WHITE PAPER

TEXAS INSTRUMENTS

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# Fresh Innovators Put Ideas into Action in Robot Contest

## Introduction

*Texas Instruments puts tools in the hands of creators of tomorrow's machine control systems.*

The annual *FIRST*® Robotics Challenge (FRC) inspires young men and women to explore applications of motors to make good use of mechanical motion in imaginative ways, all in the name of a real-life game. In doing so, these high school students learn to work on a team toward a common goal, stretch their knowledge and exercise their creativity, apply critical thinking and develop a strategic game plan, and move from theoretical and book learning to practical application of concepts, all the while learning valuable lessons that will help them in the workplace and in life throughout their adulthood. But as much as anything, the *FIRST*® programs are designed to interest children in science and math by making it fun and engaging through the use of robots.

Texas Instruments is one of the FRC suppliers, lending its motor control technology to the materials and tool kit from which each team of students builds its robot. The Stellaris® microcontroller-based motor control system and software used by the students is from the same Jaguar® developer's kit used by professionals to build sophisticated motion-control systems used in industry day in and day out. The easy-to-use kits let naive high school students, as well as industry professionals, control various types of motors in complex systems without having to comprehend the underlying algorithms in use or details of the microcontroller (MCU) program code that is implementing the algorithms. The same way a cook can prepare a tasty meal without understanding the complex chemical reactions brewing at the stove top, the high school student or industry robotics designer can put together an efficient, smoothly moving mechanical system by setting a few simple parameters in pre-configured software and sequencing operations to fit the needs of the equipment.

*FIRST* ®–
“For Inspiration and Recognition
of Science and Technology”
Robotic Programs

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|---|---|
| Junior *FIRST* LEGO League | ages 6-9 |
| *FIRST* LEGO League | ages 9-14 |
| *FIRST* Tech Challenge | ages 14-18 |
| *FIRST* Robotics Competition | ages 14-18 |

The *FIRST*® Robotics Challenge is the most advanced of a number of robotic design programs set up to interest children through young adults in the application of scientific principles to make machines perform tasks under automatic control. *FIRST*®, an acronym for, “For Inspiration and Recognition of Science and Technology” and these contests are the embodiment of an idea advanced by inventor and entrepreneur Dean Kamen, well-known inventor of the Segway® Human Transporter, nearly twenty years ago. Every year, the contests draw nearly 50,000 students and 10,000 mentors and teachers to spur on the budding engineers. The variety of the resulting robots show the range of imagination going into the machines, and the robots' sophistication demonstrate the learning that goes into their creation, while watching the competition in action clearly shows the student’s interest to be as enthusiastic as for any sport.

## The Game

Let's face it. The *FIRST*® Robotics Competition (FRC) isn't just about building things. It's about a game. It's a full size, real-life game. It involves balls, goals, people, rules, strategy, machines, and lots of action. It involves fun and somebody wins, but more importantly, everybody gets to play.

Each year the game is different but there are common themes from year to year and concepts familiar to anybody who plays a sport. It helps to have played games before, and teams that have participated in prior years have a leg up, even though game specifics change each year.

### What Makes Students Want to Build Robots?

Hundreds of thousands of students are attracted to the prospect of building a robot. The reasons for their enthusiasm are as varied as their backgrounds. But the characteristics that do show up in these students point to the beginnings of a productive adulthood and successful career. And the building of the machines and the competition between teams let these high school students nurture new interests and reveal hidden personal abilities. The more a student does the work himself or herself, the better he or she learns from the experience. What are the kids like? Why do they do it? What do they learn? Why do they return the next year?

The students that join Robotics clubs and participate in *FIRST*® and other robot-building contests are typically very interested in science and mathematics. But they might not excel in the classroom. The theory of books and chalk boards might be esoteric, but the robotics experience can translate theory and formulae into a real-world application with a visible purpose.

This isn't just a laboratory where you follow instructions until the liquid turns green or you find the frog's stomach. This is an open-ended project. These kids start with a Kit of Parts and have a vague idea of what they eventually need to do, but the journey really is more important than the destination and they have to plan every step of the way based on hundreds of decisions.

They may enjoy working in groups or being a part of a larger movement. Lisa plays the clarinet in the school marching band, and specializes in the elite jazz band. Many become leaders in leadership organizations. The team works around Mark's schedule, who devotes his Monday nights to Eagle Scout activities.

