS_PRIVATE;
        // FUNCTIONS
        } elseif (strend($line, ');') && !$supressingBlock) {
            if(strstart($line, "$classname(")) {
                verboseprint("Line $linenum declares a constructor.\n");
                $ctors[] = visibility() . ' ' . $line;
            } elseif($line == "~$classname();") {
                verboseprint("Line $linenum declares the destructor.\n");
            } else {
                verboseprint("Line $linenum declares a function.\n");
                $protos[] = visibility() . ' ' . $line;
            }
        // VARIABLES
        } elseif(strend($line, '[];') && !$supressingBlock) {
            verboseprint("Line $linenum declares an array -- I'm going to
skip this.\n");
            //$vars[] = visibility() . ' ' . $line;
        } elseif(strend($line, ';') && !$supressingBlock) {
            verboseprint("Line $linenum declares a variable.\n");
            $vars[] = visibility() . ' ' . $line;
        // DEFAULT
        } else {
            if(!$supressingBlock)
                print("Error parsing $file:$linenum: $line\n");
        }

        $linenum++;
    }

    debugprint("Okay, I've determined that I'm looking at
$namespace::$classname, \n");
    debugprint("which contains " . count($ctors) . " constructors, ");
    debugprint(count($protos) . " functions, and " . count($vars) . "
variables\n");

    fclose($fp);

// Step 3: Produce the C wrapper file (classname.c) > classname_method(int parameters) { invoke with real parameters }

require('gencwrapper.inc.php');

// Step 4: Produce the Java peer class (classname.java) > class containing methods with java-ized real parameters

require('genjwrapper.inc.php');

}
```

```
echo "==========================================\n";
echo "I'm done processing your files.  I mirrored " . count($files) . " files
for you:\n";
echo "You can find the C wrappers in $WRAPDIR\n";
echo "You can find the Java peers in $JAVADIR\n";

?>
```

## File Two of Three: “gencwrapper.inc.php”

```
<?php
    $header = <<<EOF
// This file is auto-generated.  DO NOT EDIT!

#include "ChipObject/{$file}"

typedef {$namespace}::{$classname} {$classname};

#ifdef __cplusplus
extern "C" {
#endif


EOF;

    $trailer = <<<EOF
#ifdef __cplusplus
}
#endif

EOF;

    echo "-------------------------------------------\n";
    echo "Generating wrapper code for $classname\n";
    $fp = fopen($WRAPDIR . $classname . '.cpp', 'w');

    fputs($fp, $header);

    foreach($vars as $var) {
        $var = FixNITypes($var);
        $words = explode(' ', trim($var, ';'));
        $varname = $words[count($words)-1];
        if($words[0] == 'private') {
            verboseprint("Skipping private variable $varname\n");
            continue;
        }

        for($w = 1; $w < count($words) - 1; $w++) {
            if($words[$w] == 'static' || $words[$w] == 'const')
                $words[$w] = '';
        }

        $words[0] = '';
        $words[count($words)-1] = "{$classname}_{$varname}";
        $newvar = trim(implode(' ', $words));

        fputs($fp, "$newvar = {$classname}::{$varname};\r\n");
    }

    fputs($fp, "\r\n");

    foreach($ctors as $ctor) {
        $ctor = FixNITypes($ctor);
        $count = count($ctors) > 1 ? count($ctors) : '';
        $paramStart = strpos($ctor, '(') + 1;
        $paramEnd = strrpos($ctor, ')');
        $paramPart = substr($ctor, $paramStart, $paramEnd - $paramStart);

        verboseprint("Constructor arguments: $paramPart\n");

        $params = split(', ', $paramPart);
        $pparams = '';
        $cparams = '';

        $longhelpers = array();

        foreach($params as $p) {
            $longhandler = false;

            CParamAction($p);

            if($longhandler)
                $longhelpers[] = $paramname;
        }

        $fnproto = "int {$classname}_Constructor{$count}($pparams) {\r\n";
        foreach($longhelpers as $lh) {
            $fnproto .= "\tlong long {$lh} = (((long long){$lh}_MSW) << 32) |
({$lh}_LSW);\r\n";
        }
        $fnproto .= "\treturn (int)(new
{$classname}($cparams));\r\n}\r\n\r\n";

        fputs($fp, $fnproto);
    }

    $fnproto = <<<EOF
void {$classname}_Destructor(int instance) {
    delete (({$classname}*)instance);
}


EOF;

    fputs($fp, $fnproto);

    foreach($protos as $proto) {
        $returntype = '';
        $longreturn = false;
        $fnname = '';
        $static = false;
        $valid = true;

        $args = '';

