

Arduino Due (Programing Port) program to command azimuth and elevation antenna motors to track space objects. Works with any type of motors.

INTRODUCTIONS-

This is a CT4BB program that uses ARDUINO's open-source libraries to read SD cards, RTC Watch, I2C, SPI, etc. The system is designed to track DSN spacecraft probes and celestial objects using NASA's Ephemeris @ <https://ssd.jpl.nasa.gov/horizons.cgi#top> The data from this NASA site is in txt and are printed in files with the name of the space objects. Ex: Copy Sun data and paste it in the SD card as SUN.txt, and Mars Reconnaissance Orbiter (MRO) data and save it in the SD card as MRO.txt.

This is a program with mapped voltages(0->5V) to 0-> 4095 bytes using 12 bits resolution so, have on the SetUp the instruction analogReadResolution(12).

The model of the (ARDUINO DUE Programming Port) used does not start when the voltage is turned on. To fix this, you must solder a surface mount resistor (0603 size) onto the board: solder a 10k resistor between the ERASE line and + 3.3V, close to Fet T3.

In practice, solder it across the 2 upper pins of T3.

<https://forum.arduino.cc/index.php?topic=256771.60>

Arduino due is 3.3 V logic. To connect with I2C LCD or RTC1307 Logic 5V, a bidirectional voltage converter is required. The SDCard reader is 3,3V Logic but feed with 5V DC

External PullUp resistors of 5K must be placed to stabilize the digital inputs of pins 3,5,6,7 and 13, because the internal PullUp resistors of ARDUINO DUE are 50K and this high value causes instability and errors in the readings caused by induced noise, namely alternating current.

SYSTEM WORKING –

1 - The tracking system will only work on the day of the recorded Ephemeris, because it will compare the actual date with the date of the Object Ephemeris in the SD card.

If the dates are equal, it will read the actual Time- Hour Minute and Seconds - to compare with an equal Time in the file of the selected space object. If the actual time is equal to the recorded, it will catch and read the azimuth and the elevation of the object to activate the relays of the Azimuth and Elevation motors. Motors will run driving a multiturn potentiometer, with pre-calibrate voltages that are mapped to the angles. Motors will stop @ that precise Voltage/angle.

2 - The system reads the file and checks if the date is correct (if not, everything is null). If it is correct, the information loop for the actual UTC time and the Azimuth / Elevation in which the antenna is located begins. Every minute it compares the real time clock with times list in the file. If it is the same, reads the azimuth and the respective elevation. Then, compare these values with the previous Azimuth and Elevation to decide the CCW or CW movement of the respective engines. For good LCD messages, you must translate to your language in the firmware, all LCD comments, and menus.

3 – A calibration must be made if you change mechanical hardware.

Normally it is only necessary to do it once. Calibration will make the motors of the Az and El to run from the minimum angle/voltage (0 °) where a microswitch is activated to stop and after, motors travel to the maximum angle/voltage (360°) to switch on another microswitch to stop movement.

HARDWARE-

The pinout used on the Arduino Due is as follows:

Pin 11 digital OUTPUT: CCW control of Elevation motor

Pin 10 digital OUTPUT: Elevation motor CW command

Pin 8 digital OUTPUT: Azimuth engine CW command

Pin 9 digital OUTPUT: Azimuth motor CCW command

Digital pin 7 INPUT_PULLUP: Elevation limit switch sensor

Digital pin 6 INPUT_PULLUP: Elevation start sensor

Digital pin 5 INPUT_PULLUP: Azimuth limit switch of 360°

Digital pin 3 INPUT_PULLUP: Azimuth start sensor of 0°

Note : Pin 5 and Pin 3 can be connected to the same switch, because as the azimuth goes CCW or CW the software will wait for Pins ground @ respective direction to give a Byte value for 0° and 360°

Digital Pin 13 INPUT_PULLUP: Clicks of the Menu Button (single click, double click or long press).

Connections of 6 Pin IDC for SPI located in the middle of ARDUINO DUE to communicate with SD Card
IDC SPI-Pin 1 pin (dot or number 1) is digital MISO .

IDC SPI-Pin 2 Not used,

IDC SPI- Pin 3 SCK Clock communication with SD CARD.