Many come from families with a proclivity for engineering or industrial design. Liz’s dad runs the town's welding shop.

Most have tinkered with robots before, be it building Lego Mindstorms or NXT, breaking into mom's Roomba, or just running a Robosapien. Ross sees robotics as a wide-open frontier ripe with opportunity, whereas automobiles have already been pretty well worked over the last hundred years. It's a great point of view for a guy with 50 years of career ahead of him.

These aren't just typical nerds, though. Ross is now a freshman at Purdue. Many are active in sports. Emily runs cross-country when she's not fine-tuning program sequences and a couple other students play lacrosse. Playing video games is one common pastime of team members. The game strategies and controls dexterity developed over the years of practice late at night and after class will prove valuable experience during the head-to-head competition. Of course, the opponents also are well-trained in this area. The faculty sponsor is the basketball coach with an eye for spotting, nurturing, and blending kids' special abilities to make the most complete whole.

Some students just want to work with friends on projects. For many, the interest is in translating the imagination to reality like the constant rebuilding of the blocks, Legos, Lincoln Logs, and Erector sets of childhood, fueled by watching how-to programs on TV. For others it's the problem solving, trying different approaches until something works. It may be the challenge of the game that eventually excites the student, out-scoring the other teams, playing defensively and offensively against both man and machine, and seeing how the strategies and design choices made during the building of the robot play out in the actual playing field.

It's being involved in the design of the robot, working late into the night because you want to, not because somebody tells you to. Going to the robot lab is the highlight of Katie’s day and she digs deep to understand how all the parts work together. It's the satisfaction of seeing your idea prove to be an advantage during the game, and the disappointment when too much jostling knocks a rail out of alignment and the team has to scramble to fix it before the next match. It's seeing shy Daniel crawl out of his silence to lead the discussion on the advantages of partnering with one team versus another. It's starting on the team not knowing how she'll contribute, but shining in the final week as Melanie becomes the key electrical person.

It's applying the math and physics learned two years ago to determine the ideal speed for the throwing arm to swing. It's maximizing traction by ramping up the motor speed rather than just jamming it to full speed - by simply using an algorithm already implemented in software drivers rather than having to explicitly pulse the current to the rotors in increasing frequency.

The four wheel independently-steered and -driven mechanism can turn out to be so complex that it hasto be scrapped at the 11th hour and replaced with a simpler, workable two-motor

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system that relies on the wheels to slide on the field surface. Sometimes the ideas are a little too grand for the time and resources available.

The playing field isn't always level. It can be kids against adults. On some teams the students plan, design, and construct the robots. On other teams, it's more the grown-ups doing the work, pitting their own skills against the competition while the children watch without really understanding.

Teams may work with CAD tools, machine shops, and simulators, but the winning solution is just as likely to have come from a student and be implemented with cardboard, Velcro, and tie wraps on race-day.

The best way to judge the success of a team is probably to look into the students' eyes and listen to their enthusiasm as they explain their project, rather than to look at the professionalism of the paint on the cowling or even whether the robot won.

## Work

With much fanfare and great theater, the game for each year's competition is outlined on a designated start date. Game play is sketched out, ideas and concepts are suggested, rules and limitations are delineated/defined, and a baseline set of components to build the robots are distributed. Hundreds of pages of rules and manuals are made available.

Six weeks later, a completed robot must be submitted to cement a team's entry into the competition, although updates, corrections, improvements, and nearly wholesale rework of the robot can continue until it's time to start the competition, perhaps four weeks later. That isn't a lot of time to conceptualize what the robot must do (see Figure 1), imagine how to implement the action, gather supplies and fabricate metal and plastic, connect the electronics and motors, program the electronic devices, test everything from operation to durability—and re-design weak points—let alone learn to drive the robot and develop game playing strategies (see Figure 2). The challenges are very similar to what businesses face every day and what students will confront when they are grown and working in industry, trying to get a product out on time that works as it is supposed to within a given set of resources and cost constraints.