        $proto = FixNITypes($proto);
        $words = explode(' ', $proto);

        for($i = 0; $i < count($words); $i++) {
            if(($argstart = strpos($words[$i], '(')) !== false) {
                $fnname = substr($words[$i], 0, $argstart);
                $words[$i] = substr($words[$i], $argstart);
                $args = implode(' ', array_slice($words, $i));
                break;
            }
            switch($words[$i]) {
                case 'private':
                    verboseprint("Private function. I should probably skip
this.\n");
                    break;
                case 'public':
                case 'protected':
                    verboseprint("Visibility: {$words[$i]}.\n");
                    break;
                case 'signed':
                case 'unsigned':
                    if(!in_array($words[$i+1], array('char', 'short', 'int',
'long', 'float'))) {
                        $words[$i] = int;
                        $i--; // HACK: rather than do something intelligent here, we just back up so we
re-process the word.
                    } else {
                        verboseprint("Function is explicitly {$words[$i]} --
not important.\n");
                    }
                    break;
                case 'const':
                    verboseprint("Function doesn't modify the instance -- not
important.\n");
                    break;
                case 'static':
                    verboseprint("Function is static.\n");
                    $static = true;
                    break;
                case 'char':
                case 'short':
                case 'int':
                case 'float':
                case 'void':
                case 'bool':
                    $returntype = $words[$i];
                    verboseprint("Function return type: $returntype\n");
                    break;
                case 'long':
                    if($words[$i+1] == 'long') {
                        $longreturn = true;
                        $returntype = 'long long';
                        $i++;
                    } else {
                        $returntype = 'long';
                    }
                    verboseprint("Function return type: $returntype\n");
                    break;
                default:
                    $valid = false;
                    print("Parsing error for Function:\n");
                    print("$proto\n");
                    print("Unrecognized symbol {$words[$i]}.  I'll keep going
and ignore the error.\n");
            }
        }

        if($words[0] == 'private')
        {
            verboseprint("Skipping private function {$fnname}\n");
            continue;
        }

        $params = split(', ', trim($args, '();'));
        $pparams = $static ? '' : 'int instance';
        $cparams = '';

        $longhelpers = array();

        foreach($params as $p) {
            $longhandler = false;

            $valid &= CParamAction($p);

            if($longhandler)
                $longhelpers[] = $paramname;
        }

        $fnproto = $valid ? '' : "/* -- Error durring parsing --\r\n";

        if($longreturn) {
            $fnproto .= "long long _{$classname}_{$fnname}_lastValue =
0;\r\n";
        }

        if($returntype == 'void')
            $fnproto .= 'void';
        else
            $fnproto .= 'int';

        $fnproto .= " {$classname}_{$fnname}($pparams) {\r\n";
        foreach($longhelpers as $lh) {
            $fnproto .= "\tlong long {$lh} = (((long long){$lh}_MSW) << 32) |
({$lh}_LSW);\r\n";
        }
        if($longreturn) {
            $fnproto .= <<<EOF
    _{$classname}_{$fnname}_lastValue = (({$classname}*)instance)-
>{$fnname}($cparams);
```

```
    return (0xFFFFFFFF & _{$classname}_{$fnname}_lastValue);
}
int {$classname}_{$fnname}_MSW() {
    return (0xFFFFFFFF & (_{$classname}_{$fnname}_lastValue >> 32));
}
EOF;
        } else {
            $fnproto .= "\t";
            if($returntype != 'void')
                $fnproto .= 'return ';

            if($static)
                $fnproto .= "{$classname}::{$fnname}($cparams)";
            else
                $fnproto .= "(({$classname}*)instance)->{$fnname}($cparams)";

            if($returntype == 'bool')
                $fnproto .= ' ? 1 : 0';
            $fnproto .= ";\r\n}";
        }

        $fnproto .= ($valid ? '' : "\r\n*/") . "\r\n\r\n";

        fputs($fp, $fnproto);
    }

    fputs($fp, $trailer);
    fclose($fp);
?>
```

### File Three of Three: “genjwrapper.inc.php”

```
<?php
    $header = <<<EOF
// This file is auto-generated.  DO NOT EDIT!

package edu.wpi.first.wpilibj.fpga;

import com.sun.cldc.jna.*;

public class {$classname} extends tSystem {

EOF;

    $trailer = <<<EOF
}

EOF;

    echo "-------------------------------------------\n";
    echo "Generating Java peer class for $classname\n";
    $fp = fopen($JAVADIR . $classname . '.java', 'w');

    fputs($fp, $header);
```

```
foreach($vars as $var) {
    $var = FixNITypes($var);
    $words = explode(' ', trim($var, ';'));
    $varname = $words[count($words)-1];
    $varsize = 1;
    $sizefn = 'Int';

    if($words[0] == 'private') {
        verboseprint("Skipping private variable $varname\n");
        continue;
    }

    for($w = 1; $w < count($words) - 1; $w++) {
        switch($words[$w]) {
            case 'const':
                $words[$w] = 'final';
                break;
            case 'bool':
                $words[$w] = 'boolean';
                $sizefn = 'Byte';
                break;
            case 'char':
                $words[$w] = 'byte';
                $sizefn = 'Byte';
                break;
            case 'unsigned':
            case 'signed':
                if($w < count($words) - 2) {
                    $words[$w] = '';
                } else {
                    $words[$w] = 'int';
                }
                break;
            case 'long':
                if($words[$w+1] == 'long') {
                    $words[$w+1] = '';
                    $w++;
                    $varsize = 2;
                    $sizefn = 'Long';
                } else {
                    $words[$w] = 'int';
                }
                break;
            case 'float':
                $sizefn = 'Float';
                break;
            case 'short':
                $sizefn = 'Short';
                break;
        }
    }

    $words[count($words)-1] = '';

    $vartype = implode(' ', array_filter($words));
```

```
        fputs($fp, "\t$vartype $varname = 
VarPointer.lookup(\"{$classname}_{$varname}\", 
{$varsize}).get{$sizefn}(0);\r\n");
    }

    fputs($fp, "\r\n");

    foreach($ctors as $ctor) {
        $ctor = FixNITypes($ctor);
        $count = count($ctors) > 1 ? count($ctors) : '';
        $paramStart = strpos($ctor, '(') + 1;
        $paramEnd = strrpos($ctor, ')');
        $paramPart = substr($ctor, $paramStart, $paramEnd - $paramStart);

        verboseprint("Constructor arguments: $paramPart\n");

