Mastwerks™/BuddiHEX™ Rotator Software System

Revision: 2024.27.03

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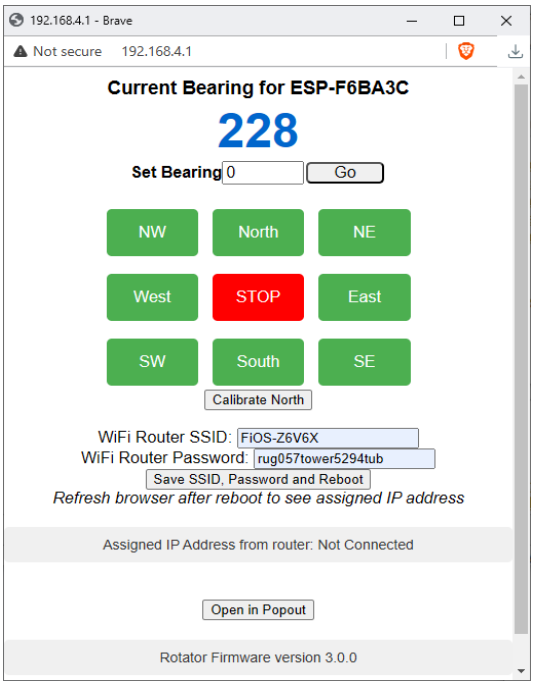
BuddiHEX™ is a product of Buddipole, Inc. https://www.buddipole.com/info.html
Mastwerks™ is a product of Mastwerks LLC. http://https://www.mastwerks.com

Overview

The software described in this manual controls a rotator system designed for use with the MastWerks Mast and BuddiHEX antenna sold by Buddipole (www.buddipole.com). A description of the hardware components and information on how to build the rotator system is found on printables.com (click here).

The heart of the system is an ESP-8266 WiFi-capable Arduino processor. Throughout this manual we refer to the ESP8266 by name for processor-specific issues, but to use the term “rotator controller” when referring to the complete system. We hope this approach will prevent confusion when building and using the rotator control system. The system has two software components; an Arduino compatible software that is loaded onto the ESP8266 and an optional Windows application with a graphical user interface (GUI).

The Arduino-compatible software allows operators to control the rotator system in two ways. Operators can connect directly to the rotator controller using a mobile phone, tablet or computer by accessing a web server page instantiated in the ESP8266 firmware. The web page GUI, shown below, provides an easy ways to change the direction of the antenna as desired.



Alternatively, operators can log the rotator controller into a local area network (LAN) by entering the network’s SSID and password into the indicated fields of the GUI and rebooting the system. Once the rotator controller is connected to the LAN, operators gain access to the same web based GUI over the WiFi network at the IP address shown in the field titled ‘Assigned IP Address from router’ (shown in figure above). This feature allows connection of multiple rotator systems to one LAN at the same time as might occur during a contest situation like Field Day.

The ESP8266 firmware listens for operator commands, collects data for display and send commands to operate the motor. It monitors the mast position with a QMC5883L 3-axis magnetic sensor and controls the rotator system motor with a L293D quadruple Half-H driver chip. The L293D is a ubiquitous chip that is used to control DC motors, stepper motors and relays.

Installing the Firmware onto the ESP8266 Micro-controller

Firmware Overview

The firmware supports commands to return the current bearing, go to a bearing or to stop rotating.

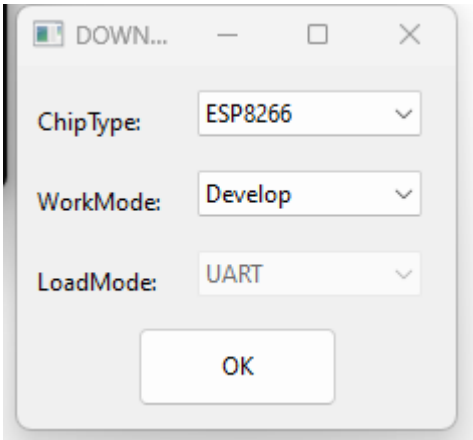
When commanded to go to a bearing, the firmware determines the rotation direction and starts the motor. Once the antenna reaches the desired bearing or the rotation stops unexpectedly (stuck), the motor is powered off. The firmware contains an algorithm that prevents feed line from wrapping around the mast.

Connecting to the access point allows WiFi router configuration and/or controlling the rotator system via a web page by using any modern browser to access the web page at 192.168.4.1. Both full size and mobile pages are available and should display properly on computer browsers as well as on small phone screens.