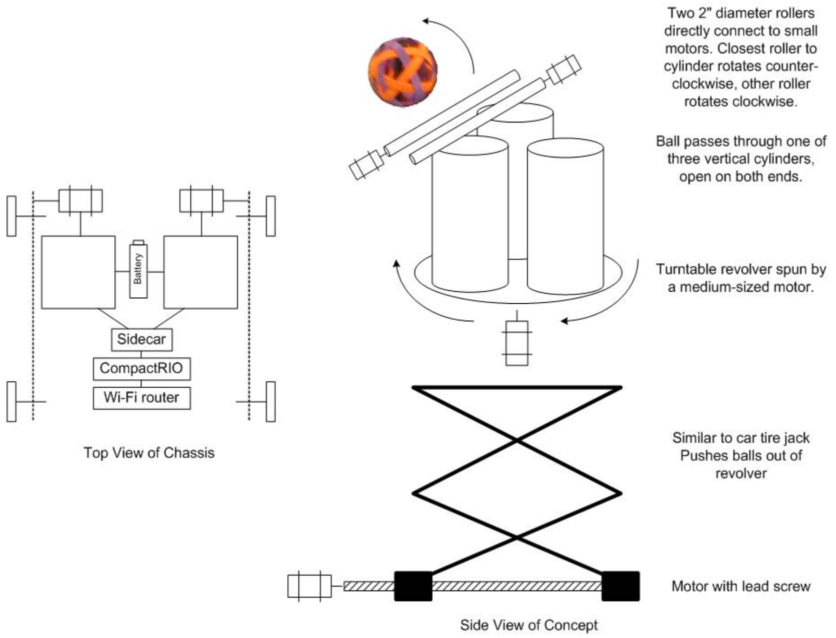

***Figure 1.*** *Sample Robot Concept*

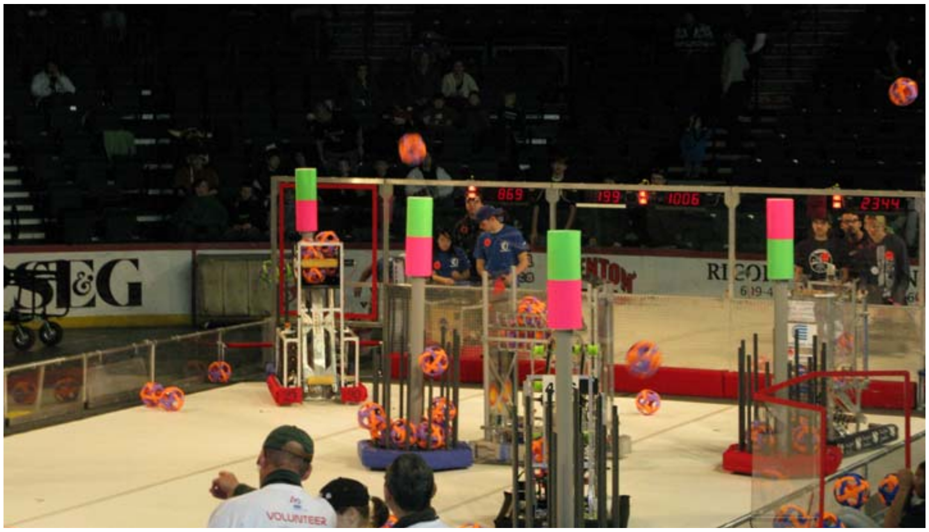

***Figure 2.*** *Competition Day*

## Play

The game can involve a ball like a soccer ball, or a number of them, which are thrown or maneuvered around the playing field which could be 25 feet by 50 feet. Points are scored for making goals and sometimes for progress, incidental activities, or just plain survival. There is head-to-head competition with opposing robots on the field at the same time, so not only is operational excellence required, but offensive and defensive battle plans are also needed. There are obstacles to overcome, some fixed or anticipated ahead of time, like a track, maze, or barrier, and others that are highly variable such as opposing robots and human interference. Robots might topple over and have to right themselves to get back into play. Blocking or burdening other robots may be appropriate, stealing balls or causing interference may be allowed, and aggressive play may put a robot in the winners circle or disable it altogether. Most games involve more than two robots on the field at a time with alliances arranged between groups of robots, requiring additional coordination and an agreed upon common strategy. One year, the playing surface was very slippery to simulate the low gravity of the moon.

Because the games, the robots, and members of opposing teams are new each year, it is hard to know how the opposing robots will behave. What works in one match may fail in a subsequent match if the new opponent has figured out an effective defense or plays the game differently. There are no well-honed playbooks of offenses and potential defenses.