        $params = split(', ', $paramPart);
        $pparams = '';
        $cparams = '';
        $paramcount = 1; // status

        $longhelpers = array();

        foreach($params as $p) {
            $longhandler = false;

            JParamAction($p);

            if($longhandler)
                $longhelpers[] = $paramname;
        }

        if($cparams != '')
            $cparams .= ', ';
        $cparams .= 'pStatus.getPointer()';

        $fnproto = <<<EOF
    private static final Function ctor{$count}Fn = 
Function.getFunction("{$classname}_Constructor{$count}");
    public {$classname}({$pparams}) {

EOF;
        foreach($longhelpers as $lh) {
            $fnproto .= <<<EOF
        int {$lh}_MSW = (int)(0xFFFFFFFF & ({$lh} >> 32));
        int {$lh}_LSW = (int)(0xFFFFFFFF & ({$lh});

EOF;
        }
        $fnproto .= <<<EOF
        thisC = ctor{$count}Fn.call{$paramcount}({$cparams});
        assertCleanStatus("{$classname}");
    }


EOF;
```

```
        fputs($fp, $fnproto);
    }

    $fnproto = <<<EOF
    private static final Function deleteFn =
Function.getFunction("{$classname}_Destructor");

    /**
     * Releases the native C++ resources held by the {$classname} instance.
     */
    public void Release() {
        if(thisC != 0)
            deleteFn.call1(thisC);
    }

    protected void finalize() {
        Release();
    }


EOF;

    fputs($fp, $fnproto);


    foreach($protos as $proto) {
        $returntype = '';
        $longreturn = false;
        $fnname = '';
        $static = false;
        $valid = true;
        $visibility = 'public';

        $args = '';

        $paramcount = 2;
        $proto = FixNITypes($proto);
        $words = explode(' ', $proto);

        for($i = 0; $i < count($words); $i++) {
            if(($argstart = strpos($words[$i], '(')) !== false) {
                $fnname = substr($words[$i], 0, $argstart);
                $words[$i] = substr($words[$i], $argstart);
                $args = implode(' ', array_slice($words, $i));
                break;
            }
            switch($words[$i]) {
                case 'private':
                    verboseprint("Private function. I should probably skip
this.\n");
                    break;
                case 'public':
                case 'protected':
                    verboseprint("Visibility: {$words[$i]}.\n");
                    $visibility = $words[$i];
                    break;
                case 'signed':
```

```
                case 'unsigned':
                    if(!in_array($words[$i+1], array('char', 'short', 'int',
'long', 'float'))) {
                        $words[$i] = int;
                        $i--;  // HACK: rather than do something intelligent here, we just back up so we
re-process the word.
                    } else {
                        verboseprint("Function is explicitly {$words[$i]} --
not important.\n");
                    }
                    break;
                case 'const':
                    verboseprint("Function doesn't modify the instance -- not
important.\n");
                    break;
                case 'static':
                    verboseprint("Function is static.\n");
                    $static = true;
                    break;
                case 'char':
                    $returntype = 'byte';
                    verboseprint("Function return type: $returntype\n");
                    break;
                case 'bool':
                    $returntype = 'boolean';
                    verboseprint("Function return type: $returntype\n");
                    break;
                case 'short':
                case 'int':
                case 'float':
                case 'void':
                    $returntype = $words[$i];
                    verboseprint("Function return type: $returntype\n");
                    break;
                case 'long':
                    if($words[$i+1] == 'long') {
                        $longreturn = true;
                        $returntype = 'long';
                        $i++;
                    } else {
                        $returntype = 'int';
                    }
                    verboseprint("Function return type: $returntype\n");
                    break;
                default:
                    if ($returntype == '')
                        $returntype = $words[$i];
                    $valid = false;
                    print("Parsing error for Function:\n");
                    print("$proto\n");
                    print("Unrecognized symbol {$words[$i]}.  I'll keep going
and ignore the error.\n");
            }
        }

        if($words[0] == 'private')
        {
            verboseprint("Skipping private function {$fnname}\n");
            continue;
        }

        $params = split(', ', trim($args, '();'));
        $pparams = '';
        $cparams = $static ? '' : 'thisC';
        if($static)
            $paramcount--; // don't need the 'this' parameter

        $longhelpers = array();

        foreach($params as $p) {
            $longhandler = false;

            $valid &= JParamAction($p);

            if($longhandler)
                $longhelpers[] = $paramname;
        }

        if($cparams != '')
            $cparams .= ', ';
        $cparams .= 'pStatus.getPointer()';

        $fnproto = $valid ? '' : "/* -- Error during parsing --\r\n";

        $static = $static ? ' static' : '';

        $fnproto .= <<<EOF
    private static final Function {$fnname}Fn =
Function.getFunction("{$classname}_{$fnname}");

EOF;
        if($longreturn) {
            $fnproto .= <<<EOF
    private static final Function {$fnname}_MSWFn =
Function.getFunction("{$classname}_{$fnname}_MSW");

EOF;
        }
        $fnproto .= <<<EOF
    {$visibility}{$static} {$returntype} {$fnname}($pparams) {

