

A Printable Az/El Rotator system with WiFi

Glenn Elmore n6gn@sonic.net

Overview

This article describes a lightweight rotator system which can be controlled in both azimuth and elevation by way of a WiFi interface. The system is completely self-contained and can be operated without any metallic connections while being powered by an expensive Lithium-Polymer (LiPo) battery. It is inexpensive with most of the components printed by a 3D printer out of PLA plastic. Only the two servo actuators, Arduino Nano IoT33 one-chip controller, battery, wire and connectors and two inexpensive thrust bearings need be purchased. Total cost for all parts should be less than US\$100.

While this is a light duty unit it should be adequate for small rotating small loads such as the HF dipole/SDR receiver system it was originally designed to accommodate as well as small VHF or UHF yagis or microwave antennas.

The impetus for a system of this sort was to be able to position a LF-HF receiving system along any axis and polarization for communications uses and for ionospheric propagation study. That system includes both a well balanced dipole probe antenna and a multi-channel LF-HF SDR receiver with WiFi interface. In order to work well, the target system needed to be free of common-mode noise and interference that could otherwise restrict its dynamic range. By mounting the entire receiver at the center of a symmetric antenna, a short dipole, it was possible to eliminate antenna feed line and conductive connections altogether. When mounted on this rotator system every linear polarization as well as azimuth and elevation angle can be examined. This also allows directing a null from the antenna towards the effective location and polarization of unwanted noise sources and thus may significantly improve the effective sensitivity of the receive system. A goal of the design was to approach propagation-limited noise floor across as much of the VLF-HF range as was possible in a small system in a typical residential location.

WiFi access for the receive system already had been provided so similar connection-less access to the rotator was required as well. For the rotator, a single-chip Arduino Nano IoT33 controller having built-in WiFi as well as a LSM6DS3 six degree of freedom inertial module was used. The module provided the additional benefit of calibration and position of the rotator since actual position could be reported and controlled in real time. Libraries for the WiFi interface as well as the inertial module are readily available which made programming the application much simpler.

Most of the mechanical pieces necessary for the system are printed with a 3D printer out of PLA filament. This plastic is sufficiently strong, easy to print and inexpensive. The parts for the individual rotors are similar with major portion common to both rotors. Inexpensive thrust bearings, of the type normally used for kitchen “lazy Susan” platter rotation bear the load while servo mechanisms of the type used for positioning model sailboat mainsails are used to control the rotational axes. For a small load, such as the active antenna/receiver system, a 25 kg-cm servo may be used. For slightly larger loads a 35 kg-cm part can be purchased for approximately twice the cost. The servos have brass gears

which operate with only a small amount of backlash. Internally a relatively linear potentiometer provides positional accuracy. Setting accuracy for both azimuth and elevation is on the order of 1 degree or better when backlash is accounted for in the software.

