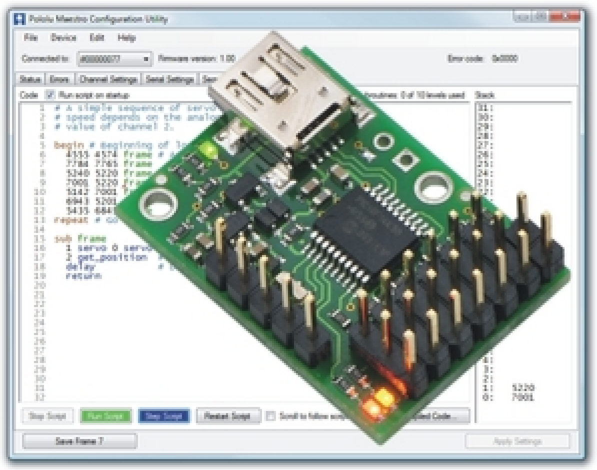
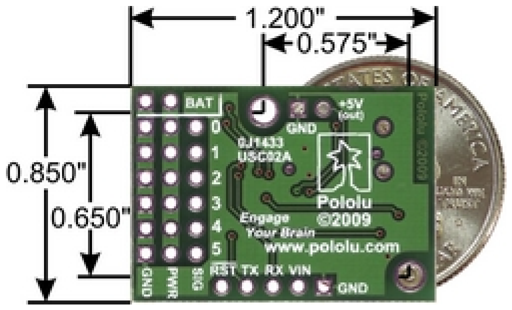
Pololu Micro Maestro Servo Controller User's Guide

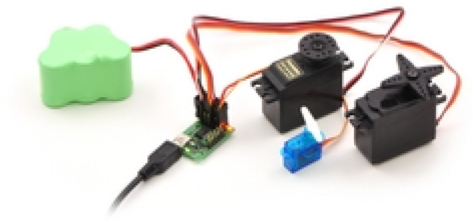


1. Overview



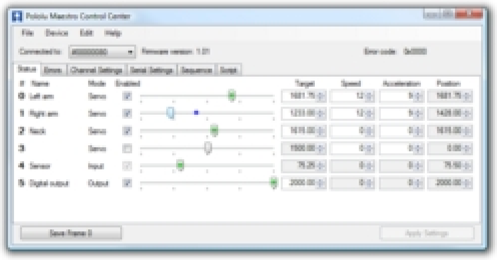
The **Micro Maestro 6-channel USB servo controller [http://www.pololu.com/catalog/product/1350]** is the first of Pololu’s second-generation USB servo controllers. With three control methods—USB for direct connection to a PC computer, TTL serial for use with embedded systems, and internal scripting for self-contained, host controller-free applications—and channels that can be configured as servo outputs for use with **radio control (RC) servos [http://www.pololu.com/catalog/category/23]** or electronic speed controls (ESCs), digital outputs, or analog inputs, the Pololu Micro Maestro is a highly versatile six-channel servo controller and general I/O board in a highly compact (0.85" × 1.20") package. The extremely accurate, high-resolution servo pulses have a jitter of less than 200 ns, making this servo controller well suited for high-precision animatronics, and built-in speed and acceleration control make it easy to achieve smooth, seamless movements without requiring the control source to constantly compute and stream intermediate position updates to the Micro Maestro.

A **USB A to mini-B cable [http://www.pololu.com/catalog/product/130]** (not included) is required to connect this device to a computer.



Features

- Three control methods: USB, TTL (5V) serial, and internal scripting
- 0.25μs output pulse width resolution (corresponds to approximately 0.025° for a typical servo, which is beyond what the servo could resolve)
- Pulse rate configurable from 33 to 100 Hz
- Wide pulse range of 64 to 3280 μs when using all six servos with a pulse rate of 50 Hz
- Individual speed and acceleration control for each channel
- Channels can also be used as general-purpose digital outputs or analog inputs
- A simple scripting language lets you program the controller to perform complex actions even after its USB and serial connections are removed
- Free configuration and control application for Windows makes it easy to:
  - Configure and test your controller
  - Create, run, and save sequences of servo movements for animatronics and walking robots
  - Write, step through, and run scripts stored in the servo controller



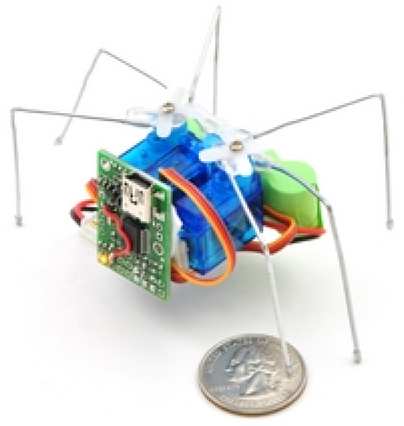
Connected to: [illegible] Firmware version: 1.01 Error code: 0x0000

#	Name	Mode	Enabled	Target	Speed	Acceleration	Position
0	Left arm	Servo	✓	1681.75	12	9	1681.75
1	Right arm	Servo	✓	1233.00	12	9	1428.00
2	Neck	Servo	✓	1615.00	0	0	1615.00
3		Servo	☐	1500.00	0	0	0.00
4	Sensor	Input		75.25	0	0	75.50
5	Digital output	Output	✓	2000.00	0	0	2000.00

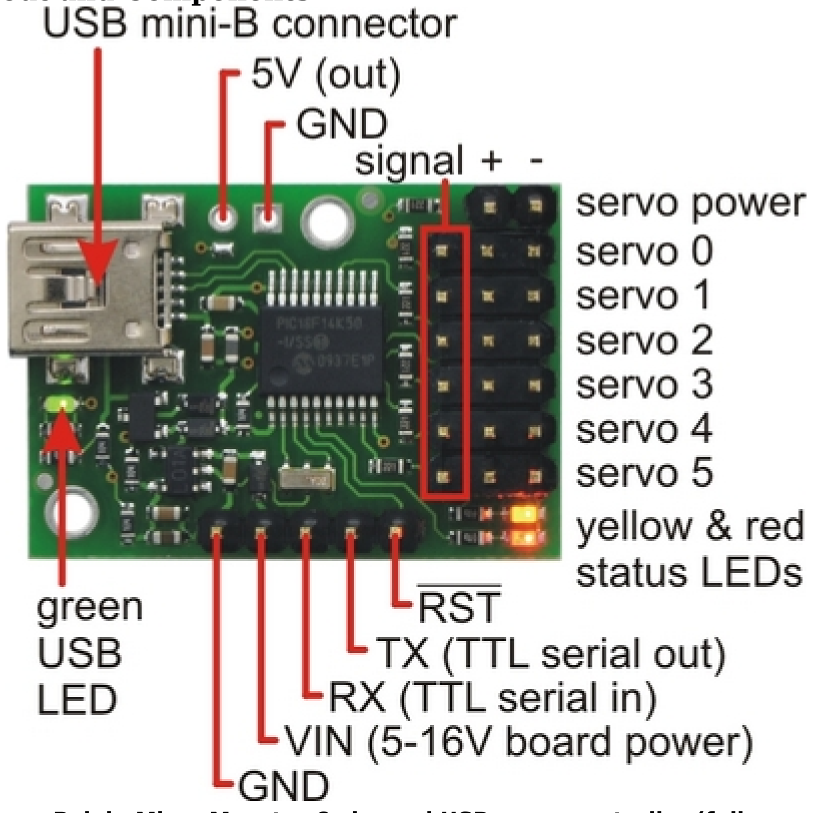
- Virtual COM port makes it easy to create custom applications to send serial commands via USB to the controller
- TTL serial features:
  - Supports 300 – 250000 kbps in fixed-baud mode
  - Supports 300 – 115200 kbps in autodetect-baud mode
  - Simultaneously supports the Pololu protocol, which gives access to advanced functionality, and the simpler Scott Edwards MiniSSC II protocol (there is no need to configure the device for a particular protocol mode)
  - Can be daisy-chained with other Pololu servo and motor controllers using a single serial transmit line
- Board can be powered off of USB or a 5 – 16 V battery, and it makes the regulated 5V available to the user
- Compact size of 0.85" × 1.20" (2.16 × 3.05 cm) and light weight of 0.17 oz (4.8 g)
- Upgradable firmware

Application Examples

- Serial servo controller for multi-servo projects (e.g. robot arms, animatronics) based on BASIC Stamp or Arduino platforms
- PC-based servo control over USB port
- PC interface for sensors and other electronics:
  - Read a **gyro [http://www.pololu.com/catalog/product/1266]** or **accelerometer [http://www.pololu.com/catalog/product/766]** from a PC for novel user interfaces
  - Control a string of **ShiftBrites [http://www.pololu.com/catalog/product/1240]** from a PC for mood lighting
- General I/O expansion for microcontroller projects
- Programmable, self-contained Halloween or Christmas display controller that responds to sensors
- Self-contained servo tester


Micro Maestro as the brains of a tiny hexapod robot.

1.a. Module Pinout and Components



Pololu Micro Maestro 6-channel USB servo controller (fully assembled) labeled top view.

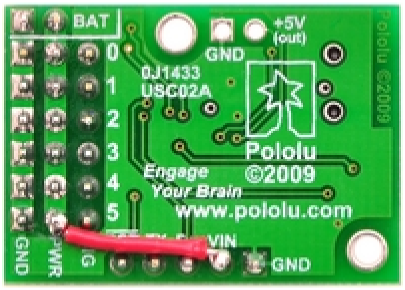
The Pololu Micro Maestro servo controller can connect to a computer's USB port via a **USB A to mini-B cable [http://www.pololu.com/catalog/product/130]** (not included). The USB connection is used to configure the servo controller. It can also be used to send commands to the servo controller, get information about the servo controller’s current state, and send and receive TTL serial bytes on the TX and RX lines.

The processor and the servos can have separate power supplies.

The processor must be powered either from USB or from an external 5–16V power supply connected to **GND** and **VIN** lines. It is okay to have an external power supply connected at the same time that USB is connected; in that case the processor will be powered from the external supply.

Servo power connections are provided in the upper right corner of the board. Servo power is passed directly to the servos without going through a regulator, so the only restrictions on your servo power supply are that it must be within the operating range of your servos and provide enough current for your application.

You can power the Maestro’s processor and servos from a single power supply by connecting the positive power line to both VIN and the servo power ports (only one ground connection is needed because all ground pins on the board are connected). One way to do this is to solder a wire on the bottom of the board between VIN and one of the servo power connections.



Pololu Micro Maestro configured to use a single power supply for both board and servos.

The **5V (out)** power output at the top of the board allows you to power your own 5V devices from the on-board regulator or from USB. The power on this pin comes from the on-board regulator if VIN is powered. Otherwise, it comes from USB.

The Maestro has three indicator LEDs:

- The **green USB LED** indicates the USB status of the device. When the Maestro is not connected to a computer via the USB cable, the green LED will be off. When you connect the Maestro to USB, the green LED will start blinking slowly. The blinking continues until the Maestro receives a particular message from the computer indicating that the Maestro’s USB drivers are installed correctly. After the Maestro gets this message, the green LED will be on, but it will flicker briefly when there is USB activity. The control center application constantly streams data from the Maestro, so when the control center is running and connected to the Maestro, the green LED will flicker constantly.
- The **red error/user LED** usually indicates an error. The red LED turns on when an error occurs, and turns off when the error flags have been cleared. See **Section 4.b** for more information about errors. The red LED can also be controlled by the user script; the red LED will be on if there is an error or if the script command for turning it on was run.
- The **yellow status LED** indicates the control status. When the Maestro is in auto-baud detect mode (the default) and has not yet detected the baud rate, the yellow LED will blink slowly. During this time the Maestro does not transmit any servo pulses. Once the Maestro is ready to drive servos, the yellow LED will periodically flash briefly. The frequency of the flashes is proportional to the servo period (the amount of time between pulses on a single channel); with a period of 20 ms the flashing occurs approximately once per second. The number of flashes indicates the channel: one flash indicates that none of the servos are enabled (no pulses are being sent) and all output channels are low, while two flashes

indicates that at least one of the servos is enabled or one of the output channels is being driven high. Also, when a valid serial command is received, the yellow LED will emit a brief, dim flash which ends when the next valid serial command is received or when the main blinking occurs (whichever happens first).

The **RX** line is used to receive non-inverted TTL (0–5 V) serial bytes, such as those from microcontroller UARTs. These bytes can either be serial commands for the Maestro, arbitrary bytes to send back to the computer via the USB connection, or both. For more information about the Maestro’s serial interface, see **Section 5.a**.

The **TX** line transmits non-inverted TTL serial bytes. These bytes can either be responses to serial commands sent to the Maestro, or arbitrary bytes sent from the computer via the USB connection.

The $\overline{\textbf{RST}}$ pin can be driven low to perform a hard reset of the Maestro’s microcontroller, but this should generally not be necessary for typical applications. The line is internally pulled high, so it is safe to leave this pin unconnected.

1.b. Supported Operating Systems

The Maestro USB drivers and configuration software work under Microsoft Windows XP, Windows Vista, Windows 7, and Linux.

The Maestro is not compatible with any version of Mac OS.

2. Contacting Pololu

You can check the **Micro Maestro 6-Servo Controller page** **[http://www.pololu.com/catalog/product/1350]** for additional information. We would be delighted to hear from you about any of your projects and about your experience with the Micro Maestro. You can **contact us** **[http://www.pololu.com/contact]** directly or post on our **forum** **[http://forum.pololu.com/]**. Tell us what we did well, what we could improve, what you would like to see in the future, or anything else you would like to say!

3. Getting Started

3.a. Installing Windows Drivers and Software

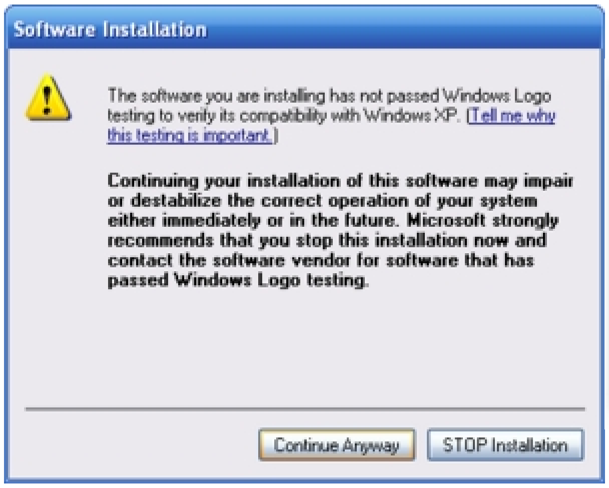
If you are using Windows XP, you will need to have **Service Pack 3** **[http://www.microsoft.com/downloads/details.aspx?FamilyId=68C48DAD-BC34-40BE-8D85-6BB4F56F5110]** installed before installing the drivers for the Maestro. See below for details.

Before you connect your Maestro to a computer running Microsoft Windows, you should install its drivers:

1. Download the **Maestro Servo Controller Windows Drivers and Software** **[http://www.pololu.com/file/download/maestro_windows_091221.zip?file_id=0J266]** (5773k zip)

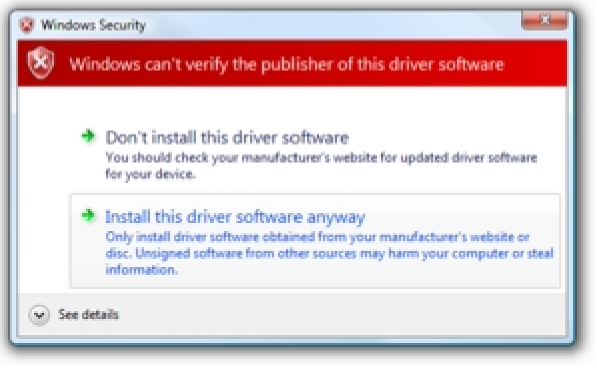
2. Open the ZIP archive and run *setup.exe*. The installer will guide you through the steps required to install the Maestro Control Center, the Maestro command-line utility (UscCmd), and the Maestro drivers on your computer. If the installer fails, you may have to extract all the files to a temporary directory, right click *setup.exe*, and select "Run as administrator".

3. During the installation, Windows will warn you that the driver has not been tested by Microsoft and recommend that you stop the installation. Click "Continue Anyway" (Windows XP) or "Install this driver software anyway" (Windows 7 and Vista).


Software Installation

The software you are installing has not passed Windows Logo testing to verify its compatibility with Windows XP. (Tell me why this testing is important.)

Continuing your installation of this software may impair or destabilize the correct operation of your system either immediately or in the future. Microsoft strongly recommends that you stop this installation now and contact the software vendor for software that has passed Windows Logo testing.


Windows Security

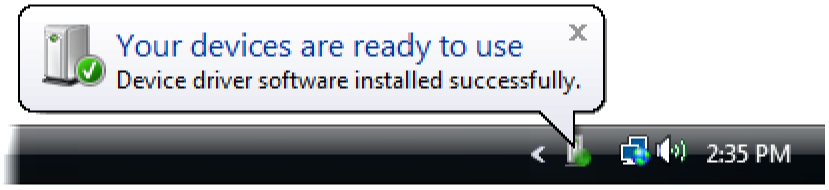
Windows can't verify the publisher of this driver software

Don't install this driver software
You should check your manufacturer's website for updated driver software for your device.