Loading the Pre-compiled Rotator Control Binary into the ESP8266 Micro-controller using Windows

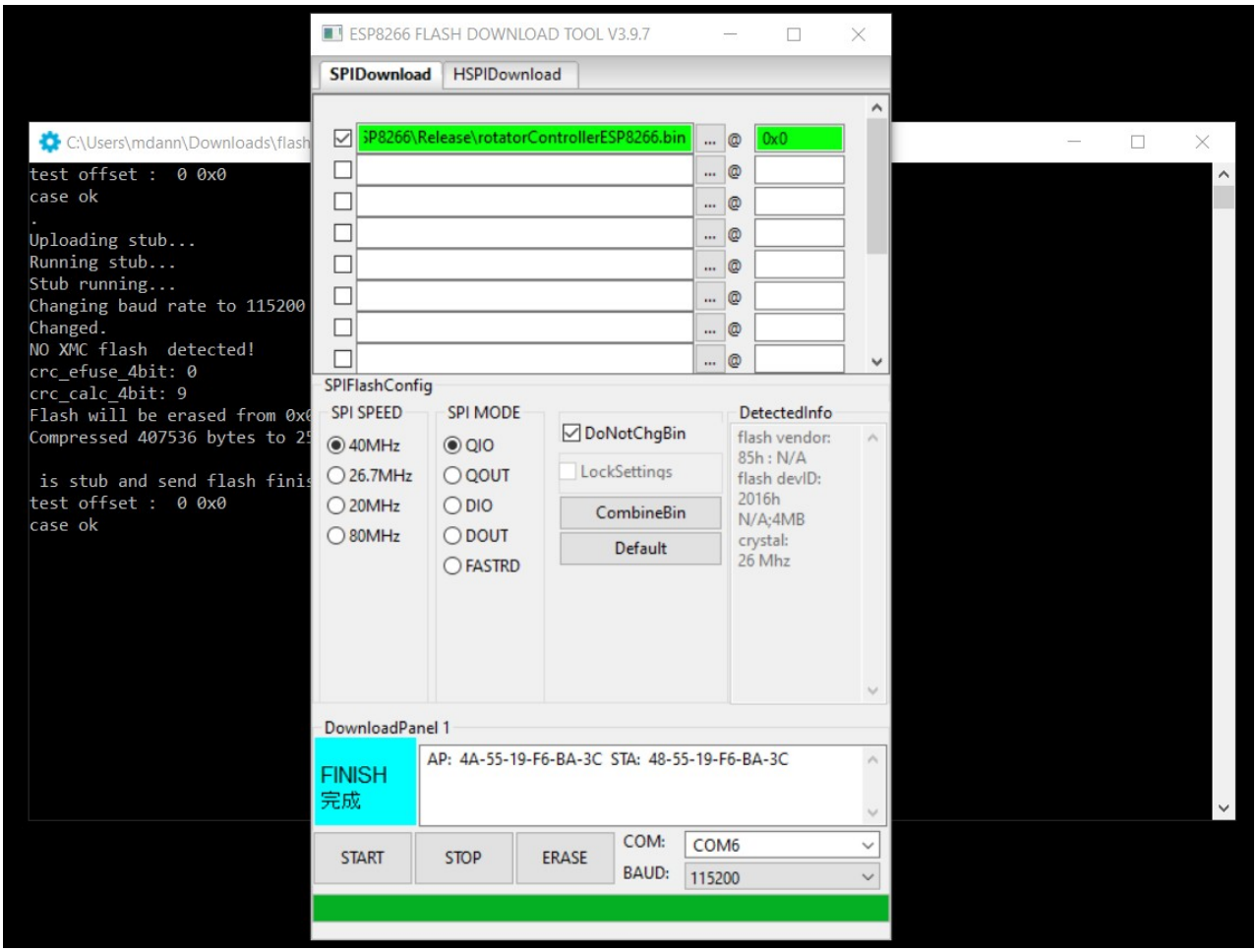
Use the ESP8266 Flash Download Tool to load the pre-compiled .bin file onto the ESP8266 on the rotator controller board. Follow these steps:

1. Download the following rotator controller files from GitHub. Links are provided in the Section GITHUB Repositories
   - rotatorControllerESP8266.bin (this is the rotator control file)
   - HexRotatorControl.exe (this is the optional Windows Application)
2. Download the ESP8266 Flash Download Tool: Obtain the tool from Espressif's official website or other trusted sources. (https://www.espressif.com/en/support/download/other-tools)
3. Connect to the ESP8266 on the rotator controller board: Use a USB cable to connect the controller to the computer.
4. Install USB Drivers: Ensure the USB-to-Serial drivers are installed on the computer. This is typically a CH340 or CP210x driver.
5. Open the Flash Download Tool: Run the flash_download_tool_X.X.X.exe file you downloaded.
6. Select the Chip: In the tool, select "ESP8266" as the chip type. WorkMode: Develop, Load Mode: UART



7. Configure the Tool (refer to the image below as a reference):
   - Select the SPIDownload tab, SPI SPEED to 40MHz and SPI MODE QIO
   - Check the DoNotChnBin checkbox.
   - Choose the rotatorControllerESP8266.bin file by clicking on the "..." button next to the file path field. (Only the first line of the tool will be used).
   - Set the appropriate offset for the firmware: In the field following the @ symbol, enter 0x0.
   - Tick the checkbox next to the file path to enable it.
   - Select the COM Port: Choose the correct COM port to which the controller is connected. This can be found in Device Manager under "Ports (COM & LPT)" on Windows.
   - Set the Baud Rate: Choose a suitable baud rate, typically 115200, for the flashing process.
8. Start the Flashing Process: Click the "START" button to begin flashing the rotatorControllerESP8266.bin file.
9. Wait for Completion: The tool will indicate when the flashing process is successful.
10. Reset the Board: After flashing, reset the controller board disconnecting both power and the USB cable. Reconnect the power.