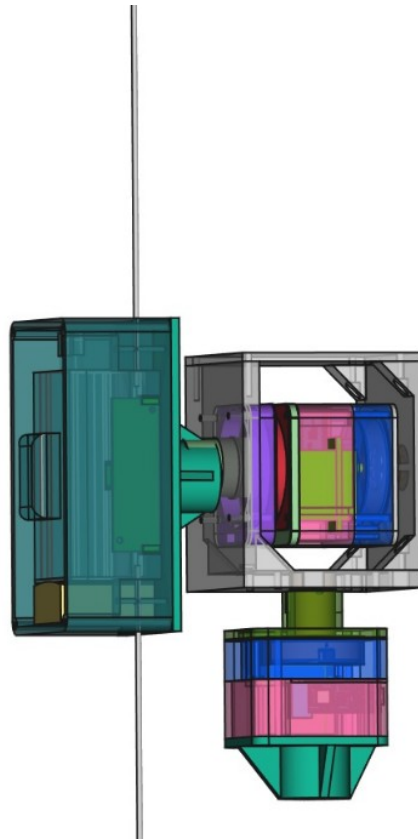


Figure 1: Broadband Antenna&SDR mounted on the Az/El Rotator System

Figure 1 shows an example broadband antenna and SDR receiver mounted on a completed rotator system. The dipole is in a vertical orientation in this view but can be rotated over 180 degrees so any linear polarization at any azimuth is possible. Azimuth can also be rotated over 180 degrees which allows the dipole to receive from any direction in any linear polarization. The entire receive system and rotator can be powered from a co-located LiPo battery. This arrangement removes all electrically conductive connections which might otherwise inject interfering noise or signal currents. No battery is shown in this figure but a small 2S, 7.4V battery of the type used for remote controlled model cars, airplanes and multi-copters can power everything for a few hours depending upon power requirements for the particular receive system. The rotator itself consumes only a few hundred milliwatts except for brief peaks of a few watts while actually rotating. Maximum current is on the order of 2-3A but is only very briefly required as the rotors began to change position. The servos 'lock' into position when not being moved, holding the position of the payload even in significant wind.

In addition to the common portions each rotor has a special winder attached. This is provided to keep the interconnecting cables out of the way and protected from tangling.

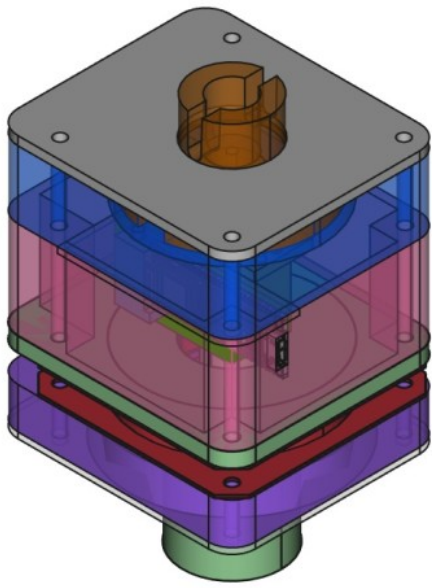


Figure 2: Elevation Rotor with Servo-Side Winder

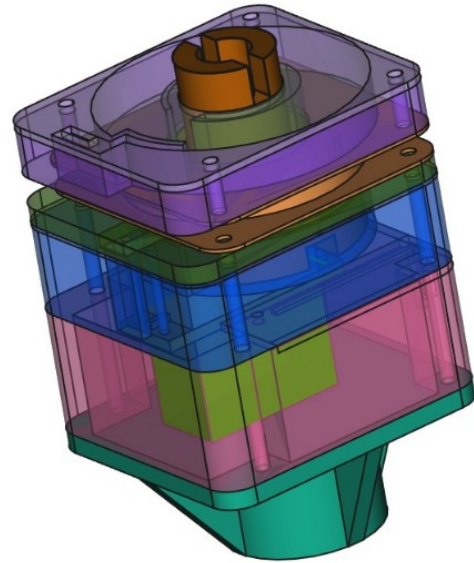


Figure 3: Azimuth Rotor with Drive-Side Winder

Figures 3&4 show the two rotors with their associated winders attached. The azimuth rotor has a mast mount at its bottom with the winder on the drive end, the end with the notched post which is driven by a servo, while the elevation rotor has its winder attached to the servo end of the housing. The Arduino Nano IoT33 is mounted inside the elevation rotor so that it rotates along with the antenna/receiver ‘payload’ of the system. The Nano is in the same frame of reference as the payload which allows a 1:1 correspondence between antenna position and the Arduino’s IMU so that antenna position can be directly measured and controlled. The micro-USB connector of the Arduino is accessible from outside even after the elevation rotor is assembled to provide for programming changes and calibration.

For the azimuth rotor, the body is held fixed to a non-conductive PVC pipe used as a vertical mast while the drive post rotates the mounting assembly containing the elevation rotor as well as the payload. The elevation rotor has its drive post held captive within a mounting box while the entire body containing the controller and servo rotate along with the mounting for the payload on the other end. For both rotors, a thrust bearing between the rotor body and the winder supports mechanical loading and allows rotation while protecting the servo from off-axis forces.

Each rotors attaches to the mounting box, shown in Figure 4, by way of a dual-D shaped opening that constrains rotation. The azimuth rotor also has its winder directly attached to the box but the elevation rotor is mounted by way of its thrust bearing and winder on the end with its servo so the mounting post can move longitudinally within the lock D hole. This allows for variations in printing and mechanical tolerance while reducing ‘slop’ in the positioning.