Install this driver software anyway
Only install driver software obtained from your manufacturer's website or disc. Unsigned software from other sources may harm your computer or steal information.

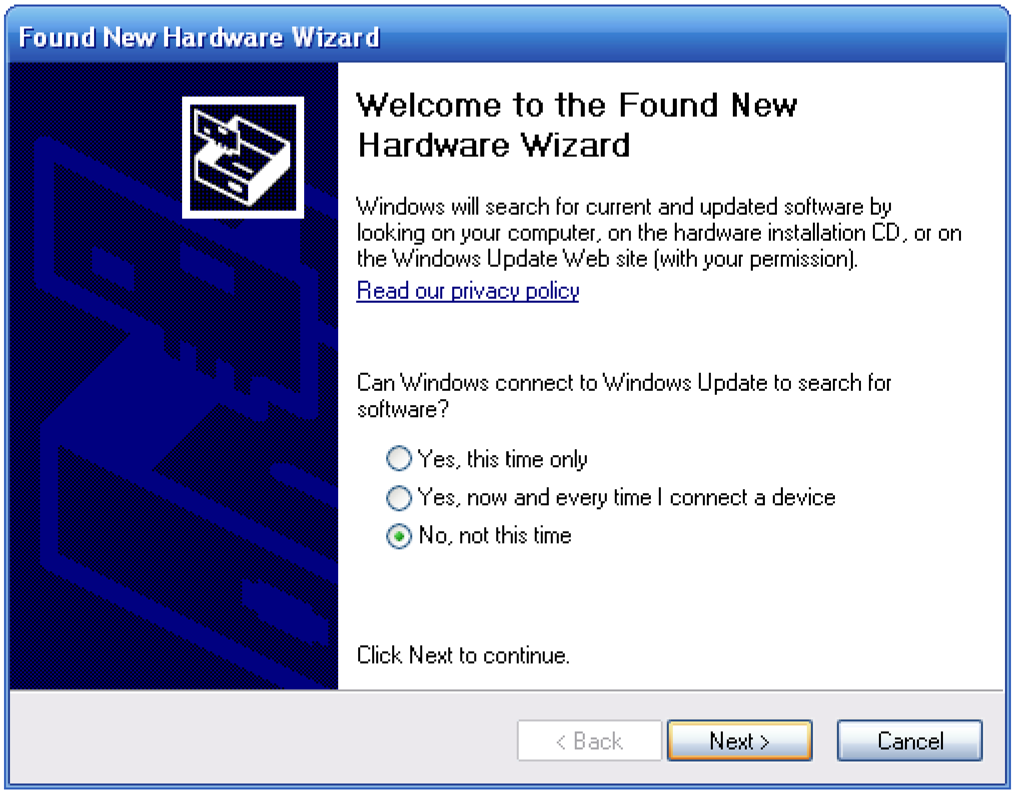
4. After the installation is finished, your start menu should have a shortcut to the *Maestro Control Center* (in the *Pololu* folder). This is a Windows application that allows you to configure, control, debug, and get real-time feedback from the Maestro. There will also be a command-line utility called *UscCmd* which you can run at a Command Prompt.

Windows 7 and Windows Vista users: Your computer should now automatically install the necessary drivers when you connect a Maestro. No further action from you is required.


Your devices are ready to use
Device driver software installed successfully.

Windows XP users: Follow steps 5–9 for each new Maestro you connect to your computer.

5. Connect the device to your computer’s USB port. **The Maestro shows up as three devices in one so your XP computer will detect all three of those new devices and display the “Found New Hardware Wizard” three times.** Each time the “Found New Hardware Wizard” pops up, follow steps 6-9.
6. When the “Found New Hardware Wizard” is displayed, select “No, not this time” and click “Next”.


Found New Hardware Wizard

Welcome to the Found New Hardware Wizard

Windows will search for current and updated software by looking on your computer, on the hardware installation CD, or on the Windows Update Web site (with your permission).

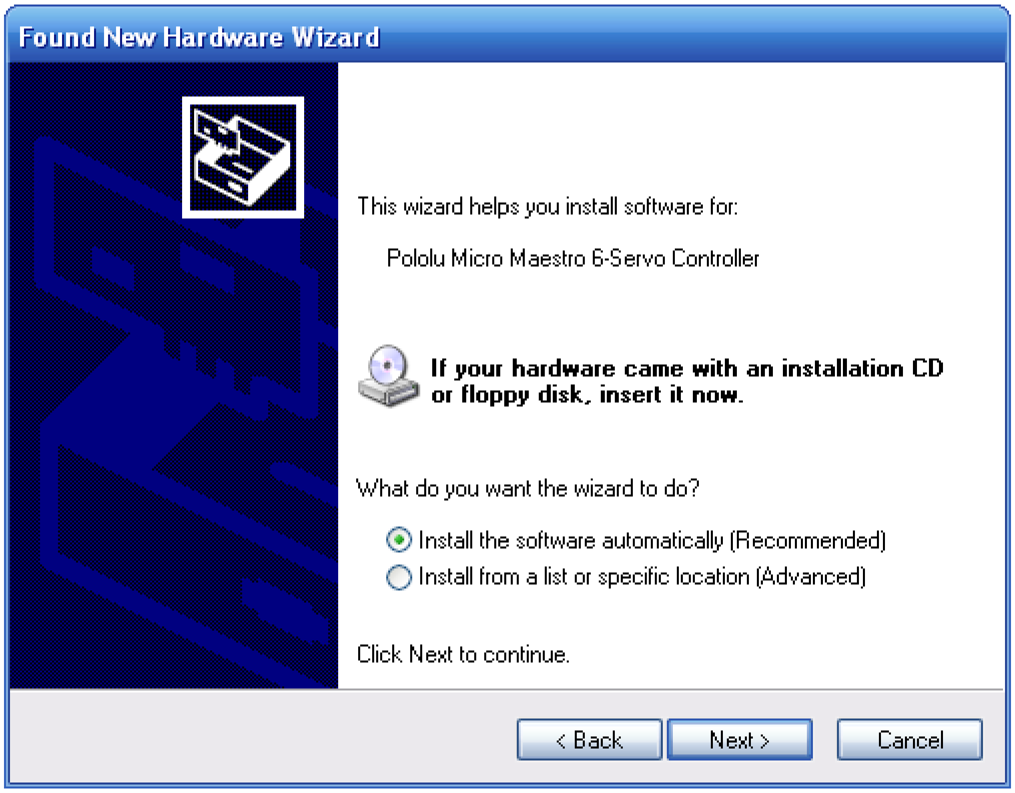
Read our privacy policy

Can Windows connect to Windows Update to search for software?

- Yes, this time only
- Yes, now and every time I connect a device
- [✓ No, not this time]

Click Next to continue.

7. On the second screen of the “Found New Hardware Wizard”, select “Install the software automatically” and click “Next”.



This wizard helps you install software for:

Pololu Micro Maestro 6-Servo Controller

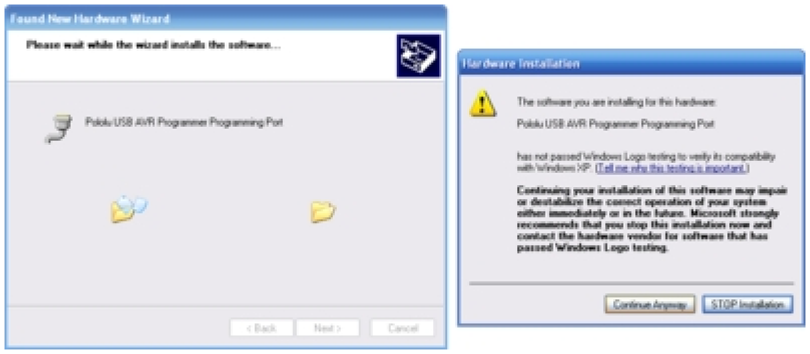
If your hardware came with an installation CD or floppy disk, insert it now.

What do you want the wizard to do?

[✓ Install the software automatically (Recommended)]
Install from a list or specific location (Advanced)

Click Next to continue.

8. Windows XP will warn you again that the driver has not been tested by Microsoft and recommend that you stop the installation. Click “Continue Anyway”.



Please wait while the wizard installs the software...

Pololu USB AVR Programmer Programming Port

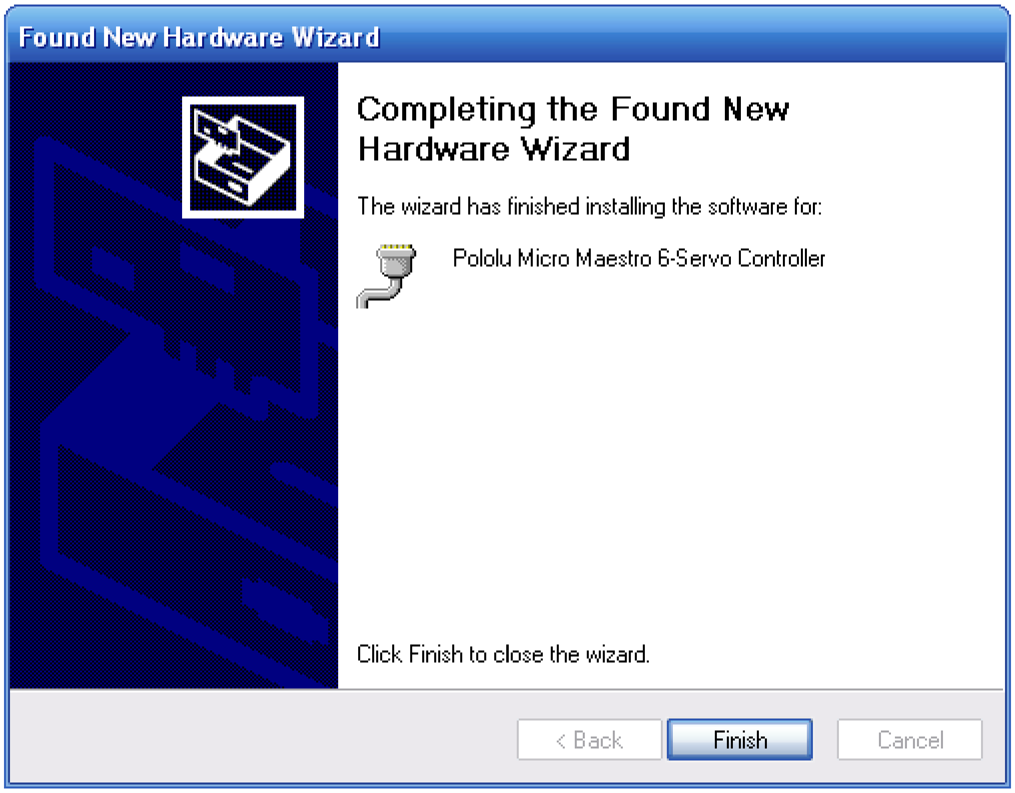
The software you are installing for this hardware:

Pololu USB AVR Programmer Programming Port

has not passed Windows Logo testing to verify its compatibility with Windows XP. (Tell me why this testing is important.)

Continuing your installation of this software may impair or destabilize the correct operation of your system either immediately or in the future. Microsoft strongly recommends that you stop this installation now and contact the hardware vendor for software that has passed Windows Logo testing.

9. When you have finished the “Found New Hardware Wizard”, click “Finish”. After that, another wizard will pop up. You will see a total of **three** wizards when plugging in the Maestro. Follow steps 6-9 for each wizard.



Completing the Found New Hardware Wizard

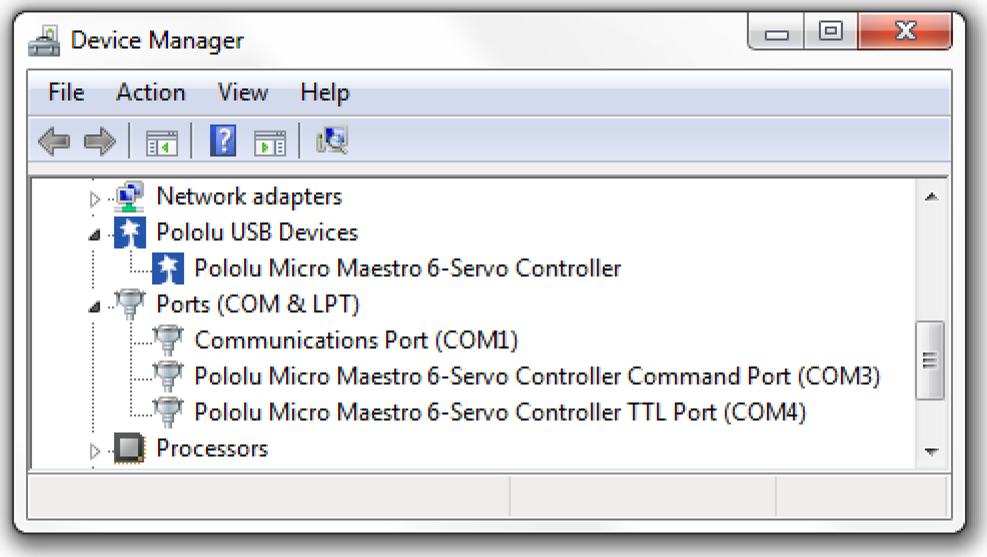
The wizard has finished installing the software for:

Pololu Micro Maestro 6-Servo Controller

Click Finish to close the wizard.

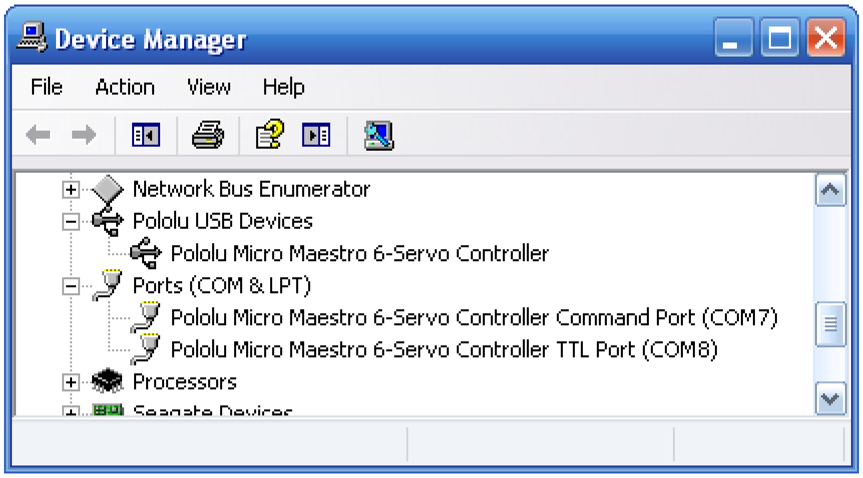
If you use Windows XP and experience problems installing or using the serial port drivers, the cause of your problems might be a bug in older versions of Microsoft's usb-to-serial driver *usbser.sys*. Versions of this driver prior to version 5.1.2600.2930 will not work with the Maestro. You can check what version of this driver you have by looking in the "Details" tab of the "Properties" window for *usbser.sys* in *C:\Windows\System32\drivers*. To get the fixed version of the driver, you will need to install **Service Pack 3** **[http://www.microsoft.com/downloads/details.aspx?FamilyId=68C48DAD-BC34-40BE-8D85-6BB4F56F5110]**. If you do not want Service Pack 3, you can try installing Hotfix KB918365 instead, but some users have had problems with the hotfix that were resolved by upgrading to Service Pack 3. The configuration software will work even if the serial port drivers are not installed properly.

After installing the drivers, if you go to your computer's Device Manager and expand the "Ports (COM & LPT)" list, you should see two COM ports: the Command Port and the TTL Port. In parentheses after these names, you will see the name of the port (e.g. "COM5" or "COM6"). If you expand the "Pololu USB Devices" list you should see an entry for the Maestro.



Network adapters
Pololu USB Devices
Pololu Micro Maestro 6-Servo Controller
Ports (COM & LPT)
Communications Port (COM1)
Pololu Micro Maestro 6-Servo Controller Command Port (COM3)
Pololu Micro Maestro 6-Servo Controller TTL Port (COM4)
Processors

Windows 7 device manager showing the Micro Maestro 6-channel USB servo controller.