IDC SPI- Pin 4 MOSI.

IDC SPI- Pin 5 RESET Not used

IDC SPI- Pin 6 GND Not used

Digital pin 4 CS (Chip select) for SPI communication with SD CARD

Analog A4 pin SDA for I2C communications RTC Watch DS1307 and I2C LCD

Analog A5 SCL pin for I2C communications RTC Watch DS1307 and I2C LCD

Analog A0 pin INPUT for analyzing the voltage of the azimuth potentiometer

Analog A1 pin INPUT for analyzing the voltage of the elevation potentiometer

STRUCTURE AND OPERATION –

(In the text, SOL means Sun).

When connecting, the system runs the Settings and Setup (). In the setup (), will read the Date and Time and the day in the DataHoraRTC () function, then in the setup (), it will compare the Year, Month, day of the card with the actual RTC. System uses as start the reading of the date of the file SOL.txt defined inside the setup () as a start reference to put the Tracking structure pointed to the Sun. The function that does this operation is ler_SOL_Data (). In this function, at the end of reading and registering, it will return to the setup () to make Date comparison with the function compara_Datas run () . Comparing the dates and, if they are the same, it will read the directories of all SDCard files. With the function * ler_DIRECTORIA_SD (File dir, int numTabs) reads the directory and stores in the Strings A, B, C, D, E, F, G, H the menu is prepared for choosing the file to open. Space Objects (Probes) selection, is done in PROBES with sondastr = "Click to open" that will appear on the LCD. When clicking to open with the probes () function, the object file to be followed is chosen. When defining this choice, all data from the object in question is loaded into the Data (u) buffer in a matrix that will be carefully accessed. The Loop then starts with the selected object where, every 5 minutes, it will be checked whether the actual Hour and Minutes are in the respective file. If there are HOURS = HORASSD and MINUTES = MINUTOSSD, the respective AzNovo and ELNovo will be read soon using the lerHM_AZ_EL () function. These data are available for processing the movement of the antenna. During the 5-minutes interval to read new data, the LCD will inform the UTC Date / Time and the azimuth and also where the Az/El is pointed or, in the case of movement, where the antenna is going to new Az/El. The program uses ARDUINO IDE by opening the file TRACKANTENUINO.ino which is inside the folder TRACKANTENUINO. The libraries used in the program are all within this folder. The use of more recent versions of the libraries may require the correction of the instructions in the software. For the operation of the system, it is not necessary to use more recent versions of the libraries. This program, essentially, operates relays that can excite other power relays or power contactors that, in turn, excite bidirectional power motors by switching contacts and connections. The stopping point of the motors is defined by a voltage 0-> 5V mapped in movements 0-> 90 degrees for Elevations and 0-> 360 degrees for Azimuths. These voltages can be obtained by rotating a multi-turn potentiometer engaged in the motors. It is a mechanical question that each one can study and develop, making the turns of the potentiometers to be mapped in the voltage of 0-> 5V and in the respective angular excursions of 0-> 90 degrees Elevations and 0-> 360 degrees Azimuths.

How get and format data from NASA Horizons Ephemeris to put in the SD Card:

- 1 – Go to the site <https://ssd.jpl.nasa.gov/horizons.cgi#top>
- 2 - Fill the Page with your requirements

The screenshot shows the NASA Horizons Web-Interface in a web browser. The page title is "Solar System Dynamics" and it features a navigation bar with links to JPL HOME, EARTH, SOLAR SYSTEM, STARS & GALAXIES, and TECHNOLOGY. Below the navigation bar is a section titled "HORIZONS Web-Interface" with a description of the tool. The "Current Settings" section shows the following configuration: Ephemeris Type: OBSERVER, Target Body: Sun [Sol] [10], Observer Location: Topocentric (9°12'39.6"W, 38°44'21.4"N, 130 m), Time Span: Start=2021-04-07 10:00, Stop=2021-04-07 20:00, Step=1 m, Table Settings: QUANTITIES=4, object page=NO, Display/Output: plain text. There is a "Generate Ephemeris" button. The "Special Options" section lists three options: set default ephemeris settings, reset all settings to their defaults, and show "batch-file" data. At the bottom, there is a footer with links to ABOUT SSD, CREDITS/AWARDS, PRIVACY/COPYRIGHT, GLOSSARY, and LINKS. The footer also includes the NASA logo, the date and time (2021-Apr-10 12:45 UT), and the site manager and webmaster information.