The mounting box that the rotors attach to is made from an L section, a left wall that the elevation rotor winder attaches to and a top cover that ties the walls together. This allows access to the elevation rotor during mounting and programming while at the same time providing enough rigidity during normal operation.

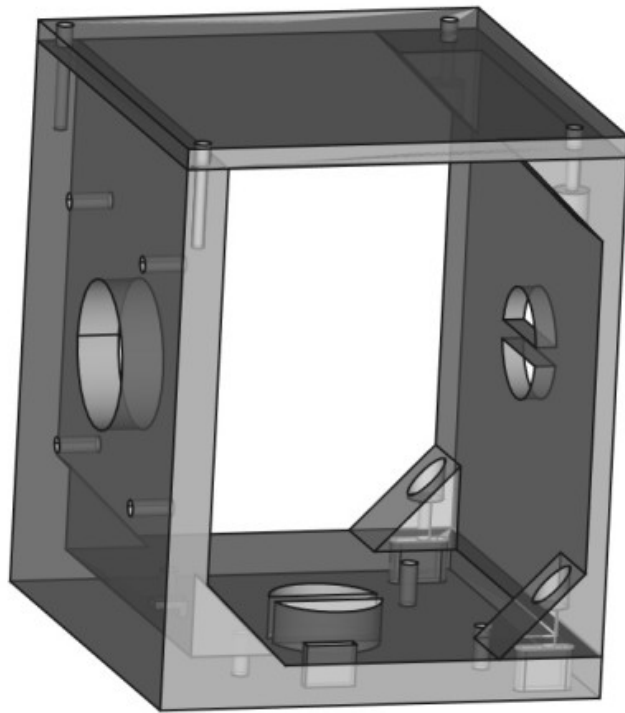


Figure 4: Mounting Box for the AzEl rotator system. The azimuth rotor attaches at the base while the elevation rotor has its rotation locked by the dual-D on the right wall but mounts onto the left wall of the L bracket.

The winders are similar but slightly different since one fits to the drive end of its main rotor enclosure and the other to the end where the servo is mounted. Figure 5 shows the Az rotor winder which mounts on the same end of the rotor as the notched drive shaft.