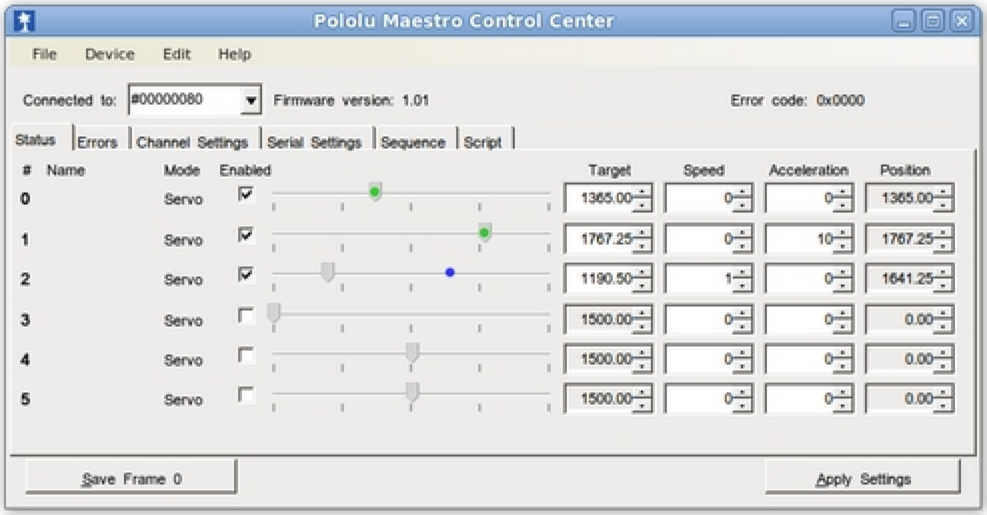


Network Bus Enumerator
Pololu USB Devices
Pololu Micro Maestro 6-Servo Controller
Ports (COM & LPT)
Pololu Micro Maestro 6-Servo Controller Command Port (COM7)
Pololu Micro Maestro 6-Servo Controller TTL Port (COM8)
Processors
Seagate Devices

Windows XP device manager showing the Micro Maestro 6-channel USB servo controller.

Some software will not allow connection to higher COM port numbers. If you need to change the COM port number assigned to your USB device, you can do so using the Device Manager. Bring up the properties dialog for the COM port and click the “Advanced…” button in the “Port Settings” tab. From this dialog you can change the COM port assigned to your device.

3.b. Installing Linux Drivers and Software



Connected to: #00000080 Firmware version: 1.01 Error code: 0x0000

#	Name	Mode	Enabled	Target	Speed	Acceleration	Position
0		Servo	✓	1365.00	0	0	1365.00
1		Servo	✓	1767.25	0	10	1767.25
2		Servo	✓	1190.50	1	0	1641.25
3		Servo		1500.00	0	0	0.00
4		Servo		1500.00	0	0	0.00
5		Servo		1500.00	0	0	0.00

The Maestro Control Center running in Ubuntu Linux.

You can download the Maestro Control Center and the Maestro command-line utility (UscCmd) for Linux here:

- **Maestro Servo Controller Linux Software** **[http://www.pololu.com/file/download/maestro_linux_091224.tar.gz?file_id=0J315]** (104k gz)

Unzip the tar/gzip archive by running “tar -xzvf” followed by the name of the file. After following the instructions in `README.txt`, you can run the programs by executing `MaestroControlCenter` and `UscCmd`.

You can also download the C# source code of *UscCmd* as part of the **Pololu USB Software Development Kit** **[http://www.pololu.com/docs/0J41]**. Read `README.txt` in the SDK for more information.

The Maestro’s two virtual serial ports can be used in Linux without any special driver installation. The virtual serial ports are managed by the *cdc-acm* kernel module, whose source code you can find in your kernel’s source code `drivers/usb/class/cdc-acm.c`. When you connect the Maestro to the PC, the two virtual serial ports should appear as devices with names like `/dev/ttyACM0` and `/dev/ttyACM1` (the number depends on how many other ACM devices you have plugged in). The port with the lower number should be the Command Port, while the port with the higher number should be the TTL Serial Port. You can use any terminal program (such as kermit) to send and receive bytes on those ports.

3.c. Using the Maestro without USB

It is possible to use the Maestro as a serial servo controller without installing any USB drivers or using a PC. Without using USB, you will not be able to change the Maestro’s settings, but you can use the default settings which are suitable for many applications. The default settings that the Maestro ships with are described below.

Default Settings

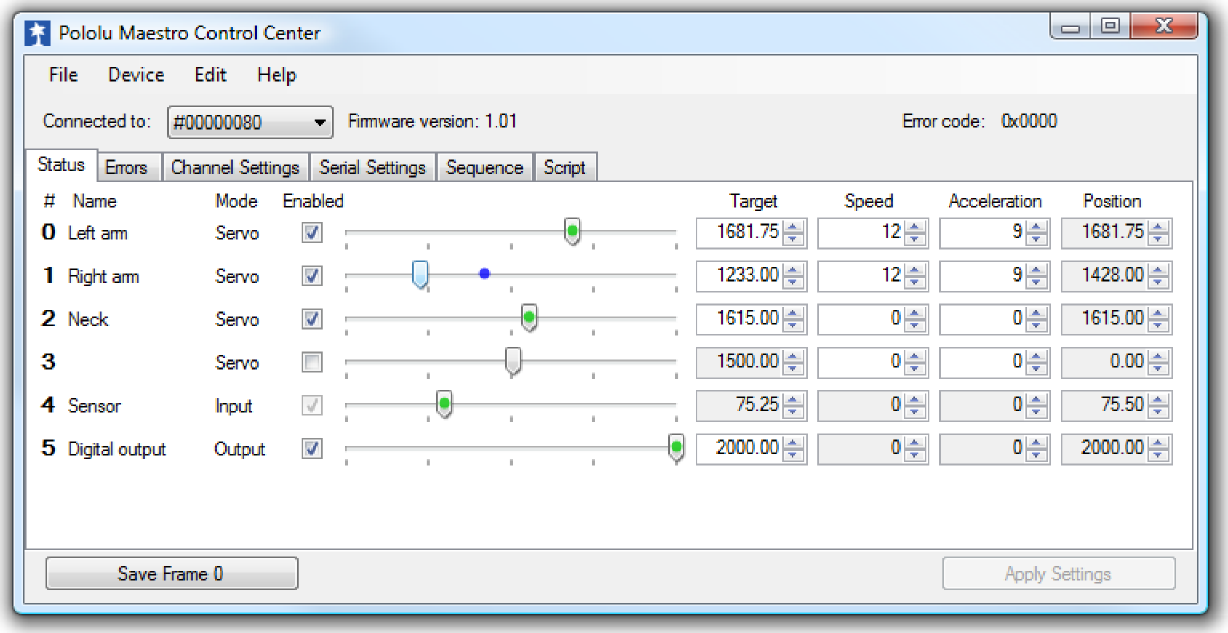
- The serial mode is “UART, detect baud rate”; after you send the 0xAA baud rate indication byte, the Maestro will accept TTL-level serial commands on the RX line.

- The Pololu Protocol device number is 12, the Mini SSC offset is 0, and serial timeout and CRC are disabled.
- All channels are configured as servos, with a minimum pulse with of 992 μs and a maximum pulse width of 2000 μs.
- The 8-bit neutral point is 1500 μs and the 8-bit range is 476.25 μs.
- On startup or error, the servos turn off (no pulses are sent).
- On startup, there are no speed or acceleration limits, but you can set speed and acceleration limits using serial commands.
- The servo period is 20 ms (each servo receives a pulse every 20 ms).
- The user script is empty.

4. Using the Maestro Control Center

The Maestro’s USB interface provides access to all configuration options as well as support for real-time control, feedback, and debugging. The Maestro Control Center is a graphical tool that makes it easy for you to use the USB interface; for almost any project, you will want to start by using the control center to set up and test your Maestro. This section explains most of the features of the Maestro and the Maestro Control Center.

4.a. Status and Real-time Control



Connected to: #00000080 Firmware version: 1.01 Error code: 0x0000

#	Name	Mode	Enabled	Target	Speed	Acceleration	Position
0	Left arm	Servo	✓	1681.75	12	9	1681.75
1	Right arm	Servo	✓	1233.00	12	9	1428.00
2	Neck	Servo	✓	1615.00	0	0	1615.00
3		Servo	☐	1500.00	0	0	0.00
4	Sensor	Input	✓	75.25	0	0	75.50
5	Digital output	Output	✓	2000.00	0	0	2000.00

The Status tab in the Maestro Control Center.

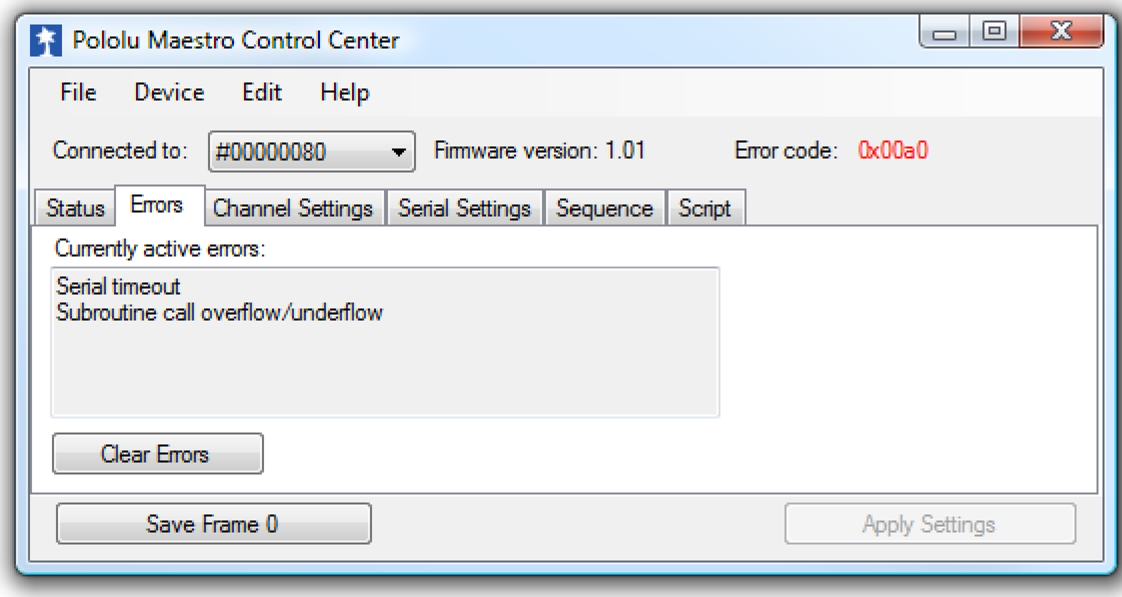
The Status tab is used for controlling the Maestro’s outputs and for monitoring its status in real time. A separate row of controls is displayed for each of the Maestro’s channels.

For a channel configured as a servo or output, the checkbox enables the output, dragging the slider adjusts the *target* setting of the channel, and the green ball indicates the channel’s current *position*. For example, if the channel is set to a relatively slow speed, when the slider is moved to a new position, the green ball will slowly move until it has reached the slider, indicating that the output has reached its target. For more precise control, a target value may also be entered directly into the “Target” input box. The slider is automatically scaled to match the minimum and maximum values specified in the Settings tab.

For a channel configured as input, the slider, green ball, “Target”, and “Position” display the current value of the input, as a value from 0 to 1023. There is no control available for inputs. The “Speed” and “Acceleration” inputs allow the *speed* and *acceleration* of individual servo channels to be adjusted in real time. The default values are specified in the Settings tab, but it can be useful to adjust them here for fine-tuning.

All of the controls on this tab always display the current values as reported by the Maestro itself, so they are useful for monitoring the actions caused by another program or device. For example, if a microcontroller uses the TTL serial interface to change the speed of servo channel 2 to a value of 10, this value will be displayed immediately in the corresponding input, even if something else was formerly entered there.

4.b. Errors



Connected to: #00000080 Firmware version: 1.01 Error code: 0x00a0

Currently active errors:

Serial timeout
Subroutine call overflow/underflow

The Errors tab in the Maestro Control Center.

The Errors tab indicates problems that the Maestro has detected while running, either communications errors or errors generated by bugs in a script.

Each error corresponds to a bit in the two-byte error register. The red LED will be on as long as any of the bits in the error register are set to 1 (it can also be turned on by the **led_on** script command). The value of the error register is displayed in the upper right corner of the main window.

When an error occurs, the corresponding bit in the error register is set to 1 and the Maestro sends all of its servos and digital outputs to their home positions, as specified in the Settings tab (**Section 4.e**). Any servos or outputs that are configured to be in the “Ignore” mode will not be changed. The error register is cleared by the “Get Errors” serial command.

The errors and their corresponding bit numbers are listed below:

- **Serial Signal Error (bit 0)**
  A hardware-level error that occurs when a byte’s stop bit is not detected at the expected place. This can occur if you are communicating at a baud rate that differs from the Maestro’s baud rate.
- **Serial Overrun Error (bit 1)**
  A hardware-level error that occurs when the UART. This should not occur during normal operation.
- **Serial RX buffer full (bit 2)**
  A firmware-level error that occurs when the firmware’s buffer for bytes received on the RX line is full and a byte from RX has been lost as a result. This error should not occur during normal operation.

- **Serial CRC error (bit 3)**

This error occurs when the Maestro is running in CRC-enabled mode and the cyclic redundancy check (CRC) byte at the end of the command packet does not match what the Maestro has computed as that packet's CRC (**Section 5.d**). In such a case, the Maestro ignores the command packet and generates a CRC error.

- **Serial protocol error (bit 4)**

This error occurs when the Maestro receives and incorrectly formatted or nonsensical command packet. For example, if the command byte does not match a known command or an unfinished command packet is interrupted by another command packet, this error occurs.

- **Serial timeout error (bit 5)**

When the serial timeout is enabled, this error occurs whenever the timeout period has elapsed without the Maestro receiving any valid serial commands. This timeout error can be used to make the servos return to their home positions in the event that serial communication between the Maestro and its controller is disrupted.

- **Script stack error (bit 6)**

This error occurs when a bug in the user script has caused the stack overflow or underflow. Any script command that modifies the stack has the potential to cause this error.

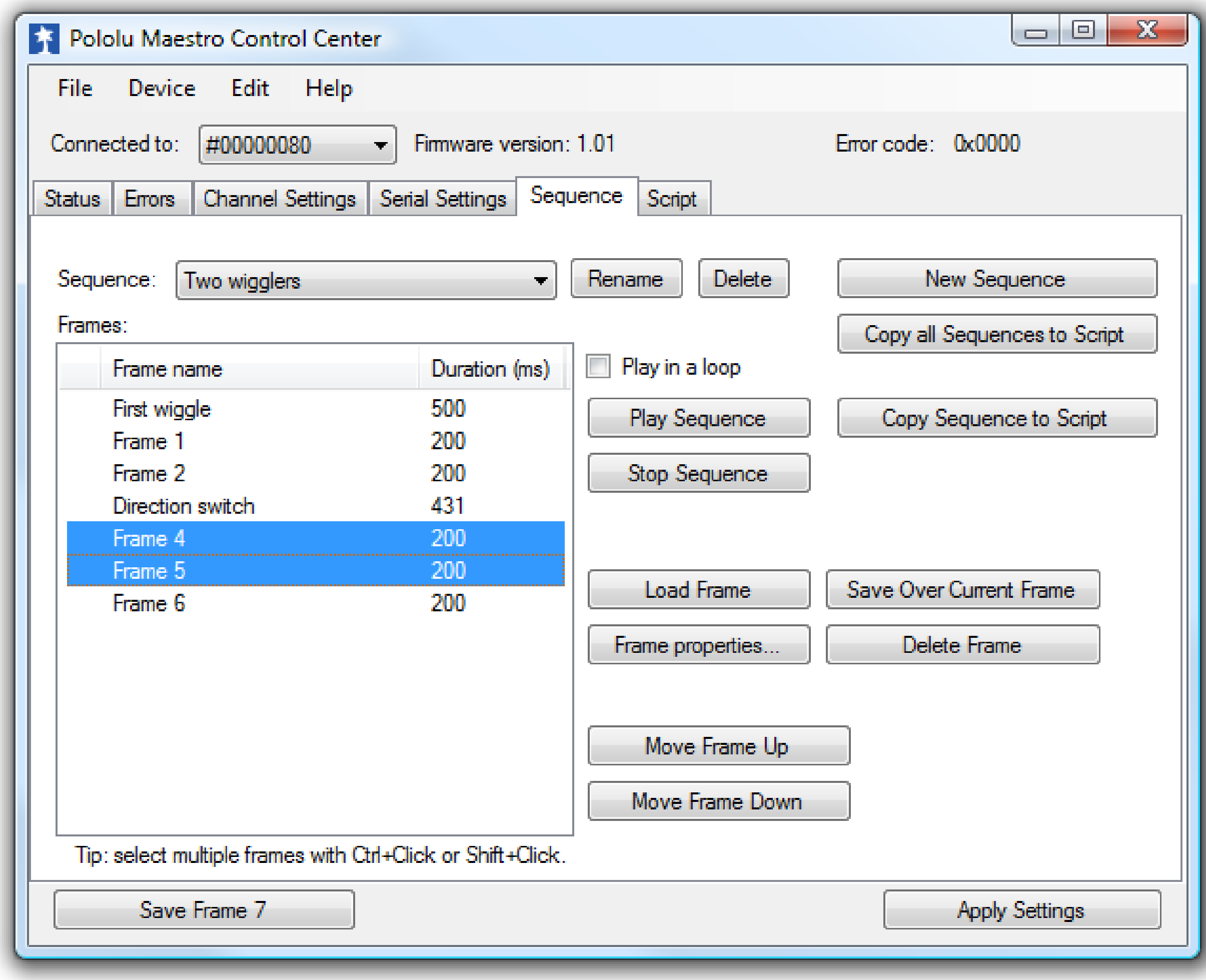
- **Script call stack error (bit 7)**

This error occurs when a bug in the user script has caused the call stack overflow or underflow. An overflow can occur if there are more than 10 levels of nested subroutines, or a subroutine that calls itself too many times. An underflow can occur when there is a return without a corresponding subroutine call. An underflow will occur if you run a subroutine using the “Restart Script at Subroutine” serial command and the subroutine terminates with a **return** command rather than a **quit** command or an infinite loop.