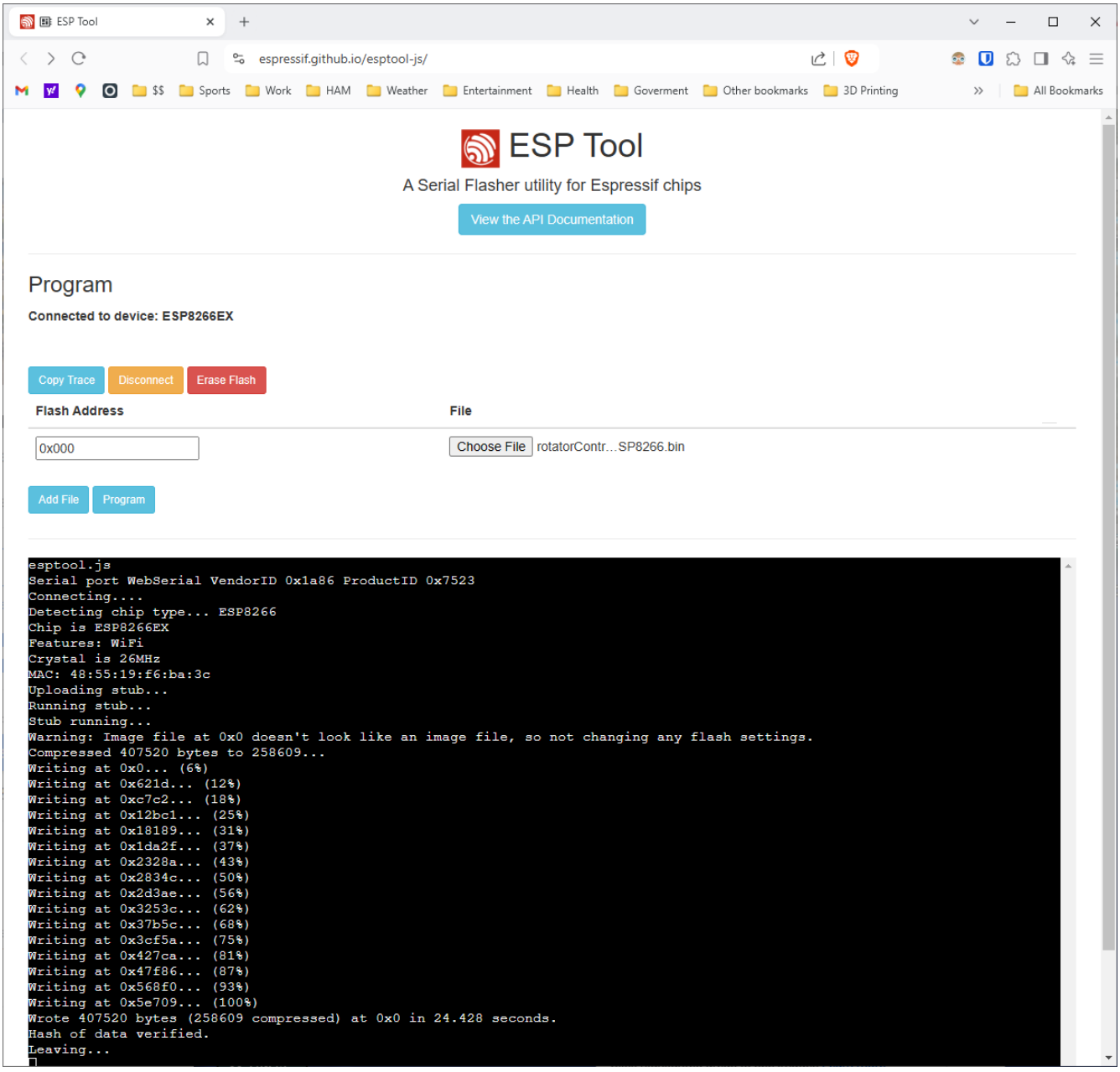
The board should now show up on the available WiFi networks as an Access Point. The name will look like ESP-XXYYZZ where the XX, YY and ZZ are unique for each ESP8266 controller board.


C:\Users\mdann\Downloads\flash
test offset : 0 0x0
case ok
.
Uploading stub...
Running stub...
Stub running...
Changing baud rate to 115200
Changed.
NO XMC flash detected!
crc_efuse_4bit: 0
crc_calc_4bit: 9
Flash will be erased from 0x0
Compressed 407536 bytes to 25
is stub and send flash finis
test offset : 0 0x0
case ok
ESP8266 FLASH DOWNLOAD TOOL V3.9.7
SPIDownload
HSPIDownload
SP8266\Release\rotatorControllerESP8266.bin
0x0
SPIFlashConfig
SPI SPEED
40MHz
26.7MHz
20MHz
80MHz
SPI MODE
QIO
QOUT
DIO
DOUT
FASTRD
DoNotChgBin
LockSettings
CombineBin
Default
DetectedInfo
flash vendor:
85h : N/A
flash devID:
2016h
N/A;4MB
crystal:
26 Mhz
DownloadPanel 1
FINISH
完成
AP: 4A-55-19-F6-BA-3C STA: 48-55-19-F6-BA-3C
START
STOP
ERASE
COM:
COM6
BAUD:
115200