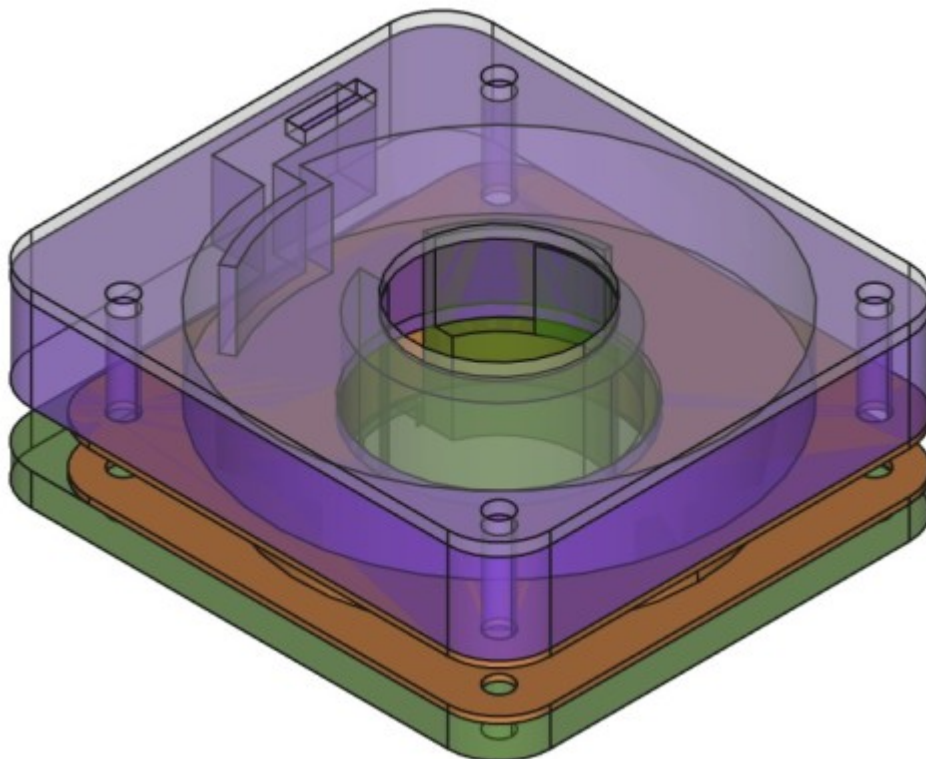


Figure 5: Azimuth Rotor (Driven Side) Winder

At the bottom of the azimuth winder is a plate with central post that goes all the way through to the external attachment point on the dual-D hole in the mounting box. The thrust bearing sits atop that plate and allows the top part of the winder to rotate around the axis of the central post and permit the ribbon cable wound in the spiral, mounted above it, to accommodate 180 degrees of rotation. At the top there is an end cap to protect the rotating cable and parts inside.

The elevation winder is similar but has an end post and plate assembly that bolts onto the servo end of the elevation rotor which has the Nano IoT33 also mounted within the compartment with the servo.

Printing the Parts

I designed all the parts for both rotors, the mounting box and the receiver assembly in an OpenSource 3D program called FreeCAD. The design was iterated, changes made along the way and then re-printed on an inexpensive Creality Ender3 printer using PLA material. For the process, the design was exported to an .STL file and then imported by another commonly used and freely available “slicer” program, Ultimaker Cura. This turns the .STL design into .gcode which is the instructions needed for the 3D printer. Cura also allows configuration and adjustment to be made to optimize the printing process. For this project, no special settings were used for most parts other than enabling “supports” and setting the interior fill to 30%. Inside the plastic is not solid but a honeycomb that requires less time to print and uses less material while maintaining significant strength compared to a solid plastic part. An exception to this is the drive and mounting posts which bear the weight of their load. These were printed with 100% fill in order to gain a little extra strength.

The parts do take quite a lot of time to print. The L mounting section takes the most time and may require on the order of 10 hours. To print the entire set of parts necessary for both rotors and the mounting box takes two to three days unless special effort is made but if the printer is set up and operating well there are no special concerns. A slight bit of cleanup is required to remove any extraneous plastic from the supports and edge adhesion if printing was done with it enabled.

Assembly

The ability to print projects like this in plastic on today’s 3D printers adds a new area of opportunity for electronic projects in general. The accuracy and flexibility of part design that a 3D printer brings allows solutions that would not be possible if one were limited to hand tools and home shop equipment. Once printed, the parts go together easily and fit well with very little or no adjustment. Typically there can be a little shrinkage to PLA material but that has been allowed for in the design of this rotator system so no extra effort is required.

The servos and the main box assemble with 6-32 screws threaded into plastic. The printer will create 3mm diameter holes which can be threaded with a hand tap. In addition to these mounts there is a single threaded hole for the stop block that holds the Nano IoT33 securely in place. The servo itself comes with a 3mm threaded metal arm which, after the arm has been securely tightened around the drive gear, attaches to the wheel/post assembly with a socket head screw. The post protrudes through

the winder and end cap in the case of the Az rotor or through only the end cap in the case of the El rotor. The wheel has two holes above the metal arm which allow attaching the wheel to the arm with 3m socket head screws. There is relief in the wheel so that the top of the wheel is flush. There is also a setscrew to secure the azimuth rotor mounting to the PVC pipe mast. No other holes need be threaded since the rotor and winder assemblies are fastened together with 3" 6-32 bolts and nuts as are the attachments of each rotor to the mounting box. I recommend building and testing each rotor alone and outside the mounting box prior to final assembly.

Winder

Probably the most difficult part of assembly is threading the ribbon cable through the rotor bodies and winders prior to attaching connectors at their ends. I connector-ed everything for easy assembly and access since in the process of developing it everything had to come apart and be put back together several times. After threading the cable for each winder I rotated the two ends of the winder clockwise until the cable had two turns wrapped around the center post and then clockwise one half turn. This allows for 360 degrees of total rotation even though the rotors will only be set to use 180 degrees of their possible 270 degree range. That could be changed during calibration if desired but for my applications a half rotation of the dipole was all that was needed.