EOF;
        foreach($longhelpers as $lh) {
            $fnproto .= <<<EOF
        long {$lh}_MSW = (0xFFFFFFFF & ({$fh} >> 32)); //(((long
long){$lh}_MSW) << 32) | ({$lh}_LSW);
        long {$lh}_LSW = (0xFFFFFFFF & {$fh});

EOF;
        }
        if($longreturn) {
            $fnproto .= <<<EOF
        int res_LSW = {$fnname}Fn.call{$paramcount}($cparams);
        int res_MSW = {$fnname}_MSWFn.call0();
        assertCleanStatus("{$classname}.{$fnname}");
        return (0xFFFFFFFF & (((long)res_MSW) << 32)) | (0xFFFFFFFF &
((long)res_LSW));
    }

EOF;
        } else {
            $fnproto .= "\t\t";
            if($returntype != 'void')
                $fnproto .= 'int res = ';
            $fnproto .= "{$fnname}Fn.call{$paramcount}($cparams)";
            $fnproto .=
";\r\n\t\tassertCleanStatus(\"{$classname}.{$fnname}\");\r\n";
            if($returntype == 'boolean')
                $fnproto .= "\t\treturn res == 1;\r\n";
            elseif($returntype == 'int')
                $fnproto .= "\t\treturn res;\r\n";
            elseif($returntype != 'void')
                $fnproto .= "\t\treturn ($returntype)res;\r\n";
            $fnproto .= "\t}\r\n";
        }

        $fnproto .= ($valid ? '' : "*/\r\n") . "\r\n";

        fputs($fp, $fnproto);
    }

    fputs($fp, $trailer);

    fclose($fp);
?>
```

# Appendix 2: Test and Analysis Code

## 1. C++ Code to test some WPILib Functionalities

***Harness.cpp***

```
      #include "harness.h"
      #include "testsuite.h"
      #include "ChipObject/tDIO.h"
      #include "ChipObject/tWatchdog.h"
      #include <stdio.h>

      void ExecTest(int (*fn)(void), const char* name) {
              printf("Running %s...\n", name);

              int res = fn();

              printf("%s...%s\n\n", name, (res == 0 ? "PASS" : "FAIL"));
      }

      void WPILibTestHarnessMain(void) {
              printf("--------------------------------------------\n");
              printf("Running WPILib Tests\n");
              printf("--------------------------------------------\n");

              printf("[Digital Systems: %d]\n\n", tDIO::kNumSystems);

              ServoTestHarness_Execute();

              printf("--------------------------------------------\n");
      }

      void PWMTest(void) {
              int status;

              nFPGA::n0BA6BBDC5CE760BA2A9A95D92CEA342A::tWatchdog rex(&status);

              bool userEn, sysEn;

              printf("System Status: %s\n", rex.readSystemActive(&status) ? "Active" :
      "Inactive");

              sysEn = rex.readEnabled(&status);
              userEn = rex.readUserEnabled(&status);

              printf("System Watchdog: %s\n", sysEn ? "Enabled" : "Disabled");
              printf("User Watchdog: %s\n", userEn ? "Enabled" : "Disabled");

              rex.writeEnabled(true, &status);
              rex.writeUserEnabled(true, &status);

              sysEn = rex.readEnabled(&status);
              userEn = rex.readUserEnabled(&status);

              printf("System Watchdog: %s\n", sysEn ? "Enabled" : "Disabled");
              printf("User Watchdog: %s\n", userEn ? "Enabled" : "Disabled");

              Servo s(4, 1);
              s.SetAngle(180);
              Wait(20);
              s.SetAngle(0);

      //      s.SetPeriodMultiplier(PWM::kPeriodMultiplier_4X);
      //      do {
      //              s.SetRaw(255);
      //              Wait(20);
      //              s.SetRaw(1);
      //              Wait(20);
      //      } while(0);
```

```
}

void RelayTest(void) {
        Relay r(4, 1);

        r.Set(Relay::kForward);

        while(1);
}

void DIOTest(void) {
        DigitalModule* dm = DigitalModule::GetInstance(4);

        bool b = dm->AllocateDIO(1, false);

        printf("AllocateDIO: %s\n", b ? "OK!" : "NO!");

        while(1) {
                dm->SetDIO(1, 1);
                Wait(20);
                dm->SetDIO(1, 0);
                Wait(20);
        }
}

void SlowPrint(const char* s) {
        int len = strlen(s);

        for(int i = 0; i < len; i++)
        {
                fputc(s[i], stdout);
                fflush(stdout);
        }
}

void SlowPrint(const long l) {
        fprintf(stdout, "%ld", l);
        fflush(stdout);
}

void DotPrinterTest() {
        for(long l = 0; l < 50000; l++) {
                SlowPrint("[WPILibC] Iteration #");
                SlowPrint(l);
                SlowPrint("\n");
                SlowPrint(".................\n");
        }
}
```

```
        void TestHelper(void) {
                //DotPrinterTest();
                //DIOTest();
                PWMTest();
        }
```

***Note: The header file for harness.cpp can be found in Appendix 2.***

## 2. Servo Test Code

**servo_tests.cpp**

```
/*******************************************************************************
 * WPILib Tests for Servo Operation                                            *
 *******************************************************************************/