- **Script program counter error (bit 8)**

This error occurs when a bug in the user script has caused the program counter (the address of the next instruction to be executed) to go out of bounds. This can happen if you program is not terminated by a **quit**, **return**, or infinite loop.

4.c. Sequencer



Connected to: #00000080 Firmware version: 1.01 Error code: 0x0000

Sequence: Two wigglers

Frames:

Frame name	Duration (ms)
First wiggle	500
Frame 1	200
Frame 2	200
Direction switch	431
Frame 4	200
Frame 5	200
Frame 6	200

Tip: select multiple frames with Ctrl+Click or Shift+Click.

The Sequence tab in the Maestro Control Center.

The Sequence tab allows simple motion sequences to be created and played back on the Maestro. A sequence is simply a list of “frames” specifying the positions of each of the servos and a duration (in milliseconds) for each frame. Sequences are stored in the registry of the computer where the sequence was created. Sequences can be copied to the script, which is saved on the Maestro. Sequences can also be exported to another computer via a saved settings file.

To begin creating a sequence, click the “New Sequence” button and enter a name for the sequence. Using the controls in the Status tab, set each of the servos to the position you would like for the first frame, then click “Save Frame” at the bottom of the window. Repeat to create several frames, then switch back to the Sequence tab. You can now play back the sequence using the “Play Sequence” button, or you can set the servos to the positions of the specific frame by clicking the “Load Frame” button.

You can drag any of the tabs out of the main window in to their own windows. If you drag the Sequence tab out of the window then you will be able to see the Status tab and the Sequence tab at the same time.

The “Sequence” dropdown box and the “Rename” and “Delete” buttons next to it allow you to create and manage multiple sequences.

The “Frame properties...” button allows you to set the duration and name of a frame.

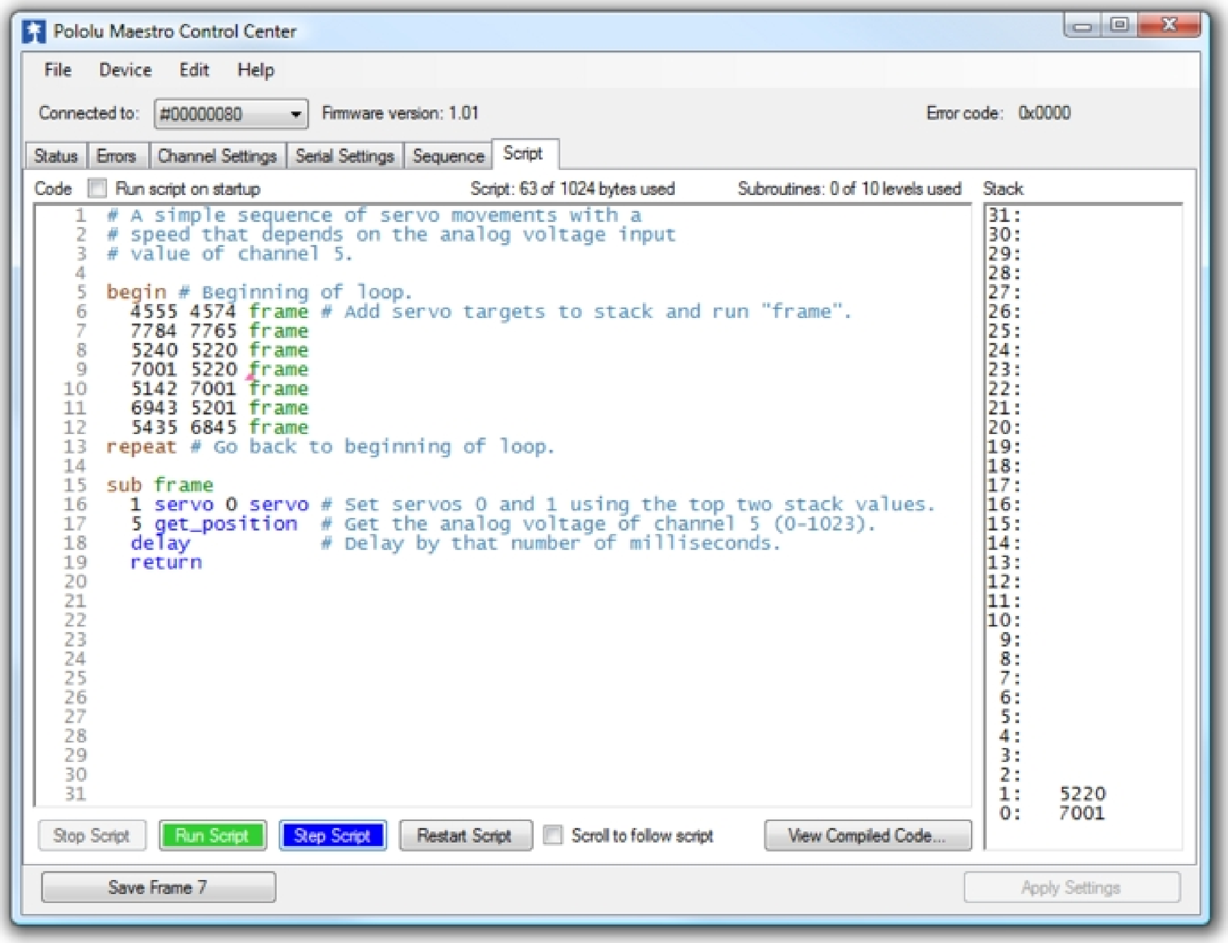
You can select multiple frames by holding down the Control or Shift buttons while clicking on them. This allows you to quickly move, delete, set the duration of, or save over several frames at once.

If the “Play in a loop” checkbox is checked, sequence playback will loop back to the beginning of the sequence whenever it reaches the end.

A sequence can also be used to create a script which is stored on the Maestro. There are two buttons for copying the sequence into the script:

- **Copy Sequence to Script** sets the script to a looped version of the sequence. In most cases, you will also want to check the “Run script on startup” option in the Script tab so that the script runs automatically when the Maestro is powered up, enabling fully automatic operation without a connection to a computer.
- **Copy all Sequences to Script** is an advanced option that adds a set of subroutines to the end of the current script. Each subroutine represents one of the sequences; calling the subroutine from the script will cause the sequence to be played back a single time. These subroutines must be used together with custom script code; for example, you could make a display in which a button connected to an input channel triggers a sequence to play back.

4.d. Entering a Script



Connected to: #00000080 Firmware version: 1.01 Error code: 0x0000

Script: 63 of 1024 bytes used Subroutines: 0 of 10 levels used

```
# A simple sequence of servo movements with a
# speed that depends on the analog voltage input
# value of channel 5.

begin # Beginning of loop.
  4555 4574 frame # Add servo targets to stack and run "frame".
  7784 7765 frame
  5240 5220 frame
  7001 5220 frame
  5142 7001 frame
  6943 5201 frame
  5435 6845 frame
repeat # Go back to beginning of loop.

sub frame
  1 servo 0 servo # Set servos 0 and 1 using the top two stack values.
  5 get_position  # Get the analog voltage of channel 5 (0-1023).
  delay           # Delay by that number of milliseconds.
  return
```

```
31:
30:
29:
28:
27:
26:
25:
24:
23:
22:
21:
20:
19:
18:
17:
16:
15:
14:
13:
12:
11:
10:
 9:
 8:
 7:
 6:
 5:
 4:
 3:
 2:
 1:    5220
 0:    7001
```

The Script tab in the Maestro Control Center.

The Script tab is where you enter a script to be loaded into the Maestro. For details on the Maestro scripting language, see **Section 6**. Once you have entered a script and clicked the “Apply Settings” button to load the script on to the device, there are a number of options available for testing and debugging your script on the Script tab.

Running and stepping through a script

To start a script running, click the green button labeled “Run Script”. Your script will be processed by the Maestro, one instruction at a time, until a QUIT instruction is reached or an error occurs. In many cases it will be useful to use a loop of some kind to cause a script to run forever. While the script is running, the red “Stop Script” button will be available, and the small pink triangle will jump around your source code, showing you the instruction that is currently being executed. If the script places data on the stack, it will be visible on the right side of the tab, and nested subroutine calls are counted in a label at the top of the tab.

To examine the operation of a script in more detail, click the blue button labeled “Step Script”. This button causes the script to execute a single instruction, then stop and wait for another command. By stepping through the script a single instruction at a time, you can check that each part of your program does exactly what you expect it to do.

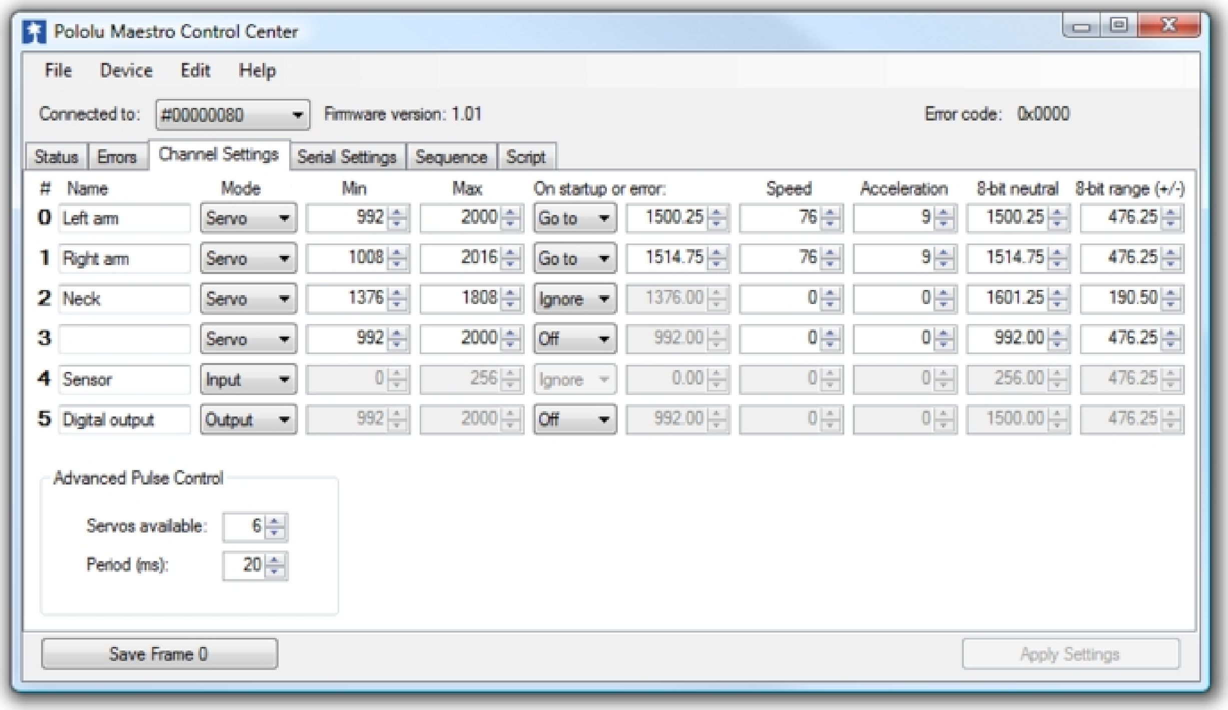
Setting the script to be run on startup

By default, the script only runs when you click the “Run Script” button. However, for many applications, you will want the script to run automatically, so that the Maestro can be used without a permanent USB connection. Check the “Run script on startup” option to cause the Maestro to automatically run the script whenever it is powered up. You will still be able to use the controls on the Script tab to for debugging or to stop the running script.

Examining the compiled code

Click the “View Compiled Code” button to see the actual bytes that are created by each line of your script. This is available mostly as a tool for developers; if you are interested in the details of the bytecode used on the Maestro (for example, if you want to write your own compiler), please **contact us** **[http://www.pololu.com/contact]**. At the end of the compiled code is a listing of all of the subroutines, including their numbers in decimal and hex notation. These numbers can be used with serial commands to enter the subroutines under external control.

4.e. Channel Settings



Connected to: #00000080 Firmware version: 1.01 Error code: 0x0000

#	Name	Mode	Min	Max	On startup or error:		Speed	Acceleration	8-bit neutral	8-bit range (+/-)
0	Left arm	Servo	992	2000	Go to	1500.25	76	9	1500.25	476.25
1	Right arm	Servo	1008	2016	Go to	1514.75	76	9	1514.75	476.25
2	Neck	Servo	1376	1808	Ignore	1376.00	0	0	1601.25	190.50
3		Servo	992	2000	Off	992.00	0	0	992.00	476.25
4	Sensor	Input	0	256	Ignore	0.00	0	0	256.00	476.25
5	Digital output	Output	992	2000	Off	992.00	0	0	1500.00	476.25

Advanced Pulse Control

Servos available: 6

Period (ms): 20

The Channel Settings tab in the Maestro Control Center.

The Channel Settings tab contains controls for many of the channel-related parameters that are stored on the Maestro, affecting its operation immediately on start-up.

A separate row of controls is displayed for each of the Maestro’s channels:

Name. Each of the channels may be assigned a name, for your convenience. Channel names are not stored on the device but instead in the system registry on your conmputer; if you want to use your Maestro on a different computer without losing the names, save a settings file on the old computer and load it into the Maestro with the new one.

Mode. The mode of the channel is the most basic setting determining its operation. There are three options:

- **Servo** (the default) indicates an R/C servo PWM output. By default, a servo output is capable of providing pulses from 64 us to 3280 us at a period of 20 ms, but the period is adjustable, and the limits depend on the value selected for “Servos available”.
- **Input** specifies that the channel should be used as an analog input. The voltage on the analog inputs are measured continuously as a value between 0 and 1023 (VCC), at a maximum rate of about 20 kHz.
- **Output** specifies that the channel should be used as a simple digital output. Instead of indicating a pulse width, the position value of the channel is used to control whether the output is low (0 V) or high (VCC). Specifically, the output is low unless the position value is greater than or equal to 1500.00 us.

On startup or error. This option specifies what value the *target* of the channel should have when the device starts up (power-up or reset) or when there is an error. Note that if there is a speed or acceleration setting for the channel, the output will smoothly transition to the specified position on an error, but not during start-up, since it has no information about the previous position of the servo in this case.

- **Off** specifies that the servo should initially be off (have a value of 0), and that it should be turned off whenever an error occurs.
- **Ignore** specifies that the servo should initially be off, but that its value should not change on error.
- **Go to** specifies a default position for the servo. The servo target will be set to this position on start-up or when an error occurs.

Speed. This option specifies the speed of the servo in units of us/period. For example, with a speed of 3.00 and a period of 20 ms, the position will change at most 3.00 us per 20 ms, or 150.00 us/s.

Acceleration. This option specifies the acceleration of the servo in units of us/period^2. For example, with an acceleration of 3.00 and a period of 20 ms, the speed of the servo will change by a maximum of 150.00 us/ms every second.

8-bit neutral. This option specifies the target value, in microseconds, that corresponds to 127 neutral) for 8-bit commands.

8-bit range. This option specifies the range of target values accesible with 8-bit commands. An 8-bit value of 0 results in a target of *neutral – range*, while an 8-bit value of 254 results in a target value of *neutral + range*.

Two advanced pulse control options are available:

Period is an advanced option that sets the period of all of the servo pulses, in milliseconds. This is the amount of time between successive pulses on a given channel. If you are unsure about this option, leave it at the default of 20 ms.

Servos available is an advanced option specifying the number of channels that may be used to control servos. For example, if this value is set to 4, only the channels 0–3 will be available as servo channels. The other channels must all be set to **Input** or **Output**. The only reasons to make fewer servos available are to allow a longer maximum pulse length or a shorter period.

4.f. Upgrading Firmware

The Maestro has field-upgradeable firmware that can be easily updated with bug fixes or new features.

You can determine the version of your Maestro's firmware by running the Maestro Control Center, connecting to a Maestro, and looking at the firmware version number which is displayed in the upper left corner next to the "Connected to" dropdown box.

Version 1.01 of the firmware contains a bug fix that makes "Ignore" mode servos behave correctly at startup. The update is recommended for devices with an earlier firmware version number, including all devices shipped before November 19, 2009.