3 - Open the Table Settings and check as shown

Table Settings

Select observer quantities from table below:
[switch to manual-entry list-of-numbers form]

Use Settings Below Cancel

Optionally preset observer quantities selection using one of the following:
planets satellites small-bodies default all none

1. <input type="checkbox"/> Astrometric RA & DEC	17. <input type="checkbox"/> North Pole position angle & distance	33. <input type="checkbox"/> Galactic longitude & latitude
* 2. <input type="checkbox"/> Apparent RA & DEC	18. <input type="checkbox"/> Heliocentric ecliptic lon. & lat.	34. <input type="checkbox"/> Local apparent SOLAR time
3. <input type="checkbox"/> Rates: RA & DEC	19. <input type="checkbox"/> Heliocentric range & range-rate	35. <input type="checkbox"/> Earth->obs. site light-time
* 4. <input checked="" type="checkbox"/> Apparent AZ & EL	20. <input type="checkbox"/> Observer range & range-rate	> 36. <input type="checkbox"/> RA & DEC uncertainty
5. <input type="checkbox"/> Rates: AZ & EL	21. <input type="checkbox"/> One-way (down-leg) light-time	> 37. <input type="checkbox"/> Plane-of-sky error ellipse
6. <input type="checkbox"/> Satellite X & Y, pos. angle	22. <input type="checkbox"/> Speed wrt Sun & observer	> 38. <input type="checkbox"/> POS uncertainty (RSS)
7. <input type="checkbox"/> Local apparent sidereal time	23. <input type="checkbox"/> Sun-Observer-Target ELONG angle	> 39. <input type="checkbox"/> Range & range-rate 3-sigmas
8. <input type="checkbox"/> Airmass & extinction	24. <input type="checkbox"/> Sun-Target-Observer ~PHASE angle	> 40. <input type="checkbox"/> Doppler & delay 3-sigmas
9. <input type="checkbox"/> Visual mag. & Surface Bright	25. <input type="checkbox"/> Target-Observer-Moon angle/ illum%	41. <input type="checkbox"/> True anomaly angle
10. <input type="checkbox"/> Illuminated fraction	26. <input type="checkbox"/> Observer-Primary-Target angle	42. <input type="checkbox"/> Local apparent hour angle
11. <input type="checkbox"/> Defect of illumination	27. <input type="checkbox"/> Sun-Target radial & -vel pos. angle	43. <input type="checkbox"/> PHASE angle & bisector
12. <input type="checkbox"/> Satellite angular separ/vis.	28. <input type="checkbox"/> Orbit plane angle	44. <input type="checkbox"/> Apparent longitude Sun (L_s)
13. <input type="checkbox"/> Target angular diameter	29. <input type="checkbox"/> Constellation ID	* 45. <input type="checkbox"/> Inertial apparent RA & DEC
14. <input type="checkbox"/> Observer sub-lon & sub-lat	30. <input type="checkbox"/> Delta-T (TDB - UT)	46. <input type="checkbox"/> Rate: Inertial RA & DEC
15. <input type="checkbox"/> Sun sub-longitude & sub-latitude	* 31. <input type="checkbox"/> Observer ecliptic lon. & lat.	
16. <input type="checkbox"/> Sub-Sun position angle & distance	32. <input type="checkbox"/> North pole RA & DEC	

Notes:
* affected by optional atmospheric refraction setting (below)
> statistical value that uses orbit covariance if available

Observer quantities are described in the [HORIZONS documentation](#).

Use Selected Settings Cancel

Optional observer-table settings:

date/time format: calendar date/time -- display date/time in year-month-day and/or Julian-day format

Observer quantities are described in the [HORIZONS documentation](#).