#include "harness.h"
#include "servo_tests.h"
#include <stdio.h>

#define SERVO_SLOT 4
#define SERVO_CHAN 1

#define kMaxServoAngle 170
#define kMinServoAngle   0

void busywait(void) {
        long l = 0;

        while(l < 100000000L)
                l++;
}

/**
 * Moves the servo arm to a specified position.
 *
 * @param sv The servo to move.
 * @param angle The angle to which to set the servo.
 *
 * @return 0 if the servo moved correctly.
 */
int ServoTestHelper_MoveToAngle(Servo* sv, const int angle) {
        printf("Moving servo arm to %d degrees.\n", angle);

        sv->SetAngle(angle);

        busywait();
        float newAngle = sv->GetAngle();

        printf("Servo arm is at %f degrees.\n", newAngle);

        AssertEqual(angle, newAngle);

        return 0;
}


/**
 * Tests the motion of a servo to its maximum position
 *
 * @return 0 on sucess, non-zero on failure.
 */
int ServoTest_MoveMax(void) {
        Servo sv(SERVO_SLOT, SERVO_CHAN);

        int angle = kMaxServoAngle;

        return ServoTestHelper_MoveToAngle(&sv, angle);
}

/**
 * Tests the motion of a servo to its minimum position
 *
 * @return 0 on sucess, non-zero on failure.
 */
int ServoTest_MoveMin(void) {
        Servo sv(SERVO_SLOT, SERVO_CHAN);

        int angle = kMinServoAngle;

        return ServoTestHelper_MoveToAngle(&sv, angle);
}

/**
 * Tests the motion of a servo to its middle position
 *
 * @return 0 on sucess, non-zero on failure.
 */
int ServoTest_MoveMid(void) {
        Servo sv(SERVO_SLOT, SERVO_CHAN);

        int angle = 85;

        return ServoTestHelper_MoveToAngle(&sv, angle);
```

```
}

/**
 * Tests the motion of a servo to above its maximum position
 *
 * @return 0 on sucess, non-zero on failure.
 */
int ServoTest_MoveAboveMax(void) {
        Servo sv(SERVO_SLOT, SERVO_CHAN);

        int angle = kMaxServoAngle + 45;

        printf("Moving servo arm to %d degrees.\n", angle);

        sv.SetAngle(angle);

        busywait();

        float newAngle = sv.GetAngle();

        printf("Servo arm is at %f degrees.\n", newAngle);

        AssertEqual(kMaxServoAngle, newAngle);

        return 0;
}

/**
 * Tests the motion of a servo to below its minimum position
 *
 * @return 0 on sucess, non-zero on failure.
 */
int ServoTest_MoveBelowMin(void) {
        Servo sv(SERVO_SLOT, SERVO_CHAN);

        int angle = kMinServoAngle - 45;

        printf("Moving servo arm to %d degrees.\n", angle);

        sv.SetAngle(angle);

        busywait();

        float newAngle = sv.GetAngle();

        printf("Servo arm is at %f degrees.\n", newAngle);

        AssertEqual(kMinServoAngle, newAngle);
        return 0;
}


void ServoTestHarness_Execute(void) {
        ExecTest(ServoTest_MoveMax, "Servo>MoveMax");
        ExecTest(ServoTest_MoveMin, "Servo>MoveMin");
        ExecTest(ServoTest_MoveMid, "Servo>MoveMid");
        ExecTest(ServoTest_MoveAboveMax, "Servo>MoveAboveMax");
        ExecTest(ServoTest_MoveBelowMin, "Servo>MoveBelowMin");
}
```

***Note: The header file to servo_tests.cpp can be found in Appendix 2.***

## 3. Analog Module Input Test

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

import edu.wpi.first.wpilibj.AnalogModule;

/**
 *
 * @author Brian
 */
public class AITest {
        private AITest() {

        }

        public static void main(String[] args) {
                AnalogModule m = AnalogModule.GetInstance((byte)1);

                System.out.print("Voltage on Channel 1: ");
                System.out.println(m.GetVoltage((byte)1));
        }
}
```

## 4. Digital Sidecar and Associates Hardware C++ Code.

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

import edu.wpi.first.wpilibj.*;

/**
 * Set of mini-tests for the DIO components (i.e. the digital sidecar)
 * @author Brian
 */
```

```
public class DIOTest {
        private static final boolean DEBUG = true;

        private DIOTest() {

        }

        private static void TestPin(DigitalModule dm) throws InterruptedException {
                dm.SetDIO((byte)1, true);
                Thread.sleep(10);
                if(DEBUG) {
                        System.out.print("[WPILibJ] DIO #1 value is ");
                        System.out.println(dm.GetDIO((byte)2));
                }

                dm.SetDIO((byte)1, false);
                Thread.sleep(10);
                if(DEBUG) {
                        System.out.print("[WPILibJ] DIO #1 value is ");
                        System.out.println(dm.GetDIO((byte)2));
                }
                Thread.sleep(10);
        }

        private static void TestServo(Servo s) throws InterruptedException {
                s.SetAngle(0);
                SensorBase.Wait(500);
                System.out.print("[WPILibJ] Moved servo to ");
                System.out.println(s.GetAngle());

                s.SetAngle(170);
                SensorBase.Wait(500);
                System.out.print("[WPILibJ] Moved servo to ");
                System.out.println(s.GetAngle());

                s.SetAngle(85);
                SensorBase.Wait(500);
                System.out.print("[WPILibJ] Moved servo to ");
                System.out.println(s.GetAngle());
        }

        public static void main(String[] args) {
                final byte SLOT_4 = 4;
                final byte CH_1 = 1;
                final byte CH_2 = 2;
                final byte CH_3 = 3;
                final byte CH_RST = 14;
```

