

# Motion Control

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## Overview

The National Instruments multiaxis motion products deliver accurate, high-performance motion for all servo and stepper applications. Our easy-to-use motion boards, software, and peripherals provide the functionality and power for integrated motion solutions. The motion boards are programmable from LabVIEW, BridgeVIEW, LabWindows/CVI, Visual Basic, and C or C++ for Windows NT/98/95 and other major operating systems. Integrated solutions and a line of easy-to-use plug and play motion controllers make our boards the best choice for PC-based motion control.

## Motion Control Boards

National Instruments has two comprehensive lines of motion control products – FlexMotion for advanced power and performance and ValueMotion for general-purpose, multiaxis motion applications.

FlexMotion offers a six-axis servo architecture with up to two stepper axes, which combines a Motorola real-time multitasking 32-bit CPU with an Analog Devices digital signal processor (DSP) to accurately control motors and generate trajectory solutions for the most complex, coordinated multiaxis control positioning sequences. FlexMotion has onboard user programming for a wide range of advanced applications.

ValueMotion consists of four-axis and two-axis stepper and servo controllers. An onboard microprocessor and per-axis DSPs or step counters offer embedded real-time control. Point-to-point motion, multiaxis coordinated control, electronic servo gearing, and velocity profiling are standard ValueMotion features.

## Motion Control Software

The National Instruments motion product line includes a wide array of application development tools for Windows NT/98/95. Use our Windows DLLs, C-Callable function libraries, LabVIEW and BridgeVIEW VIs, or C and Visual Basic examples. We include pcRunner or FlexCommander Windows software, free of charge, for quick and easy system set-up. The ServoTune software simplifies the setting of PID loop servo parameters.

The Motion VI libraries for LabVIEW and BridgeVIEW maximize the power of National Instruments motion controllers. A complete set of powerful motion functions, such as Load Target Position, Load Velocity, and Start Motion are implemented as fully functional virtual instruments. We also include ready-to-run high-level, multiaxis control VIs, along with numerous application examples.

## Motion Control Peripherals

nuDrives are motor power drivers for use with National Instruments motion control boards and application-specific motors, encoders, limits, and user I/O. A single control cable connects the motion control board to the nuDrive, providing the pathway for all command and feedback signals. Optional universal motion interface (UMI) screw terminal wiring interfaces provide access for third-party motor and driver/amplifier connection, when nuDrive features do not match the application.

# Motion Control Overview

## Advanced Motion Performance Using PC-Based Standards

Motion control on the PC is the new standard for intelligent motion integration. The combination of advanced performance, real-time, embedded CPU-based controllers, PCI bus throughput, and Windows graphical programming make PC-based motion the correct choice for powerful, easy-to-use solutions. Motion control on the PC has moved beyond ASCII text programming to interactive graphical interfaces and icon programs on multiprocessor plug-in controller boards, which offload motion tasks from the host PC. These advantages provide seamless integration of motion, vision, data acquisition, and instrument control functions in one system developed using the same software with compatible tools and backed by a uniform worldwide sales and support network. National Instruments motion products are excellent system solutions; they are unsurpassed when used in conjunction with vision and other applications.

## Motion Products for OEM Applications

OEMs need performance, reliability, flexibility, lower cost, and premium support in their motion control products. National Instruments motion control products exceed OEM expectations in all four areas; and as a result, are making equipment manufacturers successful worldwide. Our ValueMotion and FlexMotion products are performance motion controllers with the correct level of compatibility for all OEM applications. Our motion products are manufactured and tested to exceed ISO-9000 quality standards and CE conformance standards.