To upgrade your Maestro's firmware, follow these steps:

1. Save the settings stored on your Maestro using the "Save settings file…" option in the File menu. All of your settings will be reset to default values during the firmware upgrade.
2. Download the latest version of the firmware here:
   - **Firmware version 1.01 for the Micro Maestro [http://www.pololu.com/file/download/usc02a_v1.01.pgm?file_id=0J280]** (35k pgm) — released November 19, 2009
3. Connect your Maestro to a Windows or Linux computer using a USB cable.
4. Run the Pololu Maestro Control Center application and connect to the Maestro.
5. In the Device menu, select "Upgrade firmware…". You will see a message asking you if you are sure you want to proceed: click OK. The Maestro will now disconnect itself from your computer and reappear as a new device called "Pololu usc02a Bootloader".
   - **Windows 7 and Vista:** the driver for the bootloader will automatically be installed.
   - **Windows XP:** follow steps 6–8 from **Section 3.a** to get the driver working.
6. Once the bootloader's drivers are properly installed, the green LED should be blinking in a double heart-beat pattern, and there should be an entry for the bootloader in the "Ports (COM & LPT)" list of your computer's Device Manager.
7. Go to the window titled "Firmware Upgrade" that the Maestro Control Center opened. Click the "Browse…" button and select the firmware file you downloaded.
8. Select the COM port corresponding to the bootloader. If you don't know which COM port to select, go to the Device Manager and look in the "Ports (COM & LPT)" section.
9. Click the "Program" button. You will see a message warning you that your device's firmware is about to be erased and asking you if you are sure you want to proceed: click Yes.
10. It will take a few seconds to erase the Maestro's existing firmware and load the new firmware. **Do not disconnect the Maestro during the upgrade.**
11. Once the upgrade is complete, the Firmware Upgrade window will close, the Maestro will disconnect from your computer once again, and it will reappear as it was before. If

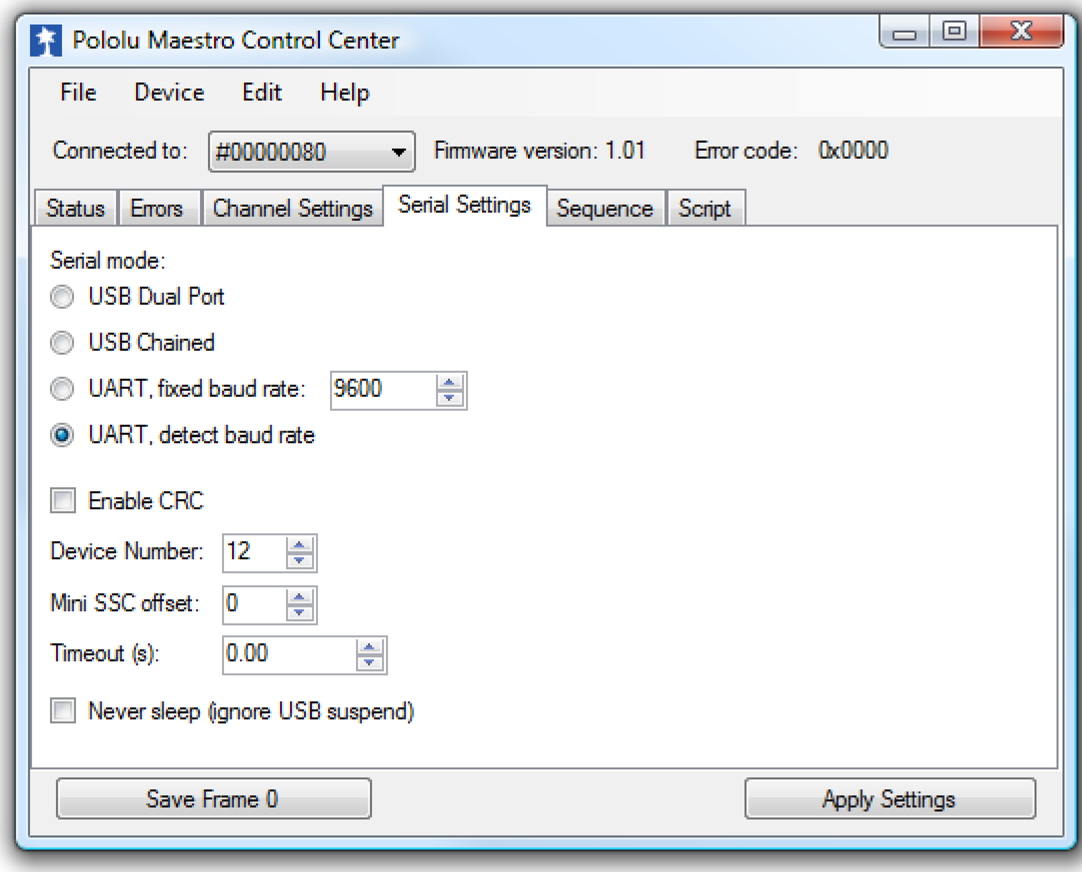
there is only one Maestro plugged in to your computer, the Maestro Control Center will connect to it. Check the firmware version number and make sure that it now indicates the latest version of the firmware.

If you run into problems during a firmware upgrade, please **contact us [http://www.pololu.com/contact]** for assistance.

5. Serial Interface

5.a. Serial Settings

The Maestro has three different serial interfaces. First, it has the **TX** and **RX** lines, which allow the Maestro to send and receive non-inverted, TTL (0 – 5 V) serial bytes (**Section 5.b**). Secondly, the Maestro shows up as two virtual serial ports on a computer if it is connected via USB. One of these ports is called the **Command Port** and the other is called the **TTL port**. In Windows, you can determine the COM port numbers of these ports by looking in your computer’s Device Manager. In Linux, the Command Port will usually be */dev/ttyACM0* and the TTL Port will usually be */dev/ttyACM1*. These numbers may be different on your computer depending on how many serial devices are active when you plug in the Maestro. This section explains the serial interface configurations options available in the **Serial Settings** tab of the Maestro Control Center.



Connected to: #00000080
Firmware version: 1.01
Error code: 0x0000

Serial mode:
- ( ) USB Dual Port
- ( ) USB Chained
- ( ) UART, fixed baud rate: 9600
- (●) UART, detect baud rate

[ ] Enable CRC

Device Number: 12

Mini SSC offset: 0

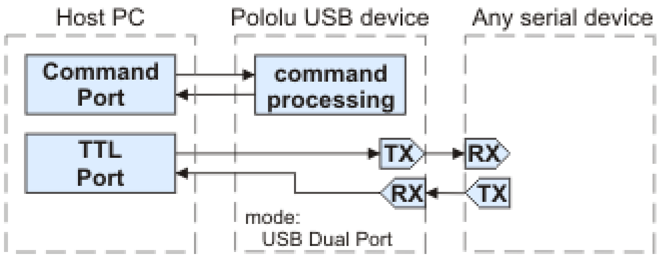
Timeout (s): 0.00

[ ] Never sleep (ignore USB suspend)

The Serial Settings tab in the Maestro Control Center.

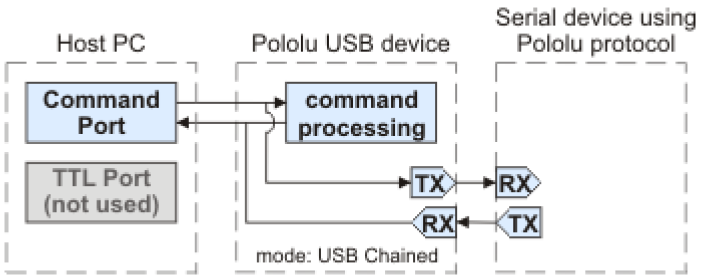
The Maestro can be configured to be in one of three basic serial modes:

USB Dual Port: In this mode, the Command Port can be used to send commands to the Maestro and receive responses from it. The baud rate you set in your terminal program when opening the Command Port is irrelevant. The TTL Port can be used to send bytes on the TX line and receive bytes on the RX line. The baud rate you set in your terminal program when opening the TTL Port determines the baud rate used to receive and send bytes on RX and TX. This allows your computer to control the Maestro and simultaneously use the RX and TX lines as a general purpose serial port that can communicate with other types of TTL serial devices.



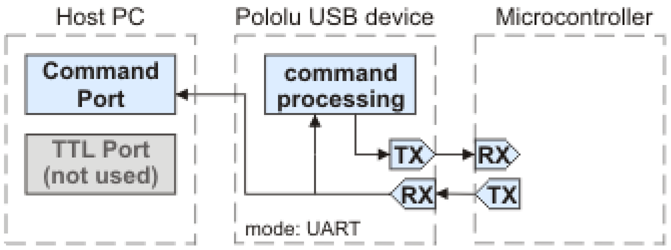
The USB Dual Port serial mode.

USB Chained: In this mode, the Command Port is used to both transmit bytes on the TX line and send commands to the Maestro. The Maestro’s responses to those commands will be sent to the Command Port but not the TX line. Bytes received on the RX line will be sent to the Command Port but will not be interpreted as command bytes by the Maestro. The baud rate you set in your terminal program when opening the Command Port determines the baud rate used to receive and send bytes on RX and TX. The TTL Port is not used. This mode allows a single COM port on your computer to control multiple Maestros, or a Maestro and other devices that have a compatible protocol.



The USB Chained serial mode.

UART: In this mode, the TX and RX lines can be used to send commands to the Maestro and receive responses from it. Any byte received on RX will be sent to the Command Port, but bytes sent from the Command Port will be ignored. The TTL Port is not used. The baud rate on TX and RX can either be automatically detected by the Maestro when a 0xAA byte is received on RX, or it can be set to a fixed value specified in bits per second (bps). This mode allows you to control the Maestro (and send bytes to a serial program on the computer) using a microcontroller or other TTL serial device.



The UART serial mode.

Other serial settings:

Enable CRC: If checked, the Maestro will require a cyclic redundancy check (CRC) byte at the end of every serial command except the Mini SSC command (see **Section 5.d**).

Device Number: This is the device number (0–127) that is used to address this device in Pololu Protocol commands. This setting is useful when using the Maestro with other devices in a daisy-chained configuration (see **Section 5.g**).

Mini SSC offset: This parameter determines which servo numbers the device will respond to in the Mini SSC protocol (see **Section 5.e**).

Timeout: This parameter specifies the duration before which a *Serial timeout* error will occur. If a valid serial command is not received within that time, the error will occur. A Timeout of 0.00 disables the serial timeout feature. The resolution of this parameter 0.01 s and the maximum value available is 655.35 s.

Never sleep (ignore USB suspend): By default, the Maestro's processor will go to sleep and stop all of its operations whenever it detects that it is only powered by USB (no VIN supply) and that the USB has entered the Suspend State. However, this behavior can be disabled by checking the *Never sleep* checkbox.

5.b. TTL Serial

The Maestro's serial receive line, RX, can receive bytes when connected to a logic-level (0 to 4.0–5 V, or "TTL"), non-inverted serial signal. The bytes sent to the Maestro on RX can be commands to the Maestro or an arbitrary stream of data that the Maestro passes on to a computer via the USB port, depending on which serial mode the Maestro is in (**Section 5.a**). The voltage on the RX pin should not go below 0 V and should not exceed 5 V.

The Maestro provides logic-level (0 to 5 V) serial output on its serial transmit line, TX. The bytes sent by the Maestro on TX can be responses to commands that request information or an arbitrary stream of data that the Maestro is receiving from a computer via the USB port and passing on, depending on which Serial Mode the Maestro is in. If you aren't interested in receiving TTL serial bytes from the Maestro, you can leave the TX line disconnected.

The serial interface is *asynchronous*, meaning that the sender and receiver each independently time the serial bits. Asynchronous TTL serial is available as hardware modules called "UARTs" on many microcontrollers. Asynchronous serial output can also be "bit-banged" by a standard digital output line under software control.

The data format is 8 data bits, one stop bit, with no parity, which is often expressed as **8-N-1**. The diagram below depicts a typical asynchronous, non-inverted TTL serial byte:

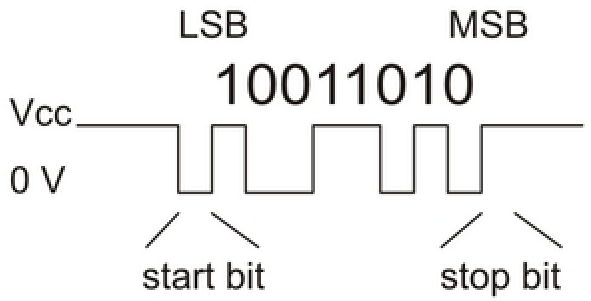


Diagram of a non-inverted TTL serial byte.

A non-inverted TTL serial line has a default (non-active) state of high. A transmitted byte begins with a single low "start bit", followed by the bits of the byte, least-significant bit (LSB) first. Logical ones are transmitted as high (VCC) and logical zeros are transmitted as low (0 V), which is why this format is referred to as "non-inverted" serial. The byte is terminated by a "stop bit", which is the line going high for at least one bit time. Because each byte requires a start bit, 8 data bits, and a stop bit, each byte takes 10 bit times to transmit, so the fastest possible data rate in bytes per second is the baud rate divided by ten. At the Maestro's maximum baud rate of 250,000 bits per second, the maximum realizable data rate, with a start bit coming immediately after the preceding byte's stop bit, is 25,000 bytes per second.

Whenever connecting devices, remember to wire the grounds together, and ensure that each device is properly powered. Unpowered devices with a TTL serial port can turn on or partially on, drawing power from the serial line, which means that extra care must be taken when turning power off and on to reset the devices.

5.c. Command Protocols

You can control the Maestro by issuing serial commands.

If your Maestro's serial mode is "UART, detect baud rate", you must first send it the baud rate indication byte **0xAA** on the RX line before sending any commands. The 0xAA baud rate indication byte can be the first byte of a Pololu protocol command.

The Maestro serial command protocol is similar to that of other Pololu products. Communication is achieved by sending command packets consisting of a single command byte followed by any data bytes that command requires. Command bytes always have their most significant bits set (they range from 128–255, or 0x80–0xFF in hex) while data bytes always have their most significant bits cleared (they range from 0–127, or 0x00–0x7F in hex). This means that each data byte can only transmit seven bits of information. The only exception to this is the Mini SSC command, where the data bytes can have any value from 0–254.

The Maestro responds to three sub-protocols:

Compact Protocol

This is the simpler and more compact of the two protocols; it is the protocol you should use if your Maestro is the only device connected to your serial line. The Maestro compact protocol command packet is simply:

command byte (with MSB set), any necessary data bytes

For example, if we want to set the target of servo 0 to 1500 µs, we could send the following byte sequence:

in hex: **0x84, 0x00, 0x70, 0x2E**
in decimal: **132, 0, 112, 46**

The byte 0x84 is the Set Target command, the first data byte 0x00 is the servo number, and the last two data bytes contain the target in units of quarter-microseconds.

Pololu Protocol

This protocol is compatible with the serial protocol used by our other serial motor and servo controllers. As such, you can daisy-chain a Maestro on a single serial line along with our other serial controllers (including additional Maestros) and, using this protocol, send commands specifically to the desired Maestro without confusing the other devices on the line.

To use the Pololu protocol, you transmit 0xAA (170 in decimal) as the first (command) byte, followed by a Device Number data byte. The default Device Number for the Maestro is **12**, but this is a configuration parameter you can change. Any Maestro on the line whose device number matches the specified device number accepts the command that follows; all other Pololu devices ignore the command. The remaining bytes in the command packet are the same as the compact protocol command packet you would send, with one key difference: the compact protocol command byte is now a data byte for the command 0xAA and hence **must have its most significant bit cleared**. Therefore, the command packet is:

0xAA, device number byte, command byte with MSB cleared, any necessary data bytes

For example, if we want to set the target of servo 0 to 1500 µs for a Maestro with device number 12, we could send the following byte sequence:

in hex: **0xAA, 0x0C, 0x04, 0x00, 0x70, 0x2E**
in decimal: **170, 12, 4, 0, 112, 46**

Note that 0x04 is the command 0x84 with its most significant bit cleared.

Mini SSC Protocol

The Maestro also responds to the protocol used by the Mini SSC servo controller. This protocol allows you to control up to 254 different servos by chaining multiple servo controllers together. It only takes three serial bytes to set the target of one servo, so this protocol is good if you need to send many commands rapidly. The Mini SSC protocol is to transmit 0xFF (255 in decimal) as the first (command) byte, followed by a servo number byte, and then the 8-bit servo target byte. Therefore, the command packet is:

0xFF, servo number byte, servo target byte

For example, if we wanted to set the target of servo 0 to its (configurable) neutral position, we could send the following byte sequence:

in hex: **0xFF, 0x00, 0x7F**
in decimal: **255, 0, 127**

The Maestro can be configured to respond to any contiguous block of Mini SSC servo numbers from 0 to 254.

The Maestro identifies the Pololu, Compact, and Mini-SSC protocols on the fly; you do not need to use a configuration parameter to identify which protocol you are using, and you can freely mix commands in the three protocols.

5.d. Cyclic Redundancy Check (CRC) Error Detection

For certain applications, verifying the integrity of the data you are sending and receiving can be very important. Because of this, the Maestro has optional 7-bit cyclic redundancy checking, which is similar to a checksum but more robust as it can detect errors that would not affect a checksum, such as an extra zero byte or bytes out of order.