Loading the Pre-compiled Rotator Control Binary into the ESP8266 Micro-controller using Web-based ESP Tool

Use the official web-based ESP Tool serial flasher, which works in the Chrome browser:

1. Connect to the ESP8266 on the rotator controller board: Use a USB cable to connect the controller to the computer.
2. Open a Chrome based browser and go to https://espressif.github.io/esptool-js/
3. Set the Program Baudrate to 115200 and click the Connect.
4. Select the proper serial port and press the Connect button.
5. After connecting, set the Flash Address to 0x000.
6. Click the Choose File and select the rotatorControllerESP8266.bin file.
7. Click the Program button. Progress messages will show and after the program is loaded, the message Leaving… will be displayed.
8. Click Disconnect.
9. Reset the rotator controller by cycling power.


ESP Tool
espressif.github.io/esptool-js/
ESP Tool
A Serial Flasher utility for Espressif chips
View the API Documentation
Program
Connected to device: ESP8266EX
Copy Trace
Disconnect
Erase Flash
Flash Address
File
0x000
Choose File
rotatorContr…SP8266.bin
Add File
Program
esptool.js
Serial port WebSerial VendorID 0x1a86 ProductID 0x7523
Connecting....
Detecting chip type... ESP8266
Chip is ESP8266EX
Features: WiFi
Crystal is 26MHz
MAC: 48:55:19:f6:ba:3c
Uploading stub...
Running stub...
Stub running...
Warning: Image file at 0x0 doesn't look like an image file, so not changing any flash settings.
Compressed 407520 bytes to 258609...
Writing at 0x0... (6%)
Writing at 0x621d... (12%)
Writing at 0xc7c2... (18%)
Writing at 0x12bc1... (25%)
Writing at 0x18189... (31%)
Writing at 0x1da2f... (37%)
Writing at 0x2328a... (43%)
Writing at 0x2834c... (50%)
Writing at 0x2d3ae... (56%)
Writing at 0x3253c... (62%)
Writing at 0x37b5c... (68%)
Writing at 0x3cf5a... (75%)
Writing at 0x427ca... (81%)
Writing at 0x47f86... (87%)
Writing at 0x568f0... (93%)
Writing at 0x5e709... (100%)
Wrote 407520 bytes (258609 compressed) at 0x0 in 24.428 seconds.
Hash of data verified.
Leaving...

Using the Rotator Controller

When the firmware is initially loaded onto the ESP8266, the WiFi router information is not configured. The WiFi SSID and password need to be set before the Rotator Controller can connect to a network router. The Rotator Controller will create an access point and start a web server to allow setting these.

WiFi connection

There are three ways to use the Rotator Controller:

1. Stand alone. An access point and DNS (domain name server) are established on the ESP8266 that will accept connections from wireless devices via an IP address provided by the server.
2. The rotator controller can be connected to a hotspot set up on the a computer.
3. The rotator controller can be connected to a WiFi router and hence a local area network.

Directions on how to use each of these methods are provided in the sections below.

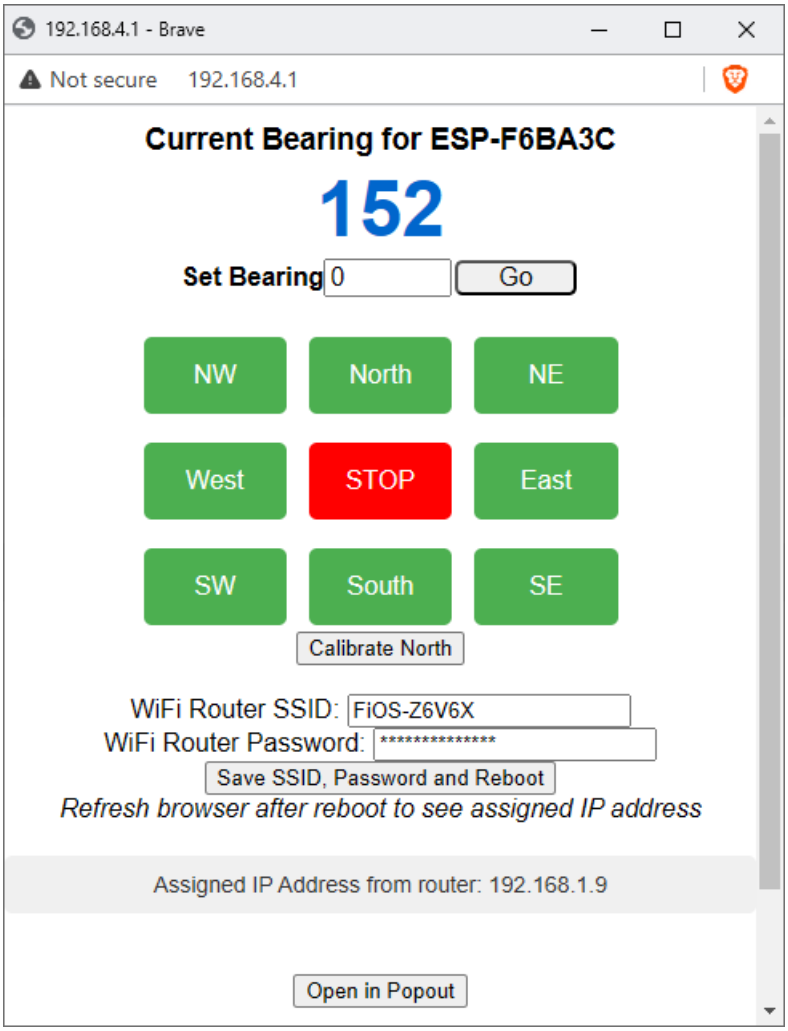
Using the Rotator Controller in Stand Alone Mode