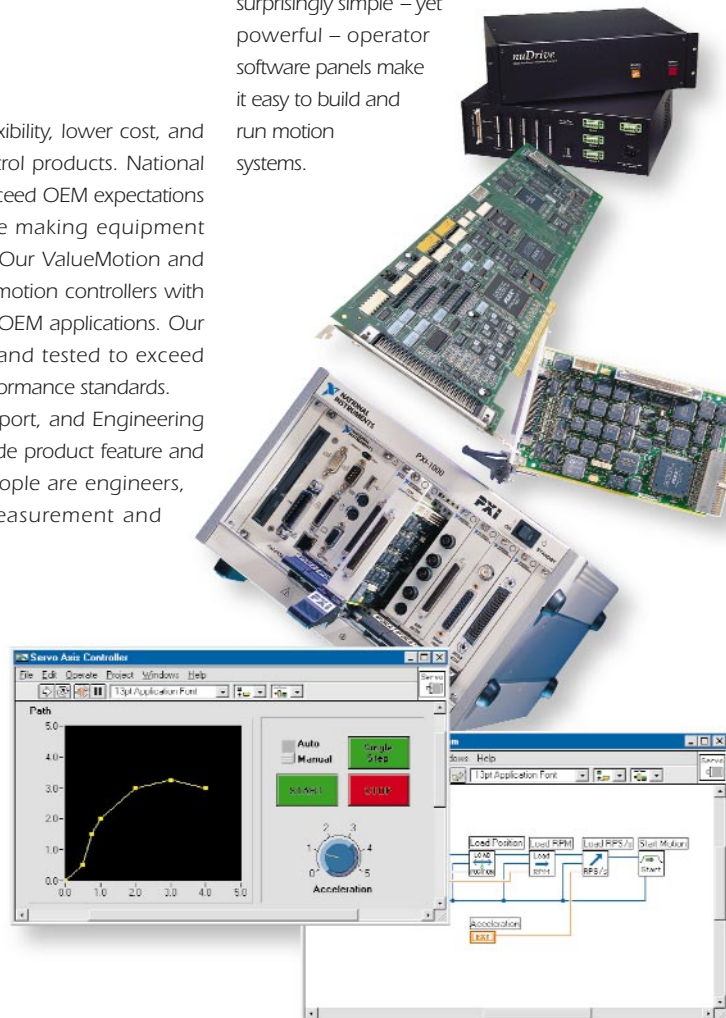
The National Instruments Sales, Support, and Engineering team works closely with OEMs to provide product feature and function enhancement. Our sales people are engineers, trained to make your PC-based measurement and automation application successful.

For OEM support well beyond the industry standard, contact one of our motion product business development managers to discuss your application requirements.

## What to Look for in Motion Control Systems

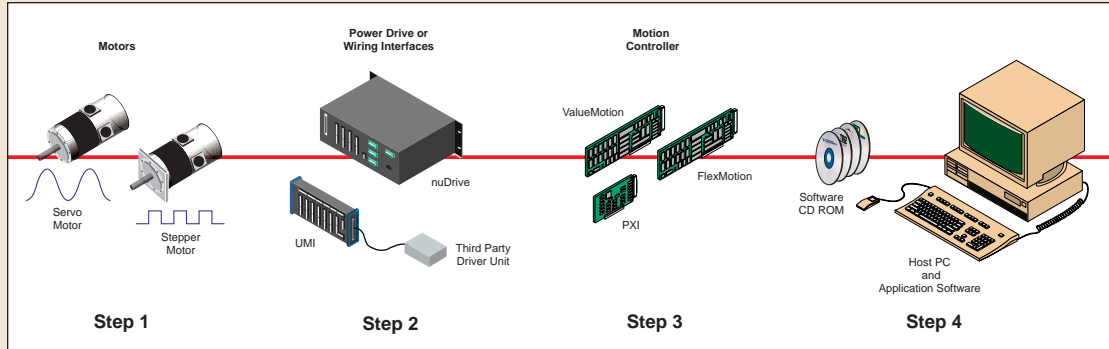
A motion control system must make integration of motion components simple while maintaining the performance and flexibility of each component. National Instruments has developed a premium offering of motion products, and software development tools designed for integration. The connectivity between National Instruments motion system components follows industry-standard specifications at each point – controller to driver, driver to motor, and software to application. This consistency makes your choice of any individual product, or an entire solution, the right choice.

To ensure rapid system development, use motion hardware and LabVIEW graphical programming software for Windows from the same company that designed these tools to work together – National Instruments. Spend more time operating your motion system and less time figuring out how to configure it. Our surprisingly simple – yet powerful – operator software panels make it easy to build and run motion systems.