Use Selected Settings Cancel

Optional observer-table settings:

date/time format:	calendar date/time	-- display date/time in year-month-day and/or Julian-day format
time digits:	minutes (HH.MM)	-- controls output precision of time
angle format:	hours/degrees minutes seconds	-- select RA/Dec output format
output units:	km & km/s	-- units for most output quantities
range units:	astronomical units	-- units for range-type quantities
refraction model:	airless model (no refraction)	-- select atmospheric refraction model
airmass cut-off:		-- suppress output when airmass is greater than limit [1 to 38]
elevation cutoff:		(deg) -- suppress output when object elevation is less than limit [-90 to 90]
solar elong. cut-off:		(deg) -- suppress output when solar elongation is outside (min,max) range [0 to 180, min to 180]
hour angle cutoff:		(h) -- suppress output when the local hour angle (LHA) exceeds value [0 to 12]
angular rate cutoff:		(arcsec/h) -- suppress output when the RA/Dec angular rate exceeds this value [0 to 100000]
suppress range-rate:	<input type="checkbox"/>	-- suppress range-rate for range/range-rate output
skip daylight:	<input type="checkbox"/>	-- suppress output during daylight
extra precision:	<input type="checkbox"/>	-- output additional digits for RA/Dec quantities
RTS flag:	disable	-- output data only at target rise/transit/set (RTS)
reference system:	ICRF/J2000.0	-- reference frame for geometric and astrometric quantities
CSV format:	<input type="checkbox"/>	-- output data in Comma-Separated-Values (CSV) format
object page:	<input type="checkbox"/>	-- include object information/data page on output

Use Settings Above Default Optional Settings Cancel

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FIRST GOV
Your First Click to the U.S. Government

2021-Apr-10 13:08 UT
(server date/time)

NASA

Site Manager: Ryan S. Park
Webmaster: Alan B. Chamberlin

4 - Click Use Selected Settings

5 - Select Target Body (Sun, Moon, MRO, Perseverance, Parker Solar Probe, etc)

6 - Click Generate Ephemeris

7 – You get:

```
https://ssd.jpl.nasa.gov/horizons: X +
ssd.jpl.nasa.gov/horizons.cgi#results

Ephemeris / WMM User Sat Apr 10 05:53:55 2021 Pasadena, USA / Horizons
*****
Target body name: Sun (10) (source: DE431mx)
Center body name: Earth (399) (source: DE431mx)
Center-site name: (user defined site below)
*****
Start time : A.D. 2021-Apr-07 10:00:00.0000 UT
Stop time : A.D. 2021-Apr-07 20:00:00.0000 UT
Step-size : 1 minutes
*****
Target pole/equ : IAU_SUN (East-longitude positive)
Target radii : 696000.0 x 696000.0 x 696000.0 k{Equator, meridian, pole}
Center geodetic : 350.789000, 38.7392780, 0.1300000 {E-lon(deg), Lat(deg), Alt(km)}
Center cylindric : 350.789000, 4981.59225, 3969.8637 {E-lon(deg), Dxy(km), Dz(km)}
Center pole/equ : High-precision EOP model (East-longitude positive)
Center radii : 6378.1 x 6378.1 x 6356.8 km {Equator, meridian, pole}
Target primary : Sun
Vis. interferer : MOON (R_eq= 1737.400) km (source: DE431mx)
Rel. light bend : Sun, EARTH (source: DE431mx)
Rel. light bnd GH: 1.3271E+11, 3.9860E+05 km^3/s^2
Atmos refraction: NO (AIRLESS)
RA format : HMS
Time format : CAL
RTS-only print : NO
EOP file : eop_210409.p210701
EOP coverage : DATA-BASED 1962-JAN-20 TO 2021-APR-09. PREDICTS-> 2021-JUN-30
Units conversion: 1 au= 149597870.700 km, c= 299792.458 km/s, 1 day= 86400.0 s
Table cut-offs 1: Elevation (-90.0deg=NO), Airmass (>38.000=NO), Daylight (NO)
Table cut-offs 2: Solar elongation ( 0.0,180.0=NO ), Local Hour Angle( 0.0=NO )
Table cut-offs 3: RA/DEC angular rate ( 0.0=NO )
*****
Date_ (UT)_HR:MN Azl (a-appr) Elev
*****
$$$$$
2021-Apr-07 10:00 *m 121.1037 42.1810
2021-Apr-07 10:01 *m 121.3518 42.3480
2021-Apr-07 10:02 *m 121.6011 42.5145
2021-Apr-07 10:03 *m 121.8517 42.6806
2021-Apr-07 10:04 *m 122.1034 42.8463
2021-Apr-07 10:05 *m 122.3564 43.0115
2021-Apr-07 10:06 *m 122.6107 43.1762
2021-Apr-07 10:07 *m 122.8662 43.3404
2021-Apr-07 10:08 *m 123.1229 43.5042
```