```
		DigitalModule dm = DigitalModule.GetInstance(SLOT_4);
		Servo s = new Servo(CH_1);

		dm.AllocateDIO(CH_1, false);
		dm.AllocateDIO(CH_2, true);

		for (long l = 0; l < 3; l++) {
			if(DEBUG) {
				System.out.print("[WPILibJ] Iteration #");
				System.out.println(l);
			}

			try {
				TestPin(dm);
				TestServo(s);

				SensorBase.Wait(1000);
			} catch (InterruptedException ex) {
				System.err.println("[WPILibJ] Someone interrupted my beauty
sleep!");
			}
		}

		dm.AllocateDIO(CH_3, true);

		DigitalInput reset = new DigitalInput(CH_RST);
		Relay r = new Relay(CH_1, Relay.DIRECTION_FORWARDONLY);

		// New Switch gadget!
		while(true) {
			try {
				if(dm.GetDIO(CH_3)) {
					s.SetAngle(180);
					r.Set(Relay.VALUE_ON);
				} else {
					s.SetAngle(0);
					r.Set(Relay.VALUE_OFF);
				}

				Thread.sleep(250);

				if(reset.Get())
					break;
			} catch (InterruptedException ex) {
				System.err.println("[WPILibJ] Someone interrupted my beauty
sleep!");
			}
		}
```

```
        }

}
```

# Appendix 3: Test and Analysis Code

## 1. C++ Code to test some WPILib Functionalities

### *Harness.h*

```
/*****************************************************************************
* WPILib Test Harness                                                        *
*                                                                            *
* This harness provides the share test execution methods for running tests   *
* against the C++ implementation of WPILib. These tests will provided the    *
* baseline results for running tests against the Java implementation         *
*****************************************************************************/

#ifndef __HARNESS_H__

#define __HARNESS_H__

#define AssertEqual(x,y) if(x != y) return -1; else (void)0

void ExecTest(int (*)(void), const char*);


#endif //__HARNESS_H__
```

-----------------------------------------------------------------------------

### *Harness.cpp*

```
        #include "harness.h"

        #include "testsuite.h"

        #include "ChipObject/tDIO.h"

        #include "ChipObject/tWatchdog.h"

        #include <stdio.h>
```

```
void ExecTest(int (*fn)(void), const char* name) {
        printf("Running %s...\n", name);

        int res = fn();

        printf("%s...%s\n\n", name, (res == 0 ? "PASS" : "FAIL"));
}
void WPILibTestHarnessMain(void) {
        printf("--------------------------------------------\n");
        printf("Running WPILib Tests\n");
        printf("--------------------------------------------\n");

        printf("[Digital Systems: %d]\n\n", tDIO::kNumSystems);

        ServoTestHarness_Execute();

        printf("--------------------------------------------\n");
}
void PWMTest(void) {
        int status;

        nFPGA::n0BA6BBDC5CE760BA2A9A95D92CEA342A::tWatchdog rex(&status);
        bool userEn, sysEn;

        printf("System Status: %s\n", rex.readSystemActive(&status) ? "Active" : "Inactive");

       sysEn = rex.readEnabled(&status);
        userEn = rex.readUserEnabled(&status);
        printf("System Watchdog: %s\n", sysEn ? "Enabled" : "Disabled");
        printf("User Watchdog: %s\n", userEn ? "Enabled" : "Disabled");

        rex.writeEnabled(true, &status);
        rex.writeUserEnabled(true, &status);

        sysEn = rex.readEnabled(&status);
        userEn = rex.readUserEnabled(&status);

        printf("System Watchdog: %s\n", sysEn ? "Enabled" : "Disabled");
        printf("User Watchdog: %s\n", userEn ? "Enabled" : "Disabled");

        Servo s(4, 1);
        s.SetAngle(180);
        Wait(20);
        s.SetAngle(0);

//      s.SetPeriodMultiplier(PWM::kPeriodMultiplier_4X);
//      do {
//              s.SetRaw(255);
//              Wait(20);
//              s.SetRaw(1);
//              Wait(20);
//      } while(0);
}
void RelayTest(void) {
        Relay r(4, 1);
        r.Set(Relay::kForward);


        while(1);

}

void DIOTest(void) {

        DigitalModule* dm = DigitalModule::GetInstance(4);


        bool b = dm->AllocateDIO(1, false);


        printf("AllocateDIO: %s\n", b ? "OK!" : "NO!");


        while(1) {

                dm->SetDIO(1, 1);

                Wait(20);

                dm->SetDIO(1, 0);

                Wait(20);

        }

}

void SlowPrint(const char* s) {

        int len = strlen(s);


        for(int i = 0; i < len; i++)

        {

                fputc(s[i], stdout);

                fflush(stdout);

        }

}

void SlowPrint(const long l) {
```

```
                fprintf(stdout, "%ld", l);

                fflush(stdout);

        }

        void DotPrinterTest() {

                for(long l = 0; l < 50000; l++) {

                        SlowPrint("[WPILibC] Iteration #");

                        SlowPrint(l);

                        SlowPrint("\n");

                        SlowPrint("................\n");

                }

        }

        void TestHelper(void) {

                //DotPrinterTest();

                //DIOTest();

                PWMTest();