Cyclic redundancy checking can be enabled by checking the "Enable CRC" checkbox in the "Serial Settings" tab of the Maestro Control Center application. In CRC mode, the Maestro expects an extra byte to be added onto the end of every command packet (except Mini SSC command packets). The most-significant bit of this byte must be cleared, and the seven least-significant bits must be the 7-bit CRC for that packet. If this CRC byte is incorrect, the Maestro will set the *Serial CRC error* bit in the error register and ignore the command. The Maestro does *not* append a CRC byte to the data it transmits in response to serial commands.

A detailed account of how cyclic redundancy checking works is beyond the scope of this document, but you can find a wealth of information using **Wikipedia** **[http://en.wikipedia.org/wiki/Cyclic_redundancy_check]**. The CRC computation is basically a carryless long division of a CRC "polynomial", 0x91, into your message (expressed as a continuous stream of bits), where all you care about is the remainder. The Maestro uses CRC-7, which means it uses an 8-bit polynomial and, as a result, produces a 7-bit remainder. This remainder is the lower 7 bits of the CRC byte you tack onto the end of your command packets.

The CRC implemented on the Maestro is the same as the one on the **jrk** **[http://www.pololu.com/catalog/product/1392]** and **qik** **[http://www.pololu.com/catalog/product/1110]** motor controller but differs from that on the **TReX** **[http://www.pololu.com/catalog/product/777]** motor controller. Instead of being done MSB first, the computation is performed LSB first to match the order in which the bits are transmitted over the serial line. In standard binary notation, the number 0x91 is written as 10010001. However, the bits are transmitted in this order: 1, 0, 0, 0, 1, 0, 0, 1, so we will write it as 10001001 to carry out the computation below.

The CRC-7 algorithm is as follows:

1. Express your 8-bit CRC-7 polynomial and message in binary, LSB first. The polynomial **0x91** is written as **10001001**.
2. Add 7 zeros to the end of your message.
3. Write your CRC-7 polynomial underneath the message so that the LSB of your polynomial is directly below the LSB of your message.
4. If the LSB of your CRC-7 is aligned under a 1, XOR the CRC-7 with the message to get a new message; if the LSB of your CRC-7 is aligned under a 0, do nothing.
5. Shift your CRC-7 right one bit. If all 8 bits of your CRC-7 polynomial still line up underneath message bits, go back to step 4.
6. What's left of your message is now your CRC-7 result (transmit these seven bits as your CRC byte when talking to the Maestro with CRC enabled).

If you have never encountered CRCs before, this probably sounds a lot more complicated than it really is. The following example shows that the CRC-7 calculation is not that difficult. For the example, we will use a two-byte sequence: **0x83, 0x01**.

```
Steps 1 & 2 (write as binary, least significant bit first, add 7 zeros to the end of the message):

    CRC-7 Polynomial = [1 0 0 0 1 0 0 1]
    message = [1 1 0 0 0 0 0 1] [1 0 0 0 0 0 0 0] 0 0 0 0 0 0 0

Steps 3, 4, & 5:
```

```
1 0 0 0 1 0 0 1 ) 1 1 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0
              XOR 1 0 0 0 1 0 0 1
                  ---------------
                    1 0 0 1 0 0 0 1
       shift  ----> 1 0 0 0 1 0 0 1

                          1 1 0 0 0 0 0 0
                          1 0 0 0 1 0 0 1

                            1 0 0 1 0 0 1 0
                            1 0 0 0 1 0 0 1

                                  1 1 0 1 1 0 0 0
                                  1 0 0 0 1 0 0 1

                                    1 0 1 0 0 0 1 0
                                    1 0 0 0 1 0 0 1

                                        1 0 1 0 1 1 0 0
                                        1 0 0 0 1 0 0 1

                                            1 0 0 1 0 1 0 0
                                            1 0 0 0 1 0 0 1

                                                  1 1 1 0 1 0 0 = 0x17
```

So the full command packet we would send with CRC enabled is: **0x83, 0x01, 0x17**.

5.e. Serial Servo Commands

The Maestro has several serial commands for setting the servo target, getting its current position, and setting is speed and acceleration limits.

Set Target (Pololu/Compact protocol)

Compact protocol: **0x84, servo number, target low bits, target high bits**
Pololu protocol: **0xAA, device number, 0x04, servo number, target low bits, target high bits**

The lower 7 bits of the third data byte represent bits 0–6 of the target (the lower 7 bits), while the lower 7 bits of the fourth data byte represent bits 7–13 of the target. The target is an integer with units of quarter-microseconds.

For example, if you want to set the target of servo 2 to 1500 µs (1500×4 = 6000 = 01011101110000 in binary), you could send the following byte sequence:

in binary: 10000100, 00000010, 01110000, 00101110
in hex: 0x84, 0x02, 0x70, 0x2E
in decimal: 132, 0, 112, 46

Here is some example C code that will generate the correct serial bytes, given an integer “servo” that holds the servo number, an integer “target” that holds the desired target (in units of quarter microseconds) and an array called serialBytes:

```
serialBytes[0] = 0x84; // Command byte: Set Target
serialBytes[1] = servo; // First data byte holds servo number.
serialBytes[2] = target & 0x7F; // Second byte holds the lower 7 bits of target.
serialBytes[3] = (target >> 7) & 0x7F;   // Third data byte holds the bits 7-13 of target.
```

Many servo control applications do not need quarter-microsecond target resolution. If you want a shorter and lower-resolution set of commands for setting the target you can use the Mini-SSC command below.

Set Target (Mini SSC protocol)

Mini-SSC protocol: **0xFF, servo number + offset, 8-bit target**

This command sets the target of a servo channel to a value specified by an 8-bit target value from 0 to 254. The 8-bit target value is converted to a full-resolution *target* value according to the *range* and *neutral* settings stored on the Maestro for that servo. Specifically, an 8-bit target of 127 corresponds to the neutral setting for that servo, while 0 or 254 correspond to the neutral setting minus or plus the range setting. These settings can be useful for calibrating motion without changing the program sending serial commands.

The servo number is a value in the range 0–254. By default, this number corresponds to the number of the servo channel, so it should be a value from 0 to 5. To allow multiple Maestros to be controlled on the same serial line, set the Mini SSC Offset parameter to different values for each Maestro. This value is added to the servo channel numbers to compute the servo number parameter for this command. For example, if the offset is 12, the channel numbers used for this command will be 12–17.

Set Speed

Compact protocol: **0x87, servo number, speed low bits, speed high bits**
Pololu protocol: **0xAA, device number, 0x07, servo number, speed low bits, speed high bits**

This command limits the *speed* at which a servo channel’s output value changes. The speed limit is given in units of (0.25 µs)/(10 ms). For example, the command 0x87, 0x05, 0x0C, 0x01 sets the speed of servo channel 5 to a value of 140, which corresponds to a speed of 3.5 µs/ms. What this means is that if you send a Set Target command to adjust the target from, say, 1000 µs to 1350 µs, it will take 100 ms to make that adjustment. A speed of 0 makes the speed unlimited, so that setting the *target* will immediately affect the *position*. Note that the actual speed at which your servo moves is also limited by the design of the servo itself, the supply voltage, and mechanical loads; this parameter will not help your servo go faster than what it is physically capable of.

At the minimum speed setting of 1, the servo output takes 40 seconds to move from 1 to 2 ms.

Set Acceleration

Compact protocol: **0x89, servo number, acceleration low bits, acceleration high bits**
Pololu protocol: **0xAA, device number, 0x09, servo number, acceleration**

This command limits the *acceleration* of a servo channel’s output. The acceleration limit is a value from 0 to 255 in units of (0.25 µs)/(10 ms)/(80 ms), with a value of 0 corresponding to no acceleration limit. An acceleration limit causes the speed of a servo to slowly ramp up until it reaches the maximum speed, then to ramp down again as *position* approaches *target*, resulting in a relatively smooth motion from one point to another. With acceleration and speed limits, only a few target settings are required to make natural-looking motions that would otherwise be quite complicated to produce.

At the minimum acceleration setting of 1, the servo output takes about 3 seconds to move smoothly from a target of 1 ms to a target of 2 ms.

Get Position

Compact protocol: **0x90, servo number**
Pololu protocol: **0xAA, device number, 0x10, servo number**
Response: position low 8 bits, position high 8 bits

This command allows the device communicating with the Maestro to get the *position* value of a servo channel. The position is sent as a two-byte response immediately after the command is received. If the specified channel is configured as a servo or an output, this position value reflects the how the Maestro is controlling the channel, reflecting the effects of any previous commands, speed and acceleration limits, or scripts running on the Maestro. For a channel configured as an input, the position is a value from 0 to 1023, representing the voltage measured on the channel, from 0 to VCC (5V).

Note the formatting of the position is different in this command, since there is no restriction on the high bit: data is formatted as a standard little-endian two-byte unsigned integer. For example, a position of 2567 corresponds to a response 0x07, 0x0A.

Get Moving State

Compact protocol: **0x93**
Pololu protocol: **0xAA, device number, 0x13, servo number**
Response: 0x00 if no servos are moving, 0x01 if servos are moving

This command is used to determine whether the servo outputs have reached their targets or are still changing, limited by speed or acceleration settings. Using this command together with the Set Target command, you can initiate several servo movements and wait for all the movements to finish before moving on to the next step of your program.

Get Errors

Compact protocol: **0xA1**
Pololu protocol: **0xAA, device number, 0x21**
Response: error bits 0-7, error bits 8-15

Use this command to examine the errors that the Maestro has detected. **Section 4.b** lists the specific errors that can be detected by the Maestro. The error register is sent as a two-byte response immediately after the command is received, then all the error bits are cleared. For most applications using serial control, it is a good idea to check errors continuously and take appropriate action if errors occur.

Go Home

Compact protocol: **0xA2**
Pololu protocol: **0xAA, device number, 0x22**

This command sends all servos and outputs to their home positions, just as if an error had occurred. For servos and outputs set to “Ignore”, the position will be unchanged.

5.f. Serial Script Commands

The Maestro has several serial commands for controlling the execution of the user script.

Stop Script

Compact protocol: **0xA4**
Pololu protocol: **0xAA, device number, 0x24**

This command causes the script to stop, if it is currently running.

Restart Script at Subroutine

Compact protocol: **0xA7, subroutine number**
Pololu protocol: **0xAA, device number, 0x27, subroutine number**

This command starts the script running at a location specified by the subroutine number argument. The subroutines are numbered in the order they are defined in your script, starting with 0 for the first subroutine. The first subroutine is sent as 0x00 for this command, the second as 0x01, etc. To find the number for a particular subroutine, click the "View Compiled Code…" button and look at the list below. Subroutines used this way should not end with the RETURN command, since there is no place to return to — instead, they should contain infinite loops or end with a QUIT command.

Restart Script at Subroutine with Parameter

Compact protocol: **0xA8, subroutine number, parameter low bits, parameter high bits**
Pololu protocol: **0xAA, device number, 0x28, subroutine number, parameter low bits, parameter high bits**

This command is just like the Restart Script at Subroutine command, except it loads a parameter on to the stack before starting the subroutine. Since data bytes can only contain 7 bits of data, the parameter must be 0 and 16383.

Get Script Status

Compact protocol: **0xAE**
Pololu protocol: **0xAA, device number, 0x2E**
Response: 0x00 if the script is running, 0x01 if the script is stopped

This command responds with a single byte, either 0 or 1, to indicate whether the script is running (0) or stopped (1). Using this command together with the commands above, you can activate a sequence stored on the Maestro and wait until the sequence is complete before moving on to the next step of your program.

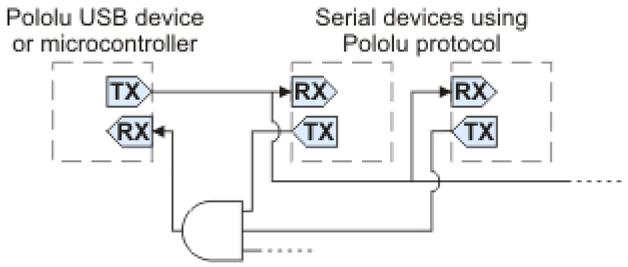
5.g. Daisy Chaining

This section is a guide to integrating the Maestro in to a project that has multiple TTL serial devices that use a compatible protocol. This section contains no new information about the Maestro: all of the information in this section can be deduced from the definitions of the three serial modes (**Section 5.a**) and the serial protocols used by the Maestro (**Section 5.c**).

First of all, you will need to decide whether to use the Pololu protocol, the Mini SSC protocol, or a mix of both. You must make sure that no serial command you send will cause unintended operations on the devices it was not addressed to. If you want to daisy chain several Maestros together, you can use a mixture of both protocols. If you want to daisy chain the Maestro with other devices that use the Pololu protocol, you can use the Pololu protocol. If you want to daisy chain the Maestro with other devices that use the Mini SSC protocol, you can use the Mini SSC protocol.

Secondly, assign each device in the project a different device number or Mini SSC offset so that they can be individually addressed by your serial commands. For the Maestro, this can be done in the Serial Settings tab of the Maestro Control Center application.

The following diagram shows how to connect one master and many slave devices together into a chain. Each of the devices may be a Maestro or any other device, such as a **jrk** **[http://www.pololu.com/catalog/product/1392]**, **qik** **[http://www.pololu.com/catalog/product/1110]** or other microcontroller.


Pololu USB device or microcontroller
Serial devices using Pololu protocol
TX
RX
RX
TX
RX
TX

Daisy chaining serial devices using the Pololu protocol. An optional AND gate is used to join multiple TX lines.

Using a PC and a Maestro together as the master device
The Maestro can enable a personal computer to be the master device. The Maestro must be connected to a PC with a USB cable and configured to be in either **USB Dual Port** or **USB Chained** serial mode. In USB Dual Port mode, the Command Port on the PC is used for sending commands directly to the Maestro, and the TTL Port on the PC is used to send commands to all of the slave devices. In the USB Chained mode, only the Command Port is used on the PC to communicate with the Maestro and all of the slave devices. Select the mode that is most convenient for your application or easiest to implement in your programming language.

Using a Maestro as a slave device
The Maestro can act as a slave device when configured to be in the **UART** serial mode. In this mode, commands are received on the RX line, and responses are sent on the TX line. A USB connection to a PC is not required, though an RX-only Comand Port is available on the PC for debugging or other purposes.

Connections
Connect the TX line of the master device to the RX lines of all of the slave devices. Commands sent by the master will then be received by all slaves.

Receiving serial responses from one of the slave devices on the PC can be achieved by connecting the TX line of that slave device to the RX line of the Maestro.

Receiving serial responses from *multiple* slave devices is more complicated. Each device should only transmit when requested, so if each device is addressed separately, multiple devices will not transmit simultaneously. However, the TX outputs are driven high when not sending data, so they cannot simply be wired together. Instead, you can use an AND gate, as shown in the diagram, to combine the signals. Note that in many cases receiving responses is not necessary, and the TX lines can be left unconnected.

Whenever connecting devices, remember to wire the grounds together, and ensure that each device is properly powered. Unpowered devices with a TTL serial port can turn on or partially on, drawing power from the serial line, which means that extra care must be taken when turning power off and on to reset the devices.

Sending commands
The Pololu Protocol or Mini SSC protocol should be used when multiple Pololu devices are receiving the same serial data. This allows the devices to be individually addressed, and it allows responses to be sent without collisions.

If the devices are configured to detect the baud rate, then when you issue your first Pololu Protocol command, the devices can automatically detect the baud from the initial 0xAA byte.

Some older Pololu devices use 0x80 as an initial command byte. If you want to chain these together with devices expecting 0xAA, you should first transmit the byte 0x80 so that these devices can automatically detect the baud rate, and only then should you send the byte 0xAA so that the Maestro can detect the baud rate. Once all devices have detected the baud rate, Pololu devices that expect a leading command byte of 0x80 will ignore command packets that start with 0xAA, and the Maestro will ignore command packets that start with 0x80.

6. The Maestro Scripting Language

A script is a sequence of commands that is executed by the Maestro. Commands can set servo targets, speeds, and accelerations, retrieve input values, and perform mathematical computations. Basic control structures – looping and conditionals – are available for use in making complicated scripts. The Maestro script language is a simple stack-based language very similar to FORTH, and scripts compile to a compact bytecode in which commands and subroutine calls each take just a single byte. A basic editor/debugger is available in the Script tab of the Maestro Control Center application.

6.a. Maestro Script Language Basics

Commands and the stack

A program in the Maestro script language consists of a sequence of *commands* which act on a *stack* of values. Values in the stack are integers from -32768 to +32767, and there is room for up to 32 values on the stack. Commands always act on the topmost values of the stack and leave their results on the top of the stack. The simplest kind of commands are *literals*, numerical values that are placed directly onto the stack. For example, the program “-10 20 35 0” puts the values -10, 20, 35, and 0 sequentially onto the stack, so that it looks like this:

	value
3	0
2	35
1	20
0	-10

A more complicated command is the PLUS command, which adds the top two numbers, leaving the result on the top of the stack. Suppose the numbers 1, 2, 4, and 7 are sequentially placed on the stack, and the PLUS command is run. The following table shows the result:

	before	**after**
3	7	
2	4	11
1	2	2
0	1	1

Note that the PLUS command always decreases the size of the stack by one. It is up to you to make sure that you have enough values on the stack to complete the commands you want to run!