# Selecting Motion Control Products

## Motion Products Selection Guide



### Step 1 – Servo or stepper motor control?

Motion systems control and drive servo motors, stepper motors, or both. When selecting the components of a system, you must first determine the type of motors that you will be operating and controlling. When identifying motor type, it is important to know how many motors or axes of motion are in the system; whether all motors are the same size or varied; and which type of position and speed feedback (if any) will the motors or motion axes send back to the controller board. Typical motor and feedback types for use with National Instruments motion products include:

#### Servo Motors

- DC brush motors
- Brushless motors
- AC servo motors
- Linear motors

#### Stepper Motors

- 2-phase stepper motors
- 5-phase stepper motors
- Linear steppers

#### Feedback Devices

- Quadrature encoder feedback
- Analog signal feedback

#### Motion I/O

- Limit switches
- Home switches
- Breakpoint outputs
- High-speed position capture inputs
- E-Stop and inhibit signals
- Stored program trigger inputs

#### Analog and Digital I/O

- A/D inputs
- D/A outputs
- Nondedicated digital I/O
- Opto-22 compatible I/O

### Step 2 – Select a nuDrive or UMI.

Motion systems include a power driver or amplifier unit that converts the control signals from the motion controller board into current and voltage power signals for the motor. The nuDrive is a fully integrated motor driver unit, and the UMI is a universal motion interface connectivity module for discrete wiring to third-party amplifier, driver and power electronics devices.

#### nuDrive

- Servo, DC brush type
- Stepper, 2-phase microstep
- 2 or 4-axis versions
- Power supplies enclosed
- Per-axis motor drivers
- Motion signal conditioning
- Power monitoring and E-Stop
- Pluggable screw terminals

#### UMI

- Universal wiring interface
- Per-axis connector layout
- Per-axis and global inhibits
- Motion signal conditioning
- Pluggable screw terminals
- 1-4 axis ValueMotion
- 1-4 or 1-6 axis FlexMotion
- All servo and stepper motor types

### Step 3 – Select a FlexMotion or ValueMotion controller.

Which motion control board family you choose depends on a number of factors. Do you need general purpose point-to-point motion or is the motion more complex, with circular movement, vector movement, and blended profiles? Are the motors stepper or servo or does the system use both? How many axes or motors do you have to control? Does your system require embedded motion programs or will the motion control programs run on the host PC? The features and capabilities of each motion control board, provide a clear indication of which board is the best choice for your system.

#### FlexMotion

- Dual processor CPU and DSP
- Powerful 6-axis servo motor control
- 16 MHz encoder input
- Up to 2-axis stepper control
- PCI and ISA versions
- Onboard embedded programs
- Advanced motion profiles
- S-curve motion
- Circular, helical, and vector motion
- Electronic gearing and blending
- Quadrature encoder and analog feedback
- Single shielded cable motion I/O
- Optocoupled limit inputs and I/O
- Fast 62  $\mu$ s PID loop update rate

#### ValueMotion

- 4-axis stepper boards for PXI/CompactPCI
- 2 or 4-axis servo for PCI and ISA
- 2 or 4-axis stepper for PCI and ISA
- Open and closed-loop stepper
- Dual processor, CPU and DSP
- Single and multiaxis point-to-point motion
- Electronic gearing for servo control
- Quadrature encoder feedback
- Single cable to nuDrive or UMI
- Lower cost general-purpose control

### Step 4 – Select your motion programming method.

#### Development Environments and Languages

- LabVIEW
- BridgeVIEW
- LabWindows/CVI
- C/C++
- Visual Basic

#### NI-Motion Driver Software

- Complete motion function libraries
- Windows NT/98/95 Programming
- 32-bit DLLs, C/C++ libraries
- Free pcRunner and FlexCommander software
- Out-of-the-box motion without programming
- Free with all motion control boards
- Multiplatform compatibility

# Motion Control Tutorial

## Introduction

Motion control is a broad term that can be simply defined as the precise control of anything that moves. National Instruments motion control products include PC-based controller boards, wiring, and connectivity devices, power driver units, and software tools and applications. These motion products are optimized for use in test and measurement automation, laboratory automation, industrial control, robotics, material handling, integrated machine vision, CNC machine tool control, and OEM motion applications.