The ESP8266 offers an access point that allows computers and other WiFi enabled devices to directly connect to it. The ESP8266 will provide an IP address for the device on a network with a netmask of 192.168.4.XXX.

Note that a WiFi adapter can only connect to a single network (access point) at a time. An adapter can not be connected to a WiFi router and the ESP8266 acting as a DNS access point at the same time unless a second WiFi adapter such as a USB-WiFi dongle is used.

Connect the device (computer, phone, etc) WiFi to the rotator by selecting the ESP8266's **SSID** from the list of available networks. The SSID will be the Rotator Controller Name has the following format: ESP-XXYYZZ.

Start a web browser and enter 192.168.4.1 address. The following web page will be displayed:



The current bearing is displayed in blue and the number will be followed by the current rotating direction, CW or CCW, if the rotator motor is running. If the rotator gets stuck, it will display STUCK.

Use the **Set Bearing** field and the **Go** button to enter a new bearing directly. Use the **Green** buttons quickly set the bearing to a new cardinal or ordinal.

The **Calibrate North** button can be used to set the magnetic declination offset. Start by clicking the green North button. After the rotation stops, check the actual direction of the antenna. Enter what ever bearing is required to get the antenna pointing true north and then click the Calibrate North button.

The WiFi Router information is explained in the section Using the Rotator Controller Connected to a LAN via a WiFi Router .

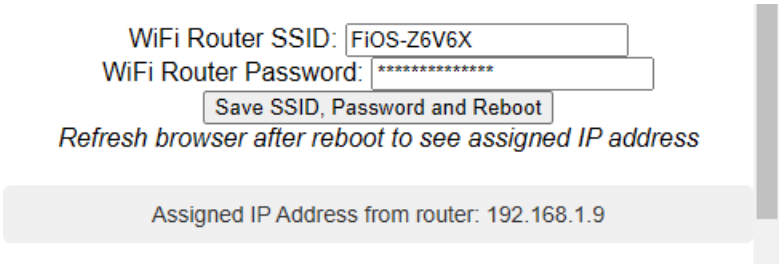
The **Open in Popout** button is intended to be used when viewing the web page on a computer. It will open a new browser window (pop out) that is devoid of the normal browser buttons, tabs and control making it more compact for easier viewing.

Using the Rotator Controller Connected to a LAN via a WiFi Router

The following procedure allows users to connect the rotator controller to an existing local area network via WiFi. Note that only WiFi routers with a 2.4GHz access point will work with the ESP8266 chip set.

The Controller's SSID and Password must be set using the Controller's access point and web server.

- Connect to the Controller's access point using the Stand Alone mode described above.
- Open a web browser and enter the IP address: 192.168.4.1 into the address field of the browser. The Rotator Controller GUI will open. Enter the SSID of the LAN into the WiFi Router SSID field. Enter the LAN password into the WiFi Router Password field:



Click on the **Save SSID, Password and Reboot** button.

The ESP8266 will reboot and the bearing should start updating again. Refresh the web page (F5 for most computer browsers) and the password should now be obscured with *s. The Assigned IP Address assigned to the controller by the LAN router will be displayed in the gray box labeled, Assigned IP Address from router. In the example above, the address assigned is 192.168.1.9.

Note this address, close the web page, connect your WiFi device to the LAN, open a web page and enter the IP address noted in the previous step into the address field of your browser. The rotator GUI will open and operate as described above. As noted earlier, multiple rotators can be operated from the same LAN at the same time.

Use this same procedure to update the SSID and password to change to a different WiFi router.

For applications on the network to access the ESP8266 they will need to know the netmask for the WiFi network. Typically this is 192.168.1.XXX. Check the router's administration page to confirm the correct address. If there is only one rotator logged onto a LAN, you can use the broadcast IP address of 192.168.1.255 to send commands to the rotator. If there is more then one rotator controller logged onto the same LAN, use the IP address assigned to the ESP8266.

Note that a WiFi adapter can only connect to a single network (access point) at a time. An adapter can not be connected to a WiFi router and the ESP8266 acting as a DNS access point at the same time unless a second WiFi adapter such as a USB-WiFi dongle is used.