After the winder is threaded and attached to its rotor, calibration to precisely set end positions can be performed and values obtained entered into the Arduino code by way of the Arduino IDE, described next.



Electrical Connections

A single 6 conductor ribbon cable interconnects the power source, rotors, Nano and payload. This ribbon runs through both winders with connectors to make assembly and testing easy.

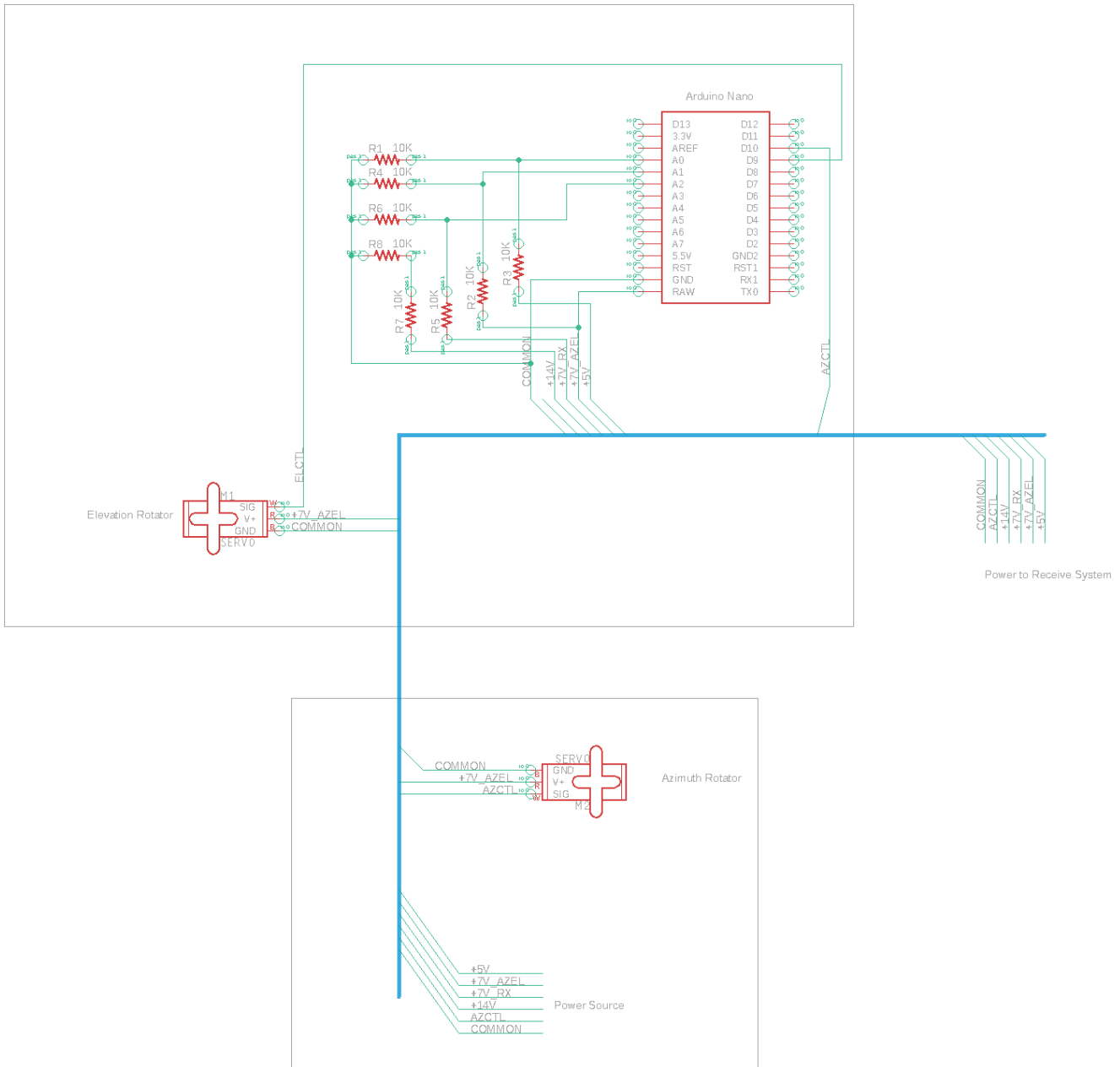


Figure 6: Wiring Diagram

Programming the Nano IoT33

The Arduino Nano IoT33 is a very appropriate inexpensive one-board solution for this project. It can be powered directly from the same 7.5VDC LiPo battery as the servo mechanisms since it has an on-board regulator. It also has built-in WiFi interface and IMU as mentioned previously. With the available libraries writing a small program with the Arduino IDE and libraries is a relatively easy task. Along