National Instruments motion products are designed for powerful yet simple application in both point-to-point and advanced multi-axis coordinated motion systems. The full complement of software tools includes – 32-bit DLL and drivers for C/C++/Visual Basic and LabWindows/CVI in Windows NT/98/95. In addition, the software tools include ready-to-run applications for out-of-the-box motion operation and VIs for graphical object-oriented motion programming with LabVIEW and BridgeVIEW. As a user or integrator of motion control products, it is easy to achieve optimal results and leverage off new standards in motion programming with our PC-based motion control products.

## PC-Based Architecture for Servo and Stepper Control

Servo and stepper motors are widely used for position and velocity control in a variety of electromechanical configurations. Use of the PC as an operator interface (HMI), local control host, and remote system controller platform is widely accepted and growing at a significant pace.

Using an intelligent real-time controller board for motion in the PC accomplishes two major objectives in integrating motion, vision, and data acquisition. The first is offloading low-level axis control, closed-loop control, and multi-axis coordination from the host PC; the second is providing a fast, flexible, industry-standard PC-based platform for integrated motion functions.

## Understanding Motion Basics

A motion control system consists of five major components – the mechanical device being moved, the motor (servo or stepper) with feedback and motion I/O, the motor driver unit, the intelligent controller, and the programming/operator interface software. While solutions exist for a stand-alone distributed motion control and closed architecture motion controllers from other vendors, it is clear that PC-based automation, as well as a focus on PC-based motion solutions and open standards for hardware and software components, is fueling growth in this area.

Understanding the requirements of your motion system and the basic technologies for motion are key in selecting products for your application. This tutorial covers motion controller board architecture, servo and stepper motors, motor drivers, feedback for closed-loop control, motion control modes, motion I/O, and industry-standard signals for third-party motion component connectivity. The National Instruments motion products access and control these technologies while emphasizing connectivity between components and graphical tools for development.