HexRotatorControl Windows Application

The custom Windows application is called **HexRotatorControl.exe**. This application is specifically designed to operate with the rotator controller.

Use of the HexRotatorControl application is optional. The rotator controller can receive commands directly from N1MM and other PST compatible programs without the need to run this application.

Installation

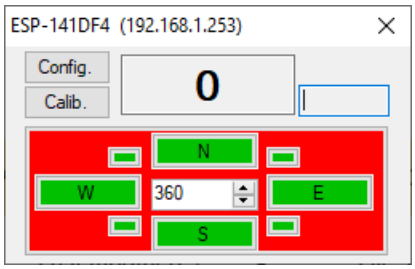
HexRotatorControl.exe is provided as a single Windows executable binary file. Simply place the file in a directory of your choosing. Run it by double clicking on the file name or right clicking on the file name and then click on Open in the window that pops up. The application is not signed so when it is started Windows may issue a warning indicating that it's an unrecognized app.

HexRotatorControl needs to open UPD ports. The first time the application is run, Windows may issue a Firewall security warning. Allow access so the program can communicate with the rotator controller and other applications on the computer.

Uninstalling

To uninstall, simply delete HexRotatorControl.exe from the folder where it resides.

User Interface



The current bearing is display top center. If the rotator controller hasn't been found yet it displays dots and dashes or if communications is lost. A set of question marks.

The interface has a set of buttons and a numeric up/down number entry box.

The number enter box in the center of the buttons is the Bearing Command box and allows entry of an arbitrary bearing value. Any time this value changes, a new bearing it sent to the rotator controller.

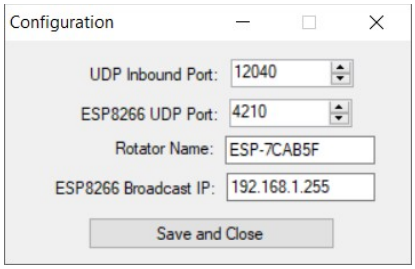
The title bar displays the name of the ESP8266 chip for the rotator controller which the app will control. The IP address of the controller is displayed after the name or "searching …" if the controller has not yet been discovered.

The buttons are:

- Conf. - Opens the Configuration dialog.
- Calib. - Performs a calibration. Discussed below.
- N, S, E and W – Pressing these sets the corresponding bearing into the Bearing Command box. If the value is different from the prior value, the new bearing is sent to the controller.
- Four ordinal buttons between the N, S, E and W – Allow quickly setting NE, SE, etc. bearings into the Bearing Command box.
- Large surrounding button – All around the other buttons is one large button. Clicking anywhere on that issues a Stop command to the controller.

To the right of the current bearing is a box that will display either CW or CCW when the mast is rotating clockwise or counterclockwise respectively. If the rotator controller detects that rotation is stalled, it will say “Stuck”.

Configuration



After launching the program, click the Config. button to open the Configuration dialog. The following settings can be configured:

- UDP Inbound Port – This is the port the application monitors for incoming commands from other rotator control programs. Refer to the rotator control program’s documentation to determine what port it sends on. For example, N1MM sends on 12040 which is the default here. Processed commands are listed below in Section External PST Interface.

- ESP8266 UDP Port – This is the port number the ESP8266 is listening on. By default this is 4210 and should only be changed if the ESP8266 value is changed. The next higher port number is used by the application for receiving response UDP packets.

- Rotator Name – Enter the name of the rotator controller. Use the IDE Serial monitor view when the sketch is loaded and run the first time and note the line displaying the Rotator Name. Label the rotator controller with the name for future reference and use that name in this enter field.

- ESP8266 IP or Netmask – Enter the broadcast address for the network the ESP8266 is on. The program will broadcast a request for the rotator controller with the Rotator Name entered above to provide its IP address.

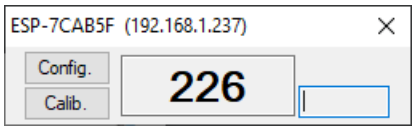
See section Using the Rotator Controller for information on methods of connecting a ESP8266 rotator controller to the network.

- If connecting to an ESP8266 rotator controller using the computer's hotspot: Windows setups the network DHCP service using 192.168.137.1 as the gateway and leases out addresses on the 192.168.137.xxx network so the default setting in this case is 192.168.137.255.
- If connecting to an ESP8266 rotator controller via a network router: Routers typically setup the network DHCP service using 192.168.1.1 as the gateway and lease out addresses on the 192.168.1.xxx network. Verify this is the case by checking the router setup and then change the default for this setting to 192.168.1.255 or what the router is providing.
- If connecting to a ESP8266 rotator controller configured as an access point and DNS: The ESP8266 setups the network DHCP service using 192.168.4.1 as the gateway and leases out addresses on the 192.168.4.xxx network. Change this setting to 192.168.4.255 or 192.168.4.1.

Press the "Save Program Settings" button and then close the dialog using the X in the upper right corner.