        }
```

## Servo Test Code

### servo_tests.h

```
/*******************************************************************************
* WPILib Tests for Servo Operation                                             *
*                                                                              *
* These tests are designed to provide a range of execution conditions for      *
* servos under WPILib. They should provide a sufficient range of tests         *
* conditions, but may not be exhaustive. See test headers for details.         *
*******************************************************************************/

#ifndef __SERVO_TESTS__

#define __SERVO_TESTS__
```

```
#include <wpilib.h>

// Helpers:

int ServoTestHelper_MoveToAngle(Servo*, const int);

// Tests:

int ServoTest_MoveMax(void);

int ServoTest_MoveMin(void);

int ServoTest_MoveMid(void);

int ServoTest_MoveAboveMax(void);

int ServoTest_MoveBelowMin(void);

// Test Harness:

void ServoTestHarness_Execute(void);

#endif
```

-----------------------------------------------------------------------------

## servo_tests.cpp

```
/******************************************************************************

* WPILib Tests for Servo Operation                                            *

******************************************************************************/

#include "harness.h"

#include "servo_tests.h"

#include <stdio.h>

#define SERVO_SLOT 4

#define SERVO_CHAN 1

#define kMaxServoAngle 170

#define kMinServoAngle  0

void busywait(void) {

        long l = 0;
        while(l < 100000000L)

                l++;

}

/**

* Moves the servo arm to a specified position.

*

* @param sv The servo to move.

* @param angle The angle to which to set the servo.

*

* @return 0 if the servo moved correctly.

*/

int ServoTestHelper_MoveToAngle(Servo* sv, const int angle) {

        printf("Moving servo arm to %d degrees.\n", angle);


        sv->SetAngle(angle);


        busywait();


        float newAngle = sv->GetAngle();


        printf("Servo arm is at %f degrees.\n", newAngle);


        AssertEqual(angle, newAngle);


        return 0;

}


/**
```

```
* Tests the motion of a servo to its maximum position

*

* @return 0 on sucess, non-zero on failure.

*/

int ServoTest_MoveMax(void) {

        Servo sv(SERVO_SLOT, SERVO_CHAN);


        int angle = kMaxServoAngle;


        return ServoTestHelper_MoveToAngle(&sv, angle);

}

/**

* Tests the motion of a servo to its minimum position

*

* @return 0 on sucess, non-zero on failure.

*/

int ServoTest_MoveMin(void) {

        Servo sv(SERVO_SLOT, SERVO_CHAN);


        int angle = kMinServoAngle;


        return ServoTestHelper_MoveToAngle(&sv, angle);

}

/**

* Tests the motion of a servo to its middle position

*

* @return 0 on sucess, non-zero on failure.

*/
```

```
int ServoTest_MoveMid(void) {

        Servo sv(SERVO_SLOT, SERVO_CHAN);


        int angle = 85;


        return ServoTestHelper_MoveToAngle(&sv, angle);

}

/**

* Tests the motion of a servo to above its maximum position

*

* @return 0 on sucess, non-zero on failure.

*/

int ServoTest_MoveAboveMax(void) {

        Servo sv(SERVO_SLOT, SERVO_CHAN);


        int angle = kMaxServoAngle + 45;


        printf("Moving servo arm to %d degrees.\n", angle);


        sv.SetAngle(angle);


        busywait();


        float newAngle = sv.GetAngle();


        printf("Servo arm is at %f degrees.\n", newAngle);


        AssertEqual(kMaxServoAngle, newAngle);
        return 0;

}

/**

* Tests the motion of a servo to below its minimum position

*

* @return 0 on sucess, non-zero on failure.

*/

int ServoTest_MoveBelowMin(void) {

        Servo sv(SERVO_SLOT, SERVO_CHAN);


        int angle = kMinServoAngle - 45;


        printf("Moving servo arm to %d degrees.\n", angle);


        sv.SetAngle(angle);


        busywait();


        float newAngle = sv.GetAngle();


        printf("Servo arm is at %f degrees.\n", newAngle);


        AssertEqual(kMinServoAngle, newAngle);


        return 0;

}


void ServoTestHarness_Execute(void) {

        ExecTest(ServoTest_MoveMax, "Servo>MoveMax");
        ExecTest(ServoTest_MoveMin, "Servo>MoveMin");

        ExecTest(ServoTest_MoveMid, "Servo>MoveMid");

        ExecTest(ServoTest_MoveAboveMax, "Servo>MoveAboveMax");

        ExecTest(ServoTest_MoveBelowMin, "Servo>MoveBelowMin");

}
```

## Analog Module Input Test

## AITest.java

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

import edu.wpi.first.wpilibj.AnalogModule;

/**

*

* @author Brian

*/

public class AITest {

        private AITest() {

        }

        public static void main(String[] args) {

                AnalogModule m = AnalogModule.GetInstance((byte)1);

                System.out.print("Voltage on Channel 1: ");

                System.out.println(m.GetVoltage((byte)1));

        }

}
```