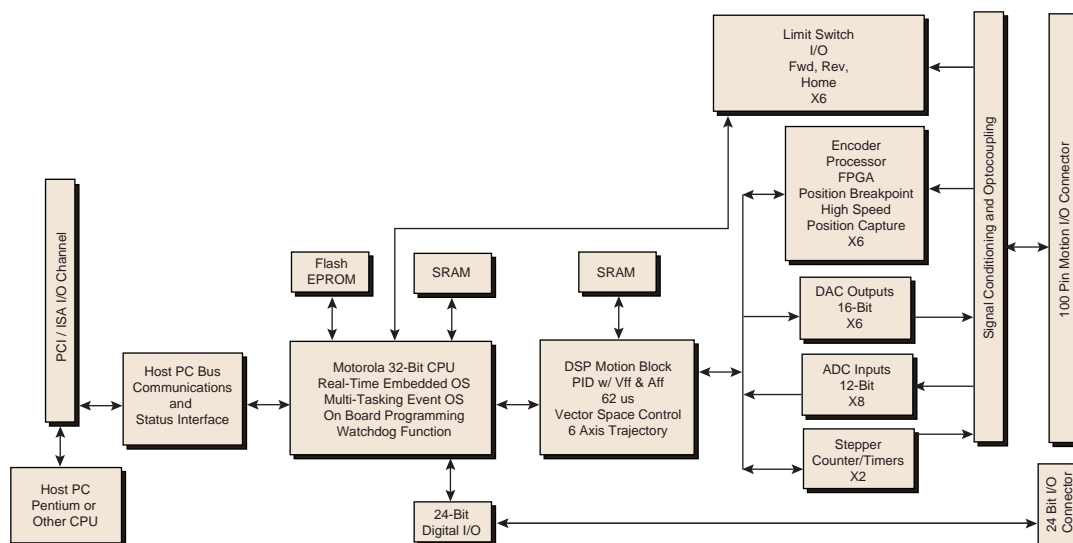


Figure 1. FlexMotion Dual-Processor Controller Block Diagram



# Motion Control Tutorial

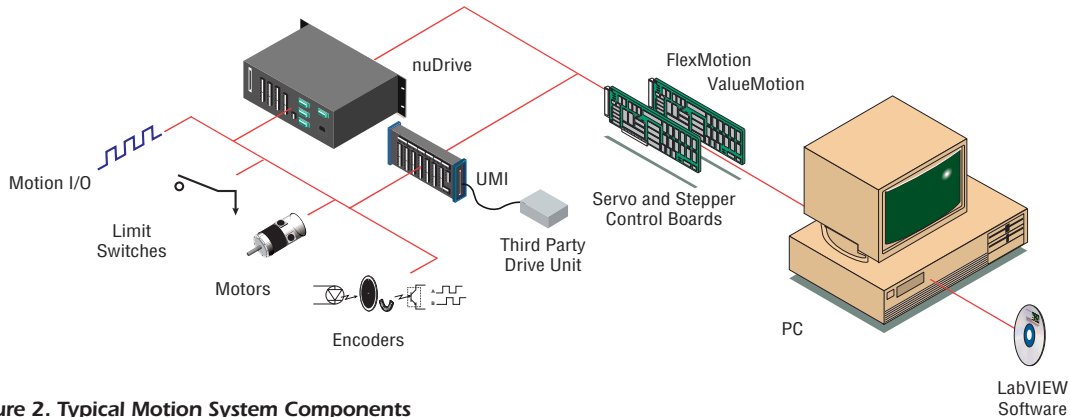


Figure 2. Typical Motion System Components

## Dual Processors for Embedded Real-Time PC-Based Motion Control

The heart of the National Instruments PC-based control architecture is a dual-processor controller board with onboard CPU and DSP components. The CPU, an embedded 32-bit microcontroller with a firmware real-time operating system (RTOS), provides high-performance motion system control, high-speed host PC-bus communications, motion trajectory path planning, motion I/O monitoring and control, and coordination of the multiaxis DSP, FPGA, and counter/timer elements. The DSP adds hard, real-time control of motion without interruption from the host PC or command communications. The DSP calculates and executes closed-loop PID servo updates simultaneously with trajectory position, velocity, acceleration, and other parameters. The DSP also updates the motor command output signals and receives the encoder feedback data for autonomous processing, leveraging off the FPGAs, DACs, ADCs, and other interface components.

While all of our motion control products are based on the dual-processor architecture, our two product families, ValueMotion and FlexMotion, use these CPU, DSP, and counter/timer capabilities differently, providing a choice of general-purpose or high-performance solutions. All National Instruments motion controller boards are designed for integrated operation of their dual processor configuration in the LabVIEW and BridgeVIEW graphical programming environments, as well as with LabWindows CVI, C/C++, Visual Basic, and other major development tools.

## Stepper and Servo Motors

Stepper and servo motors are both generic terms covering many technologies. Stepper motors are discrete motion devices that move to positions that relate directly to the number of input control pulses, at a velocity that relates directly to the pulse rate. Servo motors are continuous motion devices that use feedback signals to provide position and velocity control in a closed-loop environment.

Driving a controlled current through a number of wire coils within the motor generates the magnetic forces in a motor. Depending on their design, motors have many coils oriented in specific magnetic positions within their housing. By pulsing or steady control of current through different motor coils in a known pattern, electromagnetic fields develop in the motor, causing incremental or continuous motion.

The current and voltage that drives a motor typically comes from a power electronics device, known as an amplifier or driver. Motor drivers are located between the motion controller board and the motor.

## Servo Motors

Servo motors cover a very broad array of motor types. The National Instruments ValueMotion and FlexMotion servo motor controller boards are designed to work with all types of servo motors using industry-standard control and feedback signals.

The primary types of servo motors are DC brush servo, and brushless servo. Servo motors are continuous positioning devices that require feedback to the motion controller board to accomplish closed-loop control of positioning and velocity. An open-loop servo motor rotates or moves uncontrolled as long as power is applied to it. By implementing a control loop around a servo motor, using a PID controller and feedback from an encoder device mounted on the motor, it is possible to accurately and reliably move to the desired position at well controlled velocities following user-specified motion trajectory paths.

All servo motor systems use a motor driver power unit to control the voltage and current that flows through the motor armature and motor windings. The basic principle of motion in servo motors is based on the flow of current through a wire coil, generating a magnetic field that reacts with permanent magnets in the motor to cause attraction and repelling forces that cause movement.