Consider a more complicated example: suppose we want to compute the value of (1 – 3) × 4, using the MINUS and MULTIPLY commands. The way to write this computation as a script is “1 3 MINUS 4 TIMES”.

Comments, case, whitespace, and line breaks

All parts of the Maestro script language are case-insensitive, and you may use any kind of whitespace (spaces, tabs, and newlines) to separate commands. *Comments* are indicated by the pound sign "#" – everything from the # to the end of the line will be ignored by the compiler. For example, the computation above may be written as:

```
1 3  miNUS
4  # this is a comment!
  times
```

with absolutely no effect on the compiled program. We generally use lower-case for commands and two or four spaces of indentation to indicate control structures and subroutines, but feel free to arrange your code to suit your personal style.

Control structures

The Maestro script language has several control structures, which allow arbitrarily complicated programs to be written. Unlike subroutines, there is no limit to the level of nesting of control structures, since they are all ultimately based on GOTO commands (discussed below) and simple branching. By far the most useful control structure is the BEGIN…REPEAT infinite loop, an example of which is given below:

```
# move servo 1 back and forth with a period of 1 second
begin
  8000 1 servo
  500 delay
  4000 1 servo
  500 delay
repeat
```

This infinite loop will continue forever. If you want a loop that is bounded in some way, the WHILE keyword is likely to be useful. WHILE consumes the top number on the stack and jumps to the end of the loop if and only if it is a zero. For example, suppose we want to repeat this loop exactly 10 times:

```
10 # start with a 10 on the stack
begin
  dup     # copy the number on the stack - the copy will be consumed by WHILE
  while   # jump to the end if the count reaches 0
  8000 1 servo
  500 delay
  4000 1 servo
  500 delay
  1 minus # subtract 1 from the number of times remaining
repeat
```

Note that BEGIN…WHILE…REPEAT loops are similar to the while loops of many other languages. But, just like everything else in the Maestro script language, the WHILE comes *after* its argument.

For conditional actions, an IF…ELSE…ENDIF structure is useful. Suppose we are building a system with a sensor on channel 3, and we want to set servo 5 to 6000 (1.5 ms) if the input value is less than 512 (about 2.5 V). Otherwise, we will set the servo to 7000 (1.75 ms). The following code accomplishes this relatively complicated task:

```
3 get_position  # get the value of input 3 as a number from 0 to 1023
512 less_than   # test whether it is less than 512 -> 1 if true, 0 if false
if
  6000 5 servo   # this part is run when input3 < 512
```

```
else
  7000 5 servo   # this part is run when input3 >= 512
endif
```

As in most languages, the ELSE section is optional. Note again that this seems at first to be backwards relative to other languages, since the IF comes *after* the test.

The WHILE and IF structures are enough to create just about any kind of script. However, there are times when it is just not convenient to think about what you are trying to do in terms of a loop or a branch. If you just want to jump directly from one part of code to another, you may use a GOTO. It works like this:

```
goto mylabel
 # ...any code here is skipped...
4000 1 servo
mylabel: # the program continues here
4000 2 servo
```

In this example, only servo 2 will get set to 4000, while servo 1 will be unchanged.

Subroutines

It can be useful to use the same sequence of commands many times throughout your program. *Subroutines* are used to make this easier and more space-efficient. For example, suppose you often need to set servo 1 and servo 2 back to their neutral positions of 6000 (1.5 ms) using the sequence “6000 1 servo 6000 2 servo”. You can encapsulate this in a subroutine as follows:

```
sub neutral
  6000 1 servo
  6000 2 servo
  return
```

Then, whenever you want send these two servos back to neutral, you can just use “neutral” as a command. More advanced subroutines take values off of the stack. For example, the subroutine

```
sub set_servos
  2 servo 1 servo
  return
```

will set channel 2 to the value on the top of the stack and channel 1 to the next value. So, if you write “4000 6000 set_servos”, your script will set channel 1 to 4000 and channel 2 to 6000.

Subroutines can call other subroutines, up to a limit of 10 levels of recursion. For example, the subroutine “neutral” above can be implemented by calling set_servos:

```
sub neutral
  6000 6000 set_servos
  return
```

6.b. Command Reference

The following is the entire list of commands and keywords in the Maestro script language. The “stack effect” column specifies how many numbers are consumed and added to the stack. For example, the PLUS command takes off two numbers and returns one; so it has a stack effect of -2,+1. Commands with special effects will be marked with a *.

Keywords

keyword	stack effect	description
BEGIN	none	marks the beginning of a loop
ENDIF	none	ends a conditional block IF…ENDIF
ELSE	none	begins the alternative block in IF…ELSE…ENDIF
GOTO *label*	none	goes to the label *label* (define it with *label*:)
IF	-1	enters the conditional block if the argument is true (non-zero) in IF…ENDIF or IF…ELSE…ENDIF
REPEAT	none	marks the end of a loop
SUB *name*	none	defines a subroutine *name*
WHILE	-1	jumps to the end of a loop if the argument is false (zero)

Control commands

command	stack effect	description
QUIT	none	stops the script
RETURN	none	ends a subroutine

Timing commands

command	stack effect	description
DELAY	-1	delays by the given number of milliseconds
GET_MS	+1	gets the current millisecond timer (wraps around from 32767 to -32768)

Stack commands

command	stack effect	description
DEPTH	+1	gets the number of numbers on the stack
DROP	-1	removes the top number from the stack
DUP	+1	duplicates the top number
OVER	+1	duplicates the number directly below the top, copying it onto the top
PICK	-1,+1	takes a number *n*, then puts the *n*th number below the top onto the stack (0 PICK is equivalent to DUP)
SWAP	a,b → b,a	swaps the top two numbers
ROT	a,b,c → b,c,a	permutes the top three numbers so that the 3rd becomes the top and the others move down one position
ROLL	-1,*	takes a number *n*, then permutes the top *n+1* numbers so that the *n+1*th becomes the top and all of the others move down one

Mathematical commands (unary)

These commands take a single argument from the top of the stack, then return a single value as a result. Some of these have equivalents in C (and most other languages), listed in the "C equivalent" column below. We use "false" to mean 0 and "true" to mean any non-zero value. A command returning "true" always returns a 1.

command	C equivalent	description
BITWISE_NOT	~	inverts all of the bits in its argument
LOGICAL_NOT	!	replaces true by false, false by true
NEGATE	–	replaces *x* by – *x*
POSITIVE	none	true if and only if the argument is greater than zero
NEGATIVE	none	true if and only if the argument is less than zero
NONZERO	none	true (1) if and only if the argument is true (non-zero)

Mathematical commands (binary)

These commands take two arguments from the top of the stack, then return a single value as a result. The order of the arguments, when important, is the standard one in mathematics; for example, to compute 1 – 2, you write "1 2 MINUS". These commands all have equivalents in C (and most other languages), listed in the "C equivalent" column below.

command	C equivalent	description
BITWISE_AND	&	applies the boolean AND function to corresponding bits of the arguments
BITWISE_OR	|	applies the boolean OR function to corresponding bits of the arguments
BITWISE_XOR	^	applies the boolean XOR function to corresponding bits of the arguments
DIVIDE	/	divides the arguments
EQUALS	=	true if and only if the arguments are equal
GREATER_THAN	>	true if and only if the first argument is greater than the second
LESS_THAN		true if and only if the first argument is less than the second
LOGICAL_AND	&&	true if and only if both arguments are true
LOGICAL_OR	||	true if and only if at least one argument is true
MAX	none	selects the greater of the two arguments
MIN	none	selects the lesser of the two arguments
MINUS	–	subtracts the arguments
MOD	%	computes the remainder on division of the first argument by the second
NOT_EQUALS	!=	true if and only if the arguments are not equal
PLUS	+	adds the arguments
SHIFT_LEFT		shifts the binary representation of the second argument to the left by a number of bits given in the second argument (without wrapping)
SHIFT_RIGHT	>>	shifts the binary representation of the first argument to the right by a number of bits given in the second argument (without wrapping)
TIMES	*	multiplies the arguments

Servo and LED setting commands

command	stack effect	description
SPEED	-2	sets the *speed* of the channel specified by the top element to the value in the second element, in units of 0.25 μs / (10 ms)
ACCELERATION	-2	sets the *acceleration* of the channel specified by the top element to the value in the second element in units of (0.25 μs) / (10 ms) / (80 ms)
GET_POSITION	-1,+1	gets the *position* of the channel specified by the top element
GET_MOVING_STATE	+1	true if any servos are still moving, limited by speed or acceleration
SERVO	-2	sets the *target* of the channel specified by the top element to the value in the second element, in units of 0.25 μs
SERVO_8BIT	-2	sets the *target* of the channel specified by the top element to the value in the second element, which should be a value from 0 to 254 (see the Mini SSC command in **Section 5.e**)
LED_ON	none	turns the red LED on
LED_OFF	none	turns the red LED off (assuming no errors bits are set)

6.c. Example Scripts

Getting started: blinking an LED

The following script will cause the red LED on the Maestro to blink once per second:

```
# Blinks the red LED once per second.
begin
  led_on
  100 delay
  led_off
  900 delay
repeat
```

It is a good idea to try stepping through this script before doing anything further with scripts on the Maestro. In particular, pay attention to how the command “100” puts the number 100 on the stack, and the DELAY command consumes that number. In the Maestro scripting language, arguments to commands always need to be placed on the stack *before* the commands that use them, which makes the language seem backwards compared to other languages. It also means that you can arrange your code in a variety of different ways. For example, this program is equivalent to the one above:

```
# Blinks the red LED once per second.
begin
  900 100
  led_on delay
  led_off delay
repeat
```

The numbers are placed on the stack at the beginning of the loop, then consumed later on in execution. Pay attention to the order of the numbers used here: the 900 goes on the stack *first*, and it is used *last*.

A simple servo sequence

The following script shows how to direct servo 0 to five different positions in a loop.

```
# Move servo 0 to five different positions, in a loop.
begin
  4000 0 servo # set servo 0 to 1.00 ms
  500 delay
  5000 0 servo # 1.25 ms
  500 delay
  6000 0 servo # 1.50 ms
  500 delay
  7000 0 servo # 1.75 ms
  500 delay
  8000 0 servo # 2.00 ms
  500 delay
repeat
```

The serial mode must **not** be set to detect baud rate for this script to work. In detect baud rate mode, the Maestro does not enable any of the servo outputs until the start byte has been received.

Note that the servo positions are specified in units of 0.25 μs, so a value of 4000 corresponds to 1 ms. The text after the # is a *comment*; it does not get programmed on to the device, but it can be useful for making notes about how the program works. Good comments are essential for complicated programs. It is important to remember the DELAY commands; without these, the script will not wait at all between servo commands, running the loop hundreds of times per second.

Compressing the sequence

The program above takes 58 bytes of program space: 11 bytes for each servo position and 3 for the loop. At this rate, we could store up to 92 servo positions in the 1024-byte memory of the Micro Maestro. To get the most out of the limited memory, there are a variety of ways to compress the program. Most important is to make use of *subroutines*. For example, since we repeat the instructions “0 servo 500 delay” several times, we can move them into a subroutine to save space. At the same, this simplifies the code and makes it easier to make future modifications, such as changing the speed of the entire sequence.

```
# Move servo 0 to five different positions, in a loop.
begin
  4000
  frame
  5000
  frame
  6000
  frame
  7000
  frame
  8000
  frame
repeat

sub frame
  0 servo
  500 delay
  return
```

Using the subroutine brings the script down to 31 bytes: 4 per position and 11 bytes of overhead for the loop and to define FRAME. We can go further: inspecting the compiled code shows that putting each number on the stack requires 3 bytes: one byte as a command, and two for the two-byte number. Numbers from 0 to 255 can be loaded onto the stack with just two bytes. Suppose in our application we do not need the full 0.25 μs resolution of the device, since all of our settings are multiples of 100. Then we can use smaller numbers to save another byte:

```
# Move servo 0 to five different positions, in a loop.
begin
  40 frame
  50 frame
  60 frame
  70 frame
  80 frame
repeat

# loads a frame specified in 25 us units
sub frame
  100 times
  0 servo
  500 delay
  return
```

This program is 29 bytes long, with 3 bytes used per position and 14 bytes of overhead. Note that we could get the same efficiency if we used the SERVO_8BIT command, which takes a one-byte argument from 0 to 254. We can go even smaller by putting all of the numbers together:

```
# Move servo 0 to five different positions, in a loop.
begin
  80 70 60 50 40
  frame frame frame frame frame
repeat

# loads a frame specified in 25 us units
sub frame
  100 times
  0 servo
  500 delay
  return
```

If you step through this version program, you will also notice that all five numbers are placed on the stack in a single step: this is because the compiler can use a single command to put multiple numbers on the stack. Using a single command for multiple numbers saves space: we are now down to just 26 bytes. Only 12 bytes are used for the 5 frames, for an average of 2.4 bytes per frame. This is probably compact enough – by duplicating this structure we could fit 420 different positions into the 1024-byte program memory. However, the code can get even smaller. Consider this script, which uses 31 frames to make a smooth back-and-forth motion:

```
# Moves servo in a sine wave between 1 and 2 ms.
begin
  60 64 68 71 74 77 79 80 80 79 78 76 73 70 66 62
  58 54 50 47 44 42 41 40 40 41 43 46 49 52 56
  all_frames
repeat

sub all_frames
  begin
    depth
  while
    100 times
    0 servo
    100 delay
  repeat
  return
```

In this version of the code, we have rewritten the FRAME subroutine, using the DEPTH command to automatically load frames from the stack until there are none left. This program uses 34 bytes to store 31 frames, for an average of just 1.1 bytes per frame. We could store a sequence containing 900 different positions in the memory of the Micro Maestro using this kind of script.

Making smooth sequences with GET_MOVING_STATE

Speed and acceleration settings can be used to make smooth motion sequences with the Maestro. However, a common problem is that you do not know how much you need to delay between frames to allow the servo to reach its final position. Here is an example of how to use the built-in function GET_MOVING_STATE to make a smooth sequence, instead of DELAY:

```
# This example uses speed and acceleration to make a smooth
# motion back and forth between 1 and 2 ms.
3 0 acceleration
30 0 speed

begin
  4000 0 servo # set servo 0 to 1.00 ms
  moving_wait
  8000 0 servo # 2.00 ms
  moving_wait
repeat

sub moving_wait
  begin
    get_moving_state
  while
    # wait until it is no longer moving
  repeat
  return
```

GET_MOVING_STATE returns a 1 as long as there is at least one servo moving, so you can use it whenever you want to wait for all motion to stop before proceeding to the next step of a script.

Using an analog input to control servos

An important feature of the Maestro is that it can be used to read inputs from sensors, switches, or other devices. As a simple example, suppose we want to use a potentiometer to control the position of a servo. For this example, connect the potentiometer to form a voltage divider between 5V and 0, with the center tap connected to channel 1. Configure channel 1 to be an input, and examine the signal on the Status tab of the Maestro Control Center. You should see the position indicator vary from 0 to 255 μs as you turn the potentiometer from one side to the other. In your script, this range corresponds to numbers from 0 to 1023. We can scale this number up to approximately the full range of a servo, then set the servo position to this number, all in a loop:

```
# Sets servo 0 to a position based on an analog input.
begin
  1 get_position    # get the value of the pot, 0-1023
  4 times 4000 plus # scale it to 4000-8092, approximately 1-2 ms
  0 servo           # set servo 0 based to the value
repeat
```

Alternatively, you might want the servo to go to discrete positions depending on the input value:

```
# Set the servo to 4000, 6000, or 8000 depending on an analog input.
begin
  1 get_position    # get the value of the pot, 0-1023
  dup 300 less_than
  if
    4000   # go to 4000 for values 0-299
  else
    dup 600 less_than
    if
      6000 # go to 6000 for values 300-599
    else
      8000 # go to 8000 for values 600-1023
    endif
  endif
  0 servo
  drop     # remove the original copy of the pot value
repeat
```

The example above works, but when the potentiometer is close to 300 or 600, noise on the analog-to-digital conversion can cause the servo to jump randomly back and forth. A better way to do it is with hysteresis:

```
# Set the servo to 4000, 6000, or 8000 depending on an analog input, with hysteresis.
begin
  4000 0 300 servo_range
  6000 300 600 servo_range
  8000 600 1023 servo_range
repeat

# usage: <pos> <low> <high> servo_range
# If the pot is in the range specified by low and high,
# keeps servo 0 at pos until the pot moves out of this
# range, with hysteresis.
sub servo_range
  pot 2 pick less_than logical_not    # >= low
  pot 2 pick greater_than logical_not # <= high
  logical_and
  if
    begin
      pot 2 pick 10 minus less_than logical_not   # >= low - 10
      pot 2 pick 10 plus greater_than logical_not # <= high + 10
      logical_and
    while
      2 pick 0 servo
    repeat
  endif
  drop drop drop
  return

sub pot
  1 get_position
  return
```

This example uses one range for deciding where to go when making a transition, then it waits for the servo to leave a slightly larger range before making another transition. As long as the difference (10 in this example) is larger than the amount of noise, this will prevent the random jumping.