Game play usually starts in an autonomous mode where the robot positions itself or attempts actions towards goals through the use of sensors and predefined information. After fifteen seconds, a human operator can take over control of the robot using any number of input devices available to them that transmit their commands wirelessly to the embattled robot as the game continues for another two minutes. Other human team members might be tossing balls back to the robot or otherwise actively participating from the sidelines.

## Bots

The robots start from a 28” by 38” frame and might be 5 feet tall. Most robots are made to be utilitarian and must be sturdy, but time rarely allows for the making of sporty-looking exteriors. Each team is provided with a Kit of Parts that includes the primary electronic, electrical, and mechanical components, a simple laptop and needed software.

Numerous motors create most of the motion of the robot, although pneumatic systems can be used as well. Motors may range from “Fisher-Price motors” to automobile power-window lift motors and mechanisms (gear reductions), and straightforward brushed DC motors. Sensors can assist the robot, but the variables, unknowns, and complexity involved tend to push most designs to maximize the use of the human operator and his or her eyes, ears, logic, knowledge, intelligence, and decision-making abilities. The provided parts suggest a fundamental design as shown in Figure 3.

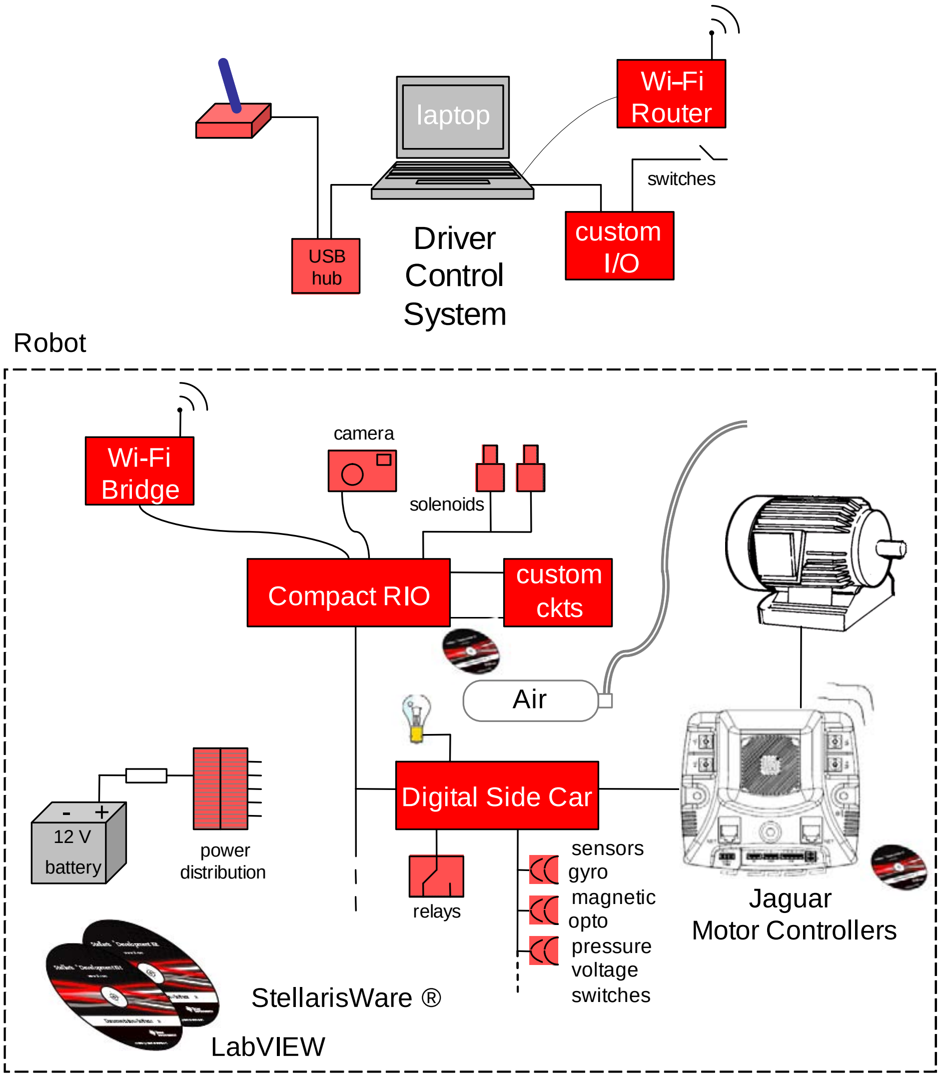

***Figure 3.*** *Block Diagram of the Robot Control System*

A driver control system is in the human operator's hands, giving him or her up to three USB joysticks, lots of buttons, and a low-cost laptop with which to drive the robot. An I/O breadboard avails the more adventuresome participant with user access to some customizable electronics with analog and digital inputs and outputs. On the playing field, the robot gets its commands from the driver over a wireless communications link consisting of a wireless router and a Wi-Fi adapter.