## DC Brush Servo Motors

The DC brush servo motor, the simplest servo motor design, is cost effective for its performance and power in general-purpose servo applications. DC brush servo motors are self-commutating motion devices that rotate continuously while current is applied to the motor brush contacts. The current flows through the brushes to the armature and then through the motor coils, creating the magnetic forces that cause motion. Changing the direction of current flow through the motor reverses the direction of rotation. Encoder feedback to the motion board is required to provide accurate control of position and velocity with a DC brush servo motor. Encoders are mounted on the shaft of a motor or on the coupled mechanical unit as a linear or rotary device, directly translating movement into feedback data.

## Stepper Motors

Stepper motors rely on the principle of commutation or alternating magnetic forces, to provide predictable controlled motion. Commutation in motion applications is the controlled sequencing of drive currents and voltages in motor coil windings to provide torque and therefore, movement. In a stepper motor system, individual step signals from a motion control board are converted into an energizing pattern for the motor coils.

As the commutation pattern varies, the motor moves from one discrete position to another. When the pattern is held in a single state, the stepper motor holds its position with a known torque (holding torque). These single-state locations are known as the full-step locations of a stepper motor. One important stepper motor specification is the number of full steps per revolution (rotary motion) or full steps per unit length (linear motion).

The steps/revolution parameter of a stepper motor indicates the basic resolution of the motor. For example, a stepper motor with a resolution of 200 steps/revolution could also be referred to as 1.8 degree/step motor. If the motion control board output 200 steps to a full-step motor driver connected to a 1.8-degree stepper motor, the resulting movement would be a full 360 degrees of movement or one revolution of the motor. If those 200 steps were generated evenly over a period of one minute, the speed of rotation of the motor would be one revolution per minute (rpm).

## Microstepping in Stepper Motor Systems

Advanced stepper motor driver technology provides a capability known as microstepping. Microstepping is based in the stepper motor driver component. It provides for the predetermined subdivision of each full step into microsteps by proportioning the currents in each coil to produce carefully balanced electromagnetic locations between the full steps. To quickly review the technology of microstepping, sine and cosine proportioned values of current are carefully sent to particular motor coils, resulting in the simulation of interim microstep locations. The advantage of microstepping is multiplication of the number of steps per revolution, thereby increasing the resolution of a stepper motor system. Additionally, because more steps are provided, the movement between steps is smaller and the resulting step motion is typically smoother. Microstepping technology is widely accepted and fully implemented in all National Instruments stepper control and driver products.

Because stepper motion is controlled by the generation of step pulses from the controller board, it is clear that the stepper motor controller must carefully control the number of pulses (position), the frequency of the pulses (velocity), and the rate of change of frequency (acceleration/deceleration). This process is referred to as trajectory control, where the trajectory is the predictable path of speed changes that the motor undergoes as it moves from its starting position to its desired end position through its profile or as it runs continuously at desired velocities.