Using a button or switch to control servos

Suppose we connect a button to an input, using a pull-up resistor, so that the input is normally high, and when the button is pressed it goes low. Since the Maestro only supports analog inputs, to get a digital value from the button we need to make a comparison to an arbitrary threshold:

```
# Returns 1 if the button is pressed, 0 otherwise.
sub button
  1 get_position 500 less_than
  return
```

The BUTTON subroutine puts a logical value of 1 or a 0 on the stack, depending on whether the button is pressed or not. Here is a subroutine that uses BUTTON to wait for a button press, including a small delay to eliminate noise or bounces on the input:

```
# Waits for a button press, with debouncing.
# (Requires the BUTTON subroutine.)
sub wait_for_button_press
  wait_for_button_open_10ms
  wait_for_button_closed_10ms
  return

# wait for the button to be NOT pressed for at least 10 ms
sub wait_for_button_open_10ms
  get_ms # put the current time on the stack
  begin
    # reset the time on the stack if it is pressed
    button
    if
      drop get_ms
    else
      get_ms over minus 10 greater_than
      if drop return endif
    endif
  repeat

# wait for the button to be pressed for at least 10 ms
sub wait_for_button_closed_10ms
  get_ms
  begin
    # reset the time on the stack if it is pressed
    button
    if
      get_ms over minus 10 greater_than
      if drop return endif
    else
      drop get_ms
    endif
  repeat
```

An example of how to use this function is shown below:

```
# Uses WAIT_FOR_BUTTON_PRESS to allow a user to step through a sequence
# of positions on servo 0.
begin
  4000 frame
  5000 frame
  6000 frame
  7000 frame
  8000 frame
repeat

sub frame
  wait_for_button_press
  0 servo
  return
```

Just like the sequencing examples above, the script steps through a sequence of frames, but instead of a timed delay between frames, this example waits for a button press. The WAIT_FOR_BUTTON_PRESS subroutine can be used in a variety of different scripts, whenever you want to wait for a button press. You could also expand this example to allow multiple buttons, continuous motion, or a variety of other types of button control.

Long delays

The longest delay possible with the DELAY command is approximately 32 seconds. In some cases, you will want to make delays much longer than that. Here is an example that shows how delays of many seconds or minutes can be accomplished:

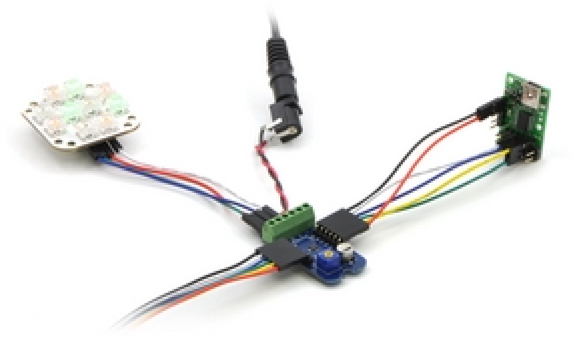
```
# Moves servo 0 back and forth, with a delay of 10 minutes between motions.
begin
  4000 0 servo
  10 delay_minutes
  8000 0 servo
  10 delay_minutes
```

```
repeat

# delay by a specified number of seconds, up to 65535 s
sub delay_seconds
  begin dup while      # check if the count has reached zero
    1 minus 1000 delay # subtract one and delay 1s
  repeat
  drop return          # remove the 0 from the stack and return

# delay by a specified number of minutes, up to 65535 min
sub delay_minutes
  begin dup while
    1 minus 60 delay_seconds # subtract one and delay 1min
  repeat
  drop return                # remove the 0 from the stack and return
```

It is easy to write subroutines for delays of hours, days, weeks, or whatever you want. Keep in mind, however, that the timer on the Micro Maestro is not as accurate as a stopwatch – these delays could easily be off by 1%.

Digital output

The digital output feature of the Maestro is capable of controlling anything from simple circuits to intelligent devices such as the **ShiftBrite LED Modules [http://www.pololu.com/catalog/product/1240]** and **ShiftBar LED Controllers [http://www.pololu.com/catalog/product/1242]**, which use a simple synchronous serial protocol. In this example, the clock, latch, and data pins of a ShiftBrite or ShiftBar are connected to servo channels 0, 1, and 2, respectively, and these channels are all configured as outputs. The subroutine RGB defined here takes 10-bit red, green, and blue values from the stack, then sends a 32-byte color packet and toggles the latch pin to update the ShiftBrite with the new color value. The subroutine could be modified to control a larger chain of ShiftBrites if desired.


Connecting the Micro Maestro to a chain of ShiftBars. A single 12V supply powers all of the devices.

Note that we use 0 to set the output low and 8000 to set the output high. These are reasonable choices, but any value from 0 to 5999 could be used for low, and anything from 6000 to 32767 could be used for high, if desired.

```
# Subroutine for setting the RGB value of a ShiftBrite/ShiftBar.
# example usage: 1023 511 255 rgb
sub rgb
  0 send_bit # this bit does not matter
  0 send_bit # the "address" bit - 0 means a color command
  swap rot rot
  send_10_bit_value
  send_10_bit_value
  send_10_bit_value
  0 1 8000 1 servo servo # toggle the latch pin
  return

# sends a numerical value as a sequence of 10 bits
sub send_10_bit_value
  512
  begin
    dup
  while
    over over bitwise_and send_bit
    1 shift_right
  repeat
  drop drop
  return

# sends a single bit
sub send_bit
  if 8000 else 0 endif
  2 servo                # set DATA to 0 or 1
  0 0 8000 0 servo servo # toggle CLOCK
  return
```

7. Wiring Examples

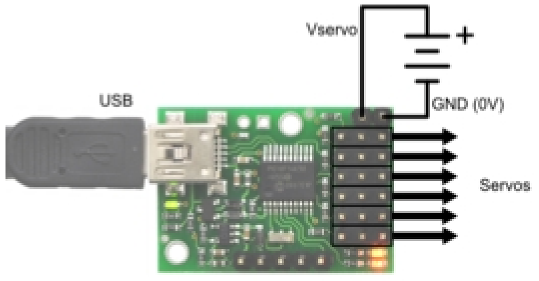
This section contains example wiring configurations for the Maestro that demonstrate the different ways it can be connected to your project.

7.a. Powering the Maestro

There are several ways to power your Maestro’s processor and the servos it is controlling.

USB power

If you connect a power supply to the servo power terminal and connect the Maestro to USB as shown in the picture to the right, then the Maestro’s processor will be powered from USB while the servos are powered from the power supply. The power supply must output a voltage within the servos’ respective operating ranges and must be capable of supplying all the current that the servos will draw.

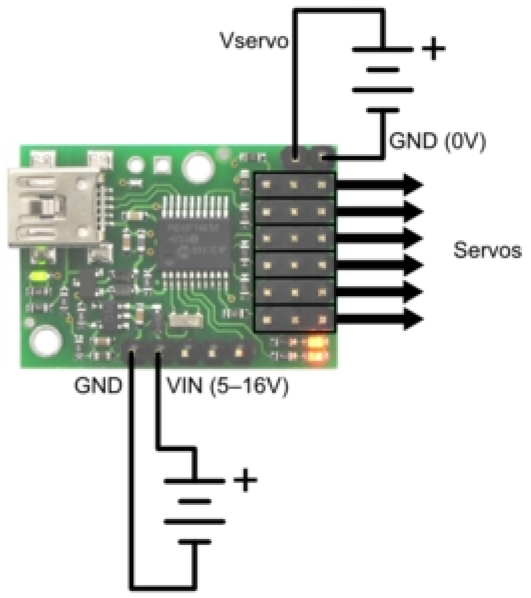


The Maestro’s processor can be powered from USB while the servos are powered by a separate supply.

In this configuration, if the computer (or other USB host) that the Maestro is connected to goes to sleep, then by default the Maestro will go to sleep and stop sending servo pulses. If you need to drive your servos while your computer is off, you can use the **Never sleep (ignore USB suspend)** option in the Serial Settings tab of the Maestro Control Center. Note that this will only work if the computer is supplying power to the USB port while it is asleep, and it will make your Maestro be non-USB-compliant.

Two power supplies

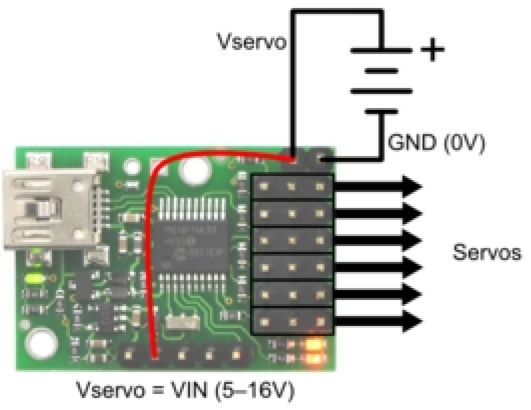
If you connect a power supply to the servo power terminal and connect another power supply to GND/VIN, then the Maestro’s processor will be powered from the VIN supply while the servos are powered from their own supply. The VIN supply must be within 5–16 V and supply at least 30 mA. The servo power supply must output a voltage within the servos’ respective operating ranges and must be capable of supplying all the current that the servos will draw.



The Maestro’s processor and servos can be powered separately.

One power supply

If you connect a single power supply to VIN and the servo power terminal, then the Maestro's processor and the servos will be powered from that supply. The supply must be within 5–16 V and be within the servos' respective operating ranges and must be capable of supplying all the current that the servos will draw. One way to do the wiring for this configuration is to add a wire to the Maestro between the servo power rail and the VIN line.



The Maestro's processor and servos can be powered from a single 5–16V supply if you connect the positive servo power rail to VIN.

7.b. Attaching Peripherals to the Servo Ports

On the Micro Maestro, any of the six servo channels can alternatively be used as an analog input or a digital output. This allows the Maestro to read button presses, read potentiometer positions, drive LEDs, and more. The lines can be controlled from the user script within the Maestro or externally over TTL-level serial or USB.

Button or switch

To connect a button or switch to the Maestro, you must first decide which channel you would like to use. In the Maestro Control Center, under the Channel Settings tab, change that channel to **Input** mode and click "Apply Settings". Next, wire a pull-up resistor (1–100 kilo-ohms) between the signal line of that channel and 5 V so that the input is high (5 V) when the switch is open. Wire the button or switch between the signal line and GND (0 V) so that when the button/switch is active the input will fall to 0 V. The picture to the right shows how to connect a button or switch to channel 0.

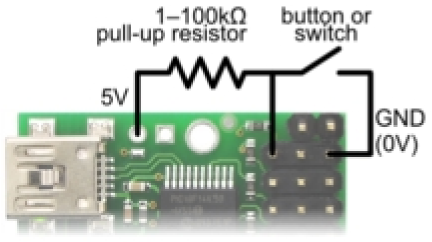


Diagram for connecting a button or switch to the Micro Maestro Servo Controller.

You can test your input by toggling the button/switch and verifying that the "Position" variable as shown in the Status tab of the Maestro Control Center reflects the state of your button/ switch: it should be close to 255.75 when the button/switch is active and close to 0 when it is inactive. Now you can read the state of the button/switch in your script using the GET_POSITION command or over serial using the "Get Position" command. These commands will return values that are close to 1023 when the button/switch is active and close to 0 when it is inactive.

Potentiometer

To connect a potentiometer to the Maestro, you must first decide which channel you would like to use. In the Maestro Control Center, under the Channel Settings tab, change that channel to **Input** mode and click "Apply Settings". Next, connect the potentiometer to the Maestro so that the two ends go to GND and 5 V, and the wiper connects to the signal line of the channel. The picture to the right shows how to connect a potentiometer to channel 0. The potentiometer should have a resistance of at least 1 kilo-ohm so that it does not draw too much current from the 5V line.

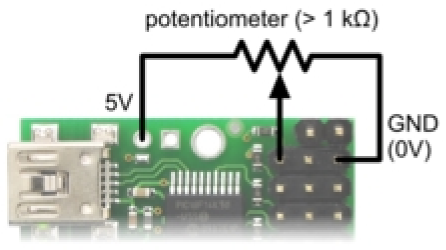


Diagram for connecting a potentiometer to the Micro Maestro servo controller.

You can test your input by rotating the potentiometer and verifying that the "Position" variable as shown in the Status tab of the Maestro Control Center reflects the position of the potentiometer: it should vary between approximately 255.75 and 0. Now you can read the position of the potentiometer in your script using the GET_POSITION command or over serial using the "Get Position" command. These commands will return values between approximately 1023 and 0.

LED

To connect an LED to the Maestro, you should first decide which channel you would like to use. In the Maestro Control Center, under the Channel Settings tab, change that channel to **Output** mode and click "Apply Settings". Next, connect the cathode of the LED to GND (any ground pad on the Maestro will suffice because they are all connected). Then connect the anode of the LED to the channel's signal line through a resistor. The resistor's resistance should be high enough so that the LED does not burn out when 5 V is applied. For most LEDs, a 1 kilo-ohm resistor will work.

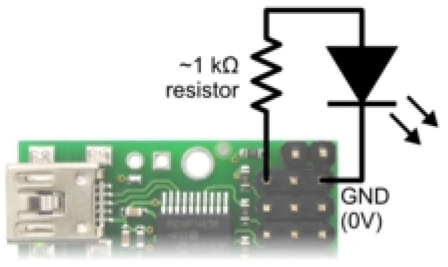


Diagram for connecting an LED to the Micro Maestro servo controller.

You can test your LED by setting the "target" of the LED channel in the Status tab of the Maestro Control Center. The LED should be on if you set the target to be greater than or equal to 1500 µs and off otherwise. You can control the LED in your script using the SERVO command or over serial using the "Set Target" command. These commands take arguments in units of quarter-microseconds, so the LED should be on if you send a number greater than or equal to 6000 and off otherwise.

7.c. Connecting to a Microcontroller

The Maestro can accept TTL serial commands from a microcontroller. To connect the microcontroller to the Maestro, you should first connect the ground line of the microcontroller to the ground line of the Maestro. Then connect the TX (serial transmit) line of the microcontroller to the RX line of the Maestro so that the microcontroller can send commands. If you need to receive serial responses from the Maestro, then you will need to connect the RX (serial receive) line of the microcontroller to the Maestro’s TX line. For more information on the different serial modes and commands, see **Section 5**.

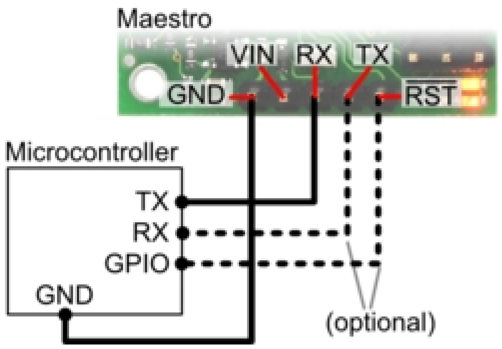


Diagram showing how to connect the Micro Maestro servo controller to a microcontroller.

If you want your microcontroller to have the ability to reset the Maestro, then connect the $\overline{\text{RST}}$ line of the Maestro to any general-purpose I/O line of the microcontroller. You should have the I/O line tri-stated or at 5 V when you want the Maestro to run and drive it low (0 V) temporarily to reset to reset the Maestro.

8. Writing PC Software to Control the Maestro

There are two ways to write PC software to control the Maestro: the native USB interface and the virtual serial port. The native USB interface provides more features than the serial port, such as the ability to change configuration parameters and select the Maestro by its serial number. Also, the USB interface allows you to recover more easily from temporary disconnections. The virtual serial port interface is easier to use if you are not familiar with programming, and it can work with existing software programs that use serial ports, such as LabView.

Native USB Interface

The **Pololu USB Software Development Kit** **[http://www.pololu.com/docs/0J41]** supports Windows and Linux, and includes C# source code for:

- **MaestroExample**: an example graphical application that uses native USB to send commands and receive feedback from the Maestro and automatically recover from disconnection.
- **UscCmd**: a command-line utility for configuring and controlling the Maestro.
- C# .NET class libraries that enable native USB communication with the Maestro.

You can modify the applications in the SDK to suit your needs or you can use the class libraries to integrate the Maestro in to your own applications.

Virtual Serial Ports

Almost any programming language is capable of accessing the COM ports created by the Maestro. We recommend the Microsoft .NET framework, which is free to use and contains a SerialPort class that makes it easy to read and write bytes from a serial port as well as set and read the control signals. You can download Visual Studio Express (for either C#, C++, or Visual Basic) and write programs that use the SerialPort class to communicate with the Maestro. You will need to set the Maestro’s serial mode to be either “USB Dual Port” or “USB Chained”.