A 12-volt battery supplies electrical power to the mobile robot through circuit breakers and distribution buses to input and feedback sensors, control electronics, and the motors. Commands from the humans come through control modules in a National Instruments Compact RIO (cRIO) chassis. Also feeding into the cRIO, and possibly back to the human, are sensor signals from an onboard camera, gyros and accelerators, optical and magnetic encoders, and pressure sensors and switches scattered around the robot. Servos, solenoids, relays, and valves can be actuated from the cRIO. A Digital SideCar provides many of the input and output interfaces between the delicate electronics and the harsh electrical world. Fine-grain motor control is provided by pulse-width modulators under the watchful observation of algorithms running on the Texas Instruments' Jaguar motor controller.

The Kit of Parts is only the beginning of a robot, and the students must make use of the mechanics, motors, and electronics, and additional body and frame fabrications to build their robot. An example of the mechanics of one such robot is shown in Figure 4.

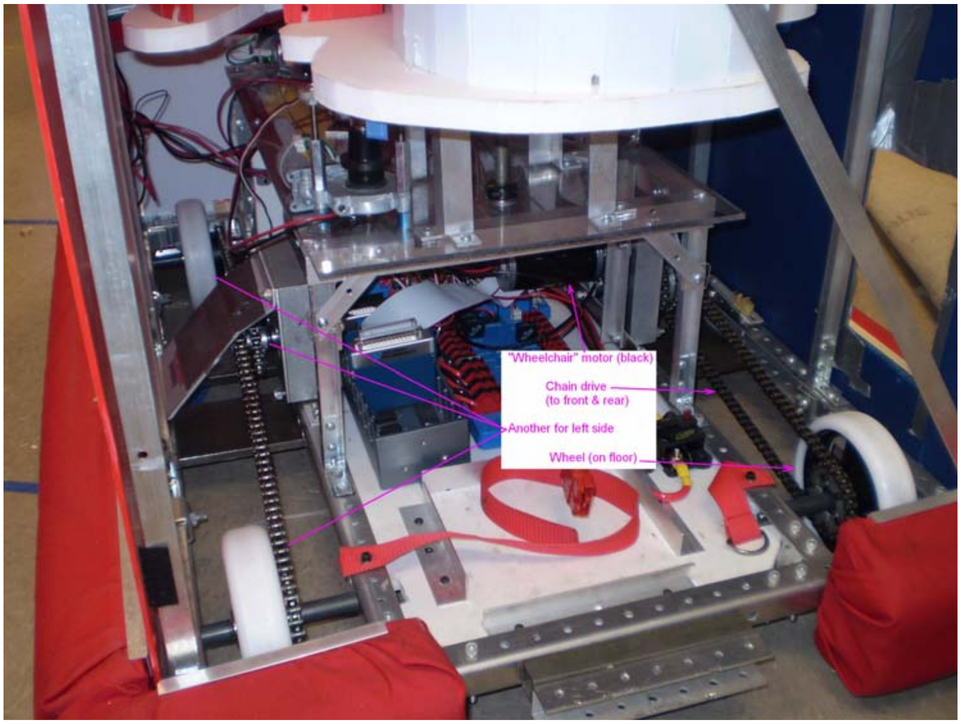

***Figure 4.*** *An Example of the Robot Mechanics in Use*

## Jaguar: TI's Stellaris® Brushed DC Motor Control

Some of the motors used in the robots are simply turned on or off. But for any sort of control of the motors or the mechanical motion they enact, perform, or enable, a Jaguar motor control module is needed. Jaguar is Texas Instruments' model MDL-BDC24 Stellaris® Brushed DC Motor Control Module with CAN (Figure 5.)