## Digital Sidecar and Associates Hardware C++ Code.

## DIOTest.java

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

```
import edu.wpi.first.wpilibj.*;

/**

* Set of mini-tests for the DIO components (i.e. the digital sidecar)

* @author Brian

*/

public class DIOTest {

        private static final boolean DEBUG = true;

        private DIOTest() {



        }

        private static void TestPin(DigitalModule dm) throws InterruptedException {

                dm.SetDIO((byte)1, true);

                Thread.sleep(10);

                if(DEBUG) {

                        System.out.print("[WPILibJ] DIO #1 value is ");

                        System.out.println(dm.GetDIO((byte)2));

                }


                dm.SetDIO((byte)1, false);

                Thread.sleep(10);

                if(DEBUG) {

                        System.out.print("[WPILibJ] DIO #1 value is ");

                        System.out.println(dm.GetDIO((byte)2));

                }

                Thread.sleep(10);

        }

        private static void TestServo(Servo s) throws InterruptedException {

                s.SetAngle(0);
                SensorBase.Wait(500);

                System.out.print("[WPILibJ] Moved servo to ");

                System.out.println(s.GetAngle());


                s.SetAngle(170);

                SensorBase.Wait(500);

                System.out.print("[WPILibJ] Moved servo to ");

                System.out.println(s.GetAngle());

                s.SetAngle(85);

                SensorBase.Wait(500);

                System.out.print("[WPILibJ] Moved servo to ");

                System.out.println(s.GetAngle());

        }

        public static void main(String[] args) {

                final byte SLOT_4 = 4;

                final byte CH_1 = 1;

                final byte CH_2 = 2;

                final byte CH_3 = 3;

                final byte CH_RST = 14;


                DigitalModule dm = DigitalModule.GetInstance(SLOT_4);

                Servo s = new Servo(CH_1);

                dm.AllocateDIO(CH_1, false);

                dm.AllocateDIO(CH_2, true);

                for (long l = 0; l < 3; l++) {

                        if(DEBUG) {

                                System.out.print("[WPILibJ] Iteration #");

                                System.out.println(l);
                        }

                        try {

                                TestPin(dm);

                                TestServo(s);

                                SensorBase.Wait(1000);

                       } catch (InterruptedException ex) {

                                System.err.println("[WPILibJ] Someone interrupted my beauty sleep!");

                        }

                }

                dm.AllocateDIO(CH_3, true);


                DigitalInput reset = new DigitalInput(CH_RST);

                Relay r = new Relay(CH_1, Relay.DIRECTION_FORWARDONLY);


                // New Switch gadget!

                while(true) {

                        try {

                                if(dm.GetDIO(CH_3)) {

                                        s.SetAngle(180);

                                        r.Set(Relay.VALUE_ON);

                                } else {

                                        s.SetAngle(0);

                                        r.Set(Relay.VALUE_OFF);

                                }

                                Thread.sleep(250);

                                if(reset.Get())

                                        break;

                        } catch (InterruptedException ex) {
```

```
                                        System.err.println("[WPILibJ] Someone interrupted my beauty sleep!");
                                }
                        }
                }
        }
```

## Robot JoyStick Java Programming

### JoyTest.java

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

import edu.wpi.first.wpilibj.*;

/**
*
* @author Brian
*/
public class JoyTest {

        private JoyTest() { }

        public static void main(String[] args) {

                Joystick stick = new Joystick(1);

                float lastX = 0, lastY = 0, lastZ = 0, lastT = 0, lastH = 0;

                boolean[] lastBtn = new boolean[] { false, false, false, false, false, false, false,
false, false, false, false, false };

                while(!stick.GetRawButton(8)) {

                        float x = stick.GetX();

                        float y = stick.GetY();

                        float z = stick.GetZ();

                        float t = stick.GetTwist();

                        float h = stick.GetThrottle();

                        boolean[] buttons = new boolean[12];

                        for(int i = 0; i < buttons.length; i++)
                                buttons[i] = stick.GetRawButton(i+1);

                        if(Math.abs(x - lastX) > 0.005) {

                                System.out.print("Moved stick X axis to ");

                                System.out.println(x);

                                lastX = x;

                        }

                        if(Math.abs(y - lastY) > 0.005) {

                                System.out.print("Moved stick Y axis to ");

                                System.out.println(y);

                                lastY = y;

                        }

                        if(Math.abs(z - lastZ) > 0.005) {

                                System.out.print("Moved stick Z axis to ");

                                System.out.println(z);

                                lastZ = z;

                        }

                        if(Math.abs(t - lastT) > 0.005) {

                                System.out.print("Moved stick twist axis to ");

                                System.out.println(t);

                                lastT = t;

                        }

                        if(Math.abs(h - lastH) > 0.005) {

                                System.out.print("Moved stick throttle to ");

                                System.out.println(h);

                                lastH = h;

                        }

                        for(int i = 0; i < buttons.length; i++) {

                                if(buttons[i] != lastBtn[i]) {
```

```
                                        System.out.print(buttons[i] ? "Pressed button " : "Released
button ");

                                        System.out.println(i);

                                        lastBtn[i] = buttons[i];

                                }

                        }

                        SensorBase.Wait(20);

                }

        }

}
```

## Video References

1. C++ Test Code :Working servo with 3 point reference (minimum, middle, and maximum angle).

   <http://hosted.filefront.com/mafiri/2335409> LINK 3

2. Java Test Code: Working servo with 3 point reference (minimum, middle, and maximum angle).

   <http://hosted.filefront.com/mafiri/2335409> LINK 2

3. Java Test Code: Working servo with 3 point reference, motor in Relay Port, and button.

   <http://hosted.filefront.com/mafiri/2335409>  LINK 4

4. WPI 2k5 Robot Programmed in Java (with Joystick and wireless drive).

   <http://hosted.filefront.com/mafiri/2335409> LINK 1