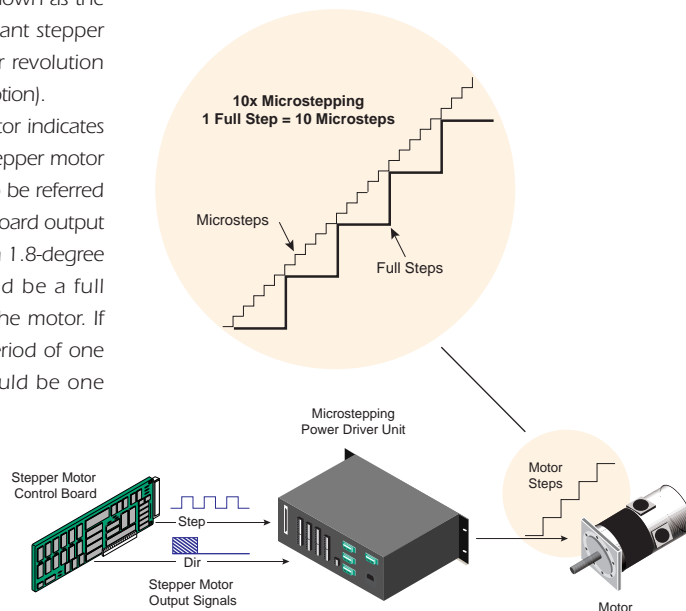


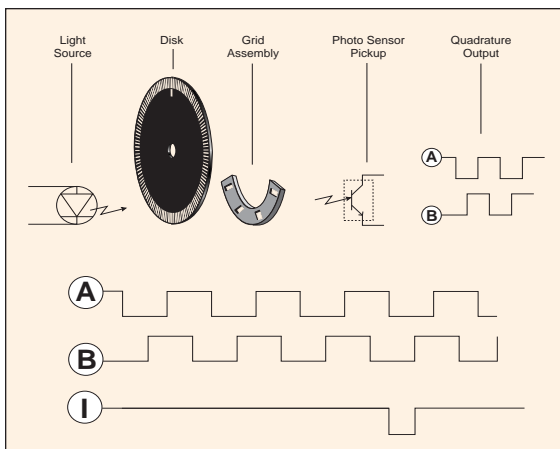
Figure 3. Stepper Motor Controllers and nuDrives Support Microstepping

# Motion Control Tutorial

## Feedback for Closed-Loop Motion Control

Motion systems use feedback signals to provide closed-loop control of position and velocity. Although feedback is optional in stepper motor systems, servo motor systems require feedback for proper control, operation, accurate motor position, and velocity maintenance. The most common feedback used with intelligent motion control boards is quadrature incremental encoder feedback.

Feedback devices provide signals that convey position and velocity data to a motion controller. The signals are converted on the motion controller into count values that correspond to position. Position values, measured over fixed periods of time, correspond to velocity. Each motion axis has separate feedback signals.



**Figure 4. Encoders are electro optic devices that provide position and velocity feedback.**

### Quadrature Encoder Feedback

Quadrature incremental encoders are optoelectronic feedback devices that use a patterned optical mask and optointerrupter-LED source/transistor detector pairs to generate two digital output waveforms, where the pulse location of the waveforms are 90 degrees out of phase with each other. This 90 degree phase difference in the waveforms (quadrature) is used by the encoder input circuitry to enhance the resolution of the position count value and to determine the direction of motion. If the A phase signal leads or comes before the B phase signal, then motion direction is considered clockwise or forward. For the opposite phasing, the direction is considered counter-clockwise or reverse.

The quadrature encoder input circuits decode the phasing of the signals and count the quadrature pulses to derive position information. The position count value is maintained in a 32-bit register, providing more than 4 billion position locations.

The detector circuits for encoder feedback on the motion controller boards incorporate digital signal filtering techniques to avoid deception by noise pulses or erroneous data that does not fit the quadrature model.

### Analog Feedback

Although quadrature encoder feedback is the most common type used, you can use analog feedback to provide the same position and velocity data. If an analog input signal is measured and converted by an ADC on the motion board, the analog value generates a corresponding digital value. This value is then used as position data and the overall range of available positions is determined from the resolution of the ADC. Analog feedback, provided on the National Instruments FlexMotion boards, is very useful in specialized motion applications.

## Motor Driver Power Devices

Motor driver power devices take the control signals generated by the motion control board and convert them into power signals that are appropriately controlled for the motor connected to the driver. Motor drivers vary with actual motor types, and as a result the motor drivers for stepper motors are different from motor drivers for DC brush or brushless servo motors. Each motor driver type is designed to convert the control signals from the controller board into power signals required by the motor.

Motor driver units require the addition of a power supply or a number of power supplies to provide the appropriate currents and voltages used in a motion system. While the level of voltage and current provided is important, additional consideration should be given to reserve capacity to store extra energy for the peak current demands of a motor during its startup or acceleration phase. Switching power supplies typically suffer from output shutdown when the motor driver attempts to draw the extra current that it requires during acceleration.

National Instruments motion control products provide two different solutions for motor driver configuration. The nuDrive units are fully enclosed motor driver subsystems with a single cable connection from the motion control board. nuDrives include the appropriate motor driver types per axis, for small DC brush type servo or stepper motors, along with bulk DC power supplies specifically designed to provide the voltage and currents demanded by these drivers. Additionally, nuDrive units incorporate all of the necessary low-voltage power supplies, wiring connectivity, signal conditioning, and monitoring that are appropriate for motion system integration with encoders, limit switches, and other motion I/O devices.