The Jaguar provides sophisticated motor control for smooth starts, increasing ramps, rock-steady motion, accurate speed, and controlled braking of 12- and 24-volt DC brushed electric motors. This module was designed, not for children to build toy robots, but for engineers needing to precisely control powerful industrial motors in coordination with complex integrated systems of motors that are part of an automated factory floor, process control, product distribution, machine tool, or medical instrument.

While sophisticated and precise control is possible, programming the Jaguar, like all Stellaris® motor controllers, is simple and straightforward. With exotic motor control algorithms already part of a library of programs that are packaged with the product including a browser-based user interface overlaying the popular National Instruments' LabVIEW control scripts, the designer can select the appropriate algorithms, enter a few parameters that describe the desired motor movements, and have the motor that comes in the kit operating properly in as little as five minutes.

***Figure 5.*** *Jaguar Stellaris® Brushed DC Motor Control Module with CAN*

This ease-of-use not only makes the kit ideal for high school students who just want to get a robot to throw a ball, but is a key feature that makes Stellaris® microcontrollers a popular choice for engineers needing motor control. Professionals under pressure to meet a deadline, don't always have time to get some algorithm implemented and debugged in C language, Java, or machine code programs on an MCU or digital signal processor (DSP). Programming is probably not his or her skill set. It's more likely to be understanding the best flow of materials around the shop floor or how a large piece of equipment should be assembled. It's a huge advantage to engineers to use off-the-shelf controls with easy-to-configure programs because time is as critical to the professionals building robotics as it is to students in a robot competition.

The Jaguar motor controller does more than just manage variable speed control for 12- and 24-volt brushed DC motors drawing up to 40 amps of continuous current. The MDL-BDC24 also includes a rich set of sensor interfaces, connectivity, and control options, including analog and quadrature encoder interfaces. Very important for multiple motor environments (like most industrial uses) are the high-performance Controller Area Network (CAN), UART, and RS232 port interfaces included in the system (other kits also offer industrialized Ethernet channels). The module uses highly optimized software and a powerful 32-bit Stellaris® microcontroller to implement open-loop voltage control as well as closed-loop control of speed, position, or motor current. The H-bridge on the MDL-BDC24 is run at high-frequency through the MCU's integrated PWM interface and enables DC motors to run smoothly and quietly over a wide speed range.

The 2010 *FIRST* competition allows teams do more with their robots though the use of the integrated CAN interface of the Jaguar motor controller. With the CAN interface, teams can:

- Update firmware over CAN, making updates faster and allowing all units to be updated simultaneously
- Read controller status, including supply voltage, temperature and current
- Configure the control mode (voltage, speed, position, current) and attributes (P, I, D, setpoint)
- Configure the attached sensor type and attributes

In addition, for *FIRST* operation, the Jaguar provides trusted communication which can be used to power down a malfunctioning robot or power down all robots to ensure that it is safe to enter the playing field.

The MDL-BDC24 is powered by the ARM® Cortex™-M3-based Stellaris® LM3S2616 microcontroller that provides efficient and deterministic performance while integrating CAN, UART, and advanced motion control capabilities. The MDL-BDC24 design also incorporates several high-quality analog components from Texas Instruments, including the SN65HVD1050 CAN Transceiver, MAX3221 RS232 Line Driver/Receiver, TPS54040 Swift DC/DC Converter, TPS73633 Voltage Regulator, and INA193 Current Shunt Monitor.

## Summary

Whether you are an engineer designing a complex system of motors, or a student participating in a robotics competition, the Jaguar module and its Stellaris microcontroller find utility in a wide variety of consumer and industrial applications, including factory automation devices and systems, mobile robots, household appliances, pumping and ventilation systems, and electric wheelchairs and mobility devices.

For more information about the *FIRST*® programs and Texas Instruments' Stellaris® microcontrollers, roam the Internet visiting:

- http://www.usfirst.org
- http://www.ti.com/stellaris
- http://focus.ti.com/docs/toolsw/folders/print/mdl-bdc24.html

FRC
FIRST Robotics Competition

The MDL-BDC24 is an official speed controller for the worldwide 2010 *FIRST*® Robotics Competition.

See http://usfirst.org for more information.

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