Minimal View

The GUI can be shrunk to a minimal showing just the top portion of the dialog. This can be useful if bearing control is being done from another program such as N1MM. In that case HexbeamRotatorControl can be used to just view the current bearing and rotation status. To toggle between the minimal view and full view, double click anywhere on the background. The minimal view looks like this:



Calibration

The magnetometer used in the controller will experience error due to magnetic declination or variation. The user can minimize magnetic declination by adjusting the magnetometer bearing error offset value used in the ESP8266 firmware. The user changes the magnetometer bearing error offset value by using the Calib. button. The first step in the calibration procedure is to verify that the antenna is pointing directly North using an independent calibrated source such as the GPS compass on a smartphone. The numeric up/down buttons can be used to incrementally rotate the mast until it points North. Once the antenna is pointing North, press the Calib. button to calculate a new offset. This should also help compensate for nearby metallic components and large magnetic fields.

Note: Magnetic declination, sometimes called magnetic variation, is the angle between magnetic north and true north. For more information see: https://ngdc.noaa.gov/geomag/declination.shtml

N1MM Notes

N1MM can be used to send rotate and stop commands to the Rotator Controller via the HexRotatorControl windows application or to the ESP8266 Controller directly so that the HexRotatorControl application is not required.

Using the HexRotatorControl app with N1MM allows the user to see the rotator controller's current bearing and rotation in the application. Alternatively, the bearing can be viewed using the web page interface. N1MM alone does not show the bearing data.

Setup

In either case; commands sent via HexRotatorControl app or direct to the Rotator Controller, N1MM must be configured with the IP address and the port number to send to. These are set by clicking on Config→ Configure Ports, Mode Control, WinKey, etc… to bring up N1MM's Configurer window. Select the tab called Broadcast Data. Under "Type of data" find the row labeled Rotor. To the right is where the IP Address and Port numbers are entered.

If you want to use HexRotatorControl with N1MM, set the IP Address to the local host: 127.0.0.1 and the port number to the value set under HexRotatorControl's Config. → UDP Inbound Port entry. The default is 12040. As an example, in the N1MM Configurer Rotor field, enter 127.0.0.1:12040.

If you want to send commands directly to the ESP8266 and not use HexRotatorControl, use the ESP8266's IP address or its subnet broadcast address and the ESP8266 UDP port number of 4210. As examples of what to enter into the N1MM Configurer Rotor field:

- To send commands directly to a specific Rotator Controller at IP address of 192.168.1.253, enter 192.168.1.253:4210
- To send broadcast commands to Rotator Controllers without knowing the specific IP addresses for them enter: 192.168.1.255:4210

Note: If the broadcast address is used, the HexRotatorControl if running and all Rotator Controllers on the network will receive the command.

Sending Rotate and Stop Commands

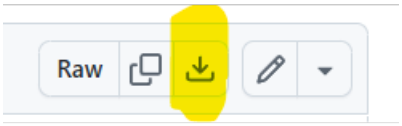
There are several ways to set a new bearing and stop commands from N1MM to the Rotator Controller:

- Enter the new bearing value in the CALLSIGN box and press Alt-J.
- Entry the callsign in the CALLSIGN box and press Alt-J. N1MM looks up the proper bearing info.
- Pressing Alt-L sets the long path when a callsign is entered.
- Pressing Ctrl-Alt-J issues a Stop command.

GITHUB Repositories

All the required software files for the system, including the most up to date user manual are here: https://github.com/lhbru/Mastwerks-BuddiHex-Rotator.git

To download, click on the filename. A new page is displayed with a download icon that allows the program to be downloaded. On the right are buttons. One is the download button. See the image below that shows the correct button highlighted in yellow:



- HexRotatorControl: In the list, click on HexRotatorControl.exe.
- rotatorControllerESP8266.bin: In the list, click on rotatorControllerESP8266.bin.

Appendix

ESP8266 Firmware Technical Notes

The ESP8266 is software compatible with the Arduino micro-controller, and as such, the Arduino IDE (https://www.arduino.cc/en/software), Arduino studio or another compatible IDE can be used to make changes to the code and to load the binary onto the device.

Data are exchanged between the ESP8266 and other applications over WiFi using UDP.

The firmware running on the ESP8266 connects to a WiFi hotspot, opens a known UDP port and then listens for incoming commands. Responses are returned to the IP address and UDP port number from which the command came. The default UDP port number is 4210. It also creates a DNS access point on 192.168.4.1.

To view the currently loaded firmware, connect to the ESP8266 with a browser at 192.168.4.1 and scroll to the bottom of the screen.

Using the ESP8266 with a computer hotspot under Windows OS

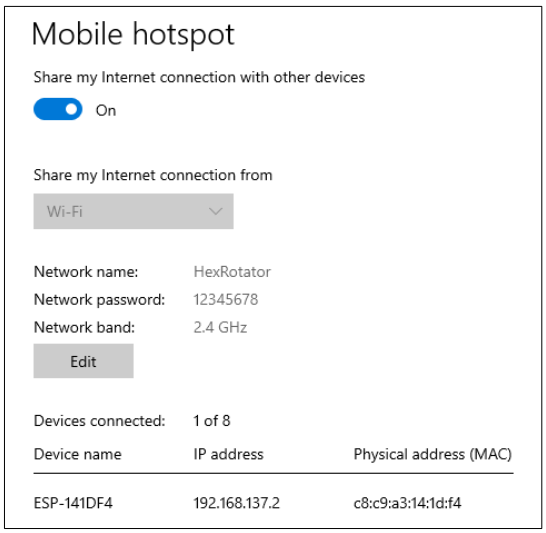
Use the same procedure as described in Using the Rotator Controller Connected to a LAN via a WiFi Router only use the SSID and password of the hotspot instead of the WiFi router's.