If nuDrive voltage and current capabilities do not meet the requirements of a specific motor, it is simple to connect to third-party motor drivers using a universal motion interface module (UMI).

# Motion Control Tutorial

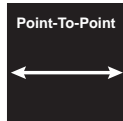
The UMI accepts the single cable connection from the motion controller board and breaks out the motor, encoder, limit, and motion I/O signals on a per-axis basis into separate pluggable screw terminal connections. The UMI provides all of the onboard signal conditioning and monitoring found in a nuDrive. Because the motion controller board outputs industry-standard signals, through the UMI, this configuration provides for limitless connectivity. You can use any size or type of motor, as long as the associated driver unit is compatible with the standard control and feedback signals.

## Motion Operation Modes

PC-based servo and stepper controller boards offer a wide variety of operation modes. The modes listed provide operational features and functionality at a high level, making it simple to solve motion applications. Access these standard operation modes in a fully integrated motion system with powerful software tools. Easy-to-use Windows software, drivers, and Motion VIs make mode operation, parameter loading, and status display a snap. Motion is controlled in absolute or relative mode, and you can use all position breakpoint, position value capture, and status functions.

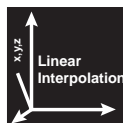
### Point-to-Point Position Mode

In point-to-point mode, each axis is independently programmed with motion profile parameters. Values for velocity, acceleration, deceleration, S-curve, and target position are loaded prior to a start command.



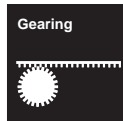
### Linear Vector Interpolation Mode

In linear vector interpolation mode, you can assign axes to a vector space; motion control of the axes accurately follows the desired vector path, at the programmed vector velocity, acceleration, and deceleration values. Vector spaces can contain one, two, or three axes and you can synchronize multiple vector spaces. You can also sequence and blend motion profiles for smooth transition.



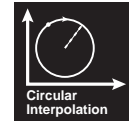
### Electronic Gearing, Master/Slave Mode

In electronic gearing and master/slave modes, you can configure any axis or axes to run at a gear ratio to any master axis. The master axis could be encoder feedback only, or a motor under closed-loop control. These powerful gearing modes are used for coil winding, flying cutoff, rotating knife, high-speed labeling, and all other geared and slaving applications.



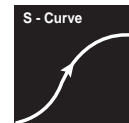
### Circular, Spherical, and Helical Interpolation Modes

In these modes, the motion parameters describing arcs, vector velocity, accel/decel, radius, start angle, and target angle are loaded before the move is started. For helical interpolation, the target height (Z) is also loaded and for spherical interpolation, two start angles and two target angles are specified. Motion will accelerate to the vector velocity while following the path indicated by target angles and height.



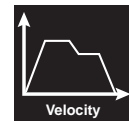
### S-Curve Acceleration/Deceleration Modes

S-curve acceleration and deceleration modes provide complete flexibility in the control of profiles for smoothing motion and eliminating jerk from mechanical systems. The degree of S-curve on a motion profile is controlled by separate acceleration and deceleration smoothing (jerk-limit) factors.



### Velocity Profiling Mode

This mode provides a user-programmed acceleration to a desired target velocity that is accurately maintained until a new target velocity value is loaded. You can change velocity on the fly.



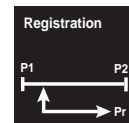
### Jog Mode

In jog mode, you can program any axis to run at a velocity (jogging speed) using loaded acceleration, deceleration, and direction values. When a start is issued, the motor runs at the jogging speed until a parameter is updated on the fly or a stop command is issued.



### Registration Mode

Registration is used to capture the exact position when the high-speed capture input signal transitions. The high-speed capture eliminates latency and provides precise motor control at high velocities. High-speed capture input position values are automatically combined with a registration move; and the new motion can be completed autonomously.



### Homing Mode

Homing is accomplished through the Find Home and Find Index commands. These control motion to search for the home switch and an optional index pulse. Find Index locates the index (marker) pulse of the feedback encoder device, and then moves to the index offset position. Homing mode is used during system setup and initialization.