with the 3D printer files and material list for the mechanical parts of this project there is an .ino file which contains everything necessary to program the Nano by way of a standard USB cable and host computer running the Arduino IDE. This host can be using a Windows, Apple or Linux operating system since each of these is supported by Arduino. No special knowledge is needed to program the IoT33 compared to the Uno, Nano or several other well-known Arduino one-board computers.

To program the AzEl rotator code all that is required is a basic familiarity with Arduino which can be obtained with a couple of hours of reading and practice with example code provided by the IDE. Download the IDE for your platform, go to the Arduino site and follow the instructions to connect to the Arduino board and once successful with that, compile and upload the AzEl .ino file in the same way.

The Arduino Nano IoT33 pages have introductory information for using this board and combined with the AzElRotor.ino 'sketch' should be suitable for understanding and successfully programming the board. Once programmed WiFi access and checkout of the AzEl rotor system is next.

It is important that initial programming and testing web access is done BEFORE connecting either rotor to power and the IoT33. This is because every time power is applied to the system, the servo in each rotor will attempt to center itself at approximately mid-range. This will be done at full rate, in a fraction of a second, and if the rotor was not already physically centered the servo will rapidly go to this point which represents a **POSSIBILITY OF INJURY TO THE OPERATOR!** Once centered and under program control, motion is controlled and slowed down by the program.

Using the Rotator

The rotator system is accessed by way of its web page which is served by the IoT33. Before the IoT33 is programmed with AzElRotor.ino code, the "Arduino_Secrets" file in the code must be provided with the local WiFi SSID and password. Then after the board has been programmed it will automatically find and receive an IP address via DHCP from the local access point or router host which is being accessed. Since the address is generated by that host, it will be necessary to log onto that host one time to discover what address has been assigned. Once this is known, that address should be reassigned the next time the power to the IoT33 is cycled.

Once running, simply opening a browser to [http:\[IPAddress\]:8078](http://[IPAddress]:8078) should result in a page similar to that shown in Figure 6:

N6GN AzEl Rotor

Azimuth

Azimuth goes from 0 degrees (North) through 90 degrees (DEFAULT East) to 180 degrees (South)

Select 0 < Azimuth Angle < 180

Elevation

Elevation of 0 degrees (DEFAULT) is Up (Horizontal Polarization). +90 degrees are Vertical Polarization

Requested ElAngle = 0.00 & IMU Reads = 5.98

Select -90 < Elevation Angle < 90

[Elevation Step](#) over the entire range and compare with IMU reading

[curl --get --data "Status=1"](#) returns status information

[curl --get --data "AzAngle=xyz" http://ip:port](#) sets Azimuthal angle to xyz degrees with servo

[curl --get --data "ElAngle=xyz" http://ip:port](#) sets Elevation angle to xyz degrees with servo

Figure 7: AzEl Rotator Home Page

Material List

AzEl Rotor Material	Part #	qty	Cost	Extended	URL
Servo	Hiwonder 20kg	2	\$17.50	\$35.00	https://amazon.com/gp/product/B07569WJ1M/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1
CPU	Nano33lot	1	\$18.40	\$18.40	https://store.arduino.cc/usa/nano-33-iot
Thrust Bearing	3 Inch Square	3	\$2.50	\$7.50	https://smile.amazon.com/gp/product/B08F9NRQ2S/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1
Ribbon Cable roll	902220736006000	1	\$2.25	\$2.25	https://www.mouser.com/ProductDetail/581-902220736006000
Bolts		8		\$0.00	
Bolts	6-32 x 1/2"	8		\$0.00	