A disadvantage of this approach with Windows is that the computer needs to have an internet connection. Windows won't allow a hotspot to operate on a computer that has no connection to the internet. Simply having a connection to a router, such as might be the case at a Field Day, is not enough.

Depending on the computer it may need to have two network cards, with one connecting to the rotator controller and the other connecting to the local area network of computers operating in the contest site. Some computer WiFi adapters allow starting a hotspot on at 2.4GHz while simultaneously connected to a router at 5GHz. Alternatively, connect to the router at the slower speed.

Windows assigns an IP netmask of 192.168.137.XXX to computer hotspot networks. If there are multiple stations and rotators in the field, each hotspot computer and the rotator it wishes to control must use a unique SSID.

If the ESP8266 has been loaded and is powered on, it should show up under the connected hotspots. Open Windows Settings → Network & Internet and click on Mobile Hotspot. Under Devices connected the ESP8266 should be displayed.



Partial screen shot of the Network & Internet Settings after proper hotspot setup.

Controller Command Interface

The ESP8266 will listen for and process commands received over the WiFi. The information presented in this section is for those wishing to interface the controller with other software packages.

The following incoming commands are accepted:

- PST commands:
  - <PST><STOP>1</STOP></PST>
  - <PST><AZIMUTH>85</AZIMUTH></PST>
  - <PST>AZ?</PST> Return the current bearing as: AZ:xxx.x<CR>
- N1MM commands:
  - <N1MMRotor><goazi>xx.x
  - <N1MMRotor><stop>
- Custom Commands:
  - GET_BEARING: Return the current bearing as: GET_BEARING:xxx If the rotator is currently rotating, the direction is appended, for example: GET_BEARING:xxx CW

HexRotatorControl Technical Notes

The application communicates with the rotator controller through a client UDP port. A second UDP port is monitored for incoming commands from external programs that support the PST protocol and for commands from N1MM.

Saving Settings

Program settings are saved in the Windows Registry under:

Computer\HKEY_CURRENT_USER\SOFTWARE\<user name>\HexbeamRotatorControl\<version>

Settings are version specific so if upgrading, the HexRotatorControl configuration will need to be re-entered and saved.

External PST Interface

As previously described, the Windows program listens on the user selected port for incoming PST compatible commands to forward them to the ESP8266 Controller.

i. The following commands are decoded and processed:
   - <PST><STOP>1</STOP></PST>
   - <PST><AZIMUTH>85</AZIMUTH></PST>

ii. N1MM commands supported are:
   - <goazi>
   - <stop>

Tips, Problems and Solutions

Tip: Twist the DC power lines together. Twist the I2C bus lines to the QMC5883L together.

Tip: Debugging data can be sent to the Arduino IDE Serial Monitor or other terminal emulator. In the Arduino file **rotatorControllerESP8266.ino**, find the line ***//#define DEBUG*** and remove the comment characters **//** so the line reads ***#define DEBUG*** Various messages will be sent to the Serial Monitor indicating rotation status that may help in debugging any problems.

Problem: The displayed bearing is a negative value and Error! is displayed to the right, a fatal error has been encountered. The follow are the possible errors:

- -1 The QMC5883L was not found.
- -2 The QMC5883L not ready.
- -3 The QMC5883L calibration failed.

Solutions: Review the controllers circuit board components, wiring and solder points. Replace the QMC5883L.

Problem: Bearing reading QMC5883L is consistently off by some factor of near 90, 180 or 270
Solutions: Check that the QMC5883L is mounted correctly and not upside down.

Problem: Bearing reading QMC5883L is consistently off by a small but inconsequential amount
Solutions: Check that there are not metal or magnetic objects near the control box. Perform a calibration to account of declination.

Problem: Large and rapidly changing swings in the bearing readings while the rotator controller motor is stationary.
Solutions: Verify that the battery is connected and the control electronics are not being powered by the USB port. The ESP8266 can not supply enough power to the QMC5883L for it to operate properly and in fact may damage the ESP8266.

Problem: Large and rapidly changing swings in the bearing readings while rotating or rotation stops almost immediately.

Solutions: Check that the motor DC power lines are routed away from the QMC5883L. The DC power lines will generate a magnetic field when current flows and the QMC5883L will detect it. If the problem persists, try mounting the QMC5883L further away from the other control electronics, even outside the control box. Twist the DC power lines together. Twist the I2C bus lines to the QMC5883L together.

References

PST Rotator documentation is here: https://www.pstrotator.com/ANT/PstRotator%20User%20Manual.pdf

N1MM References:
https://n1mmwp.hamdocs.com/setup/interfacing/#rotator-udp-packet-information
https://n1mmwp.hamdocs.com/setup/interfacing/#n1mm-rotator-control