8- Select data columns with Date Azimuth and Elevation o object like this

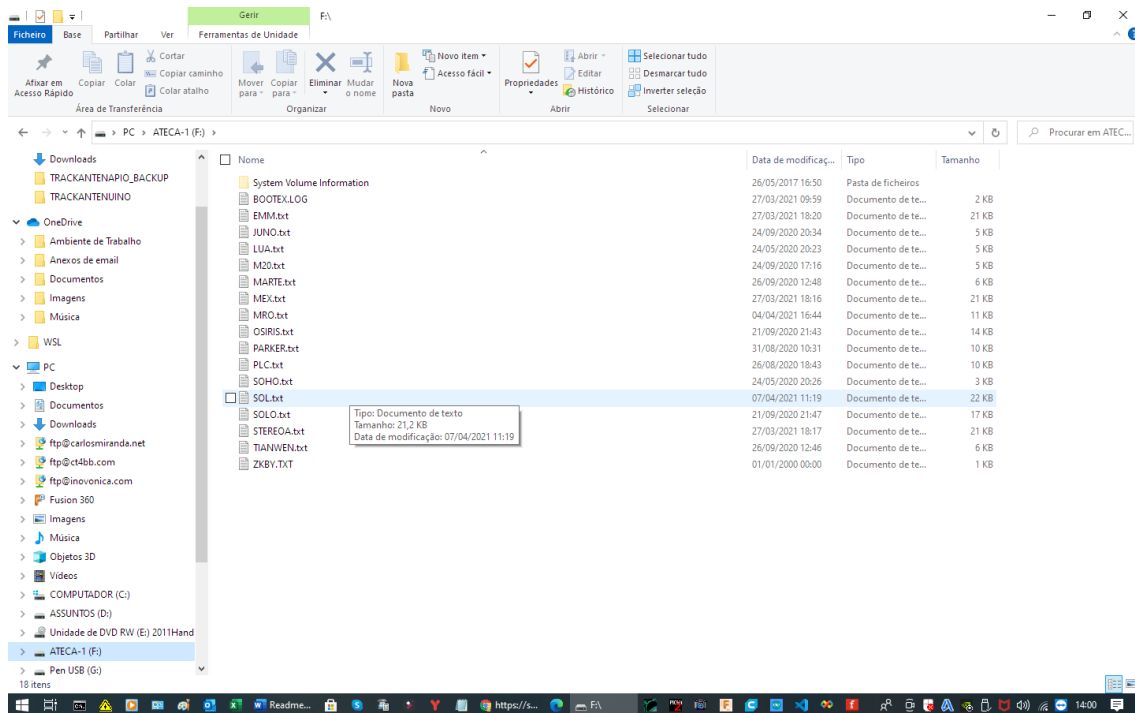
```
https://ssd.jpl.nasa.gov/horizons: X +
ssd.jpl.nasa.gov/horizons.cgi#results

RTS-only print : NO
EOP file : eop_210409.p210701
EOP coverage : DATA-BASED 1962-JAN-20 TO 2021-APR-09. PREDICTS-> 2021-JUN-30
Units conversion: 1 au= 149597870.700 km, c= 299792.458 km/s, 1 day= 86400.0 s
Table cut-offs 1: Elevation (-90.0deg=NO), Airmass (>38.000=NO), Daylight (NO)
Table cut-offs 2: Solar elongation ( 0.0,180.0=NO ), Local Hour Angle( 0.0=NO )
Table cut-offs 3: RA/DEC angular rate ( 0.0=NO )
*****
Date_ (UT)_HR:MN Azl (a-appr) Elev
*****
$$$$$
2021-Apr-07 10:00 *m 121.1037 42.1810
2021-Apr-07 10:01 *m 121.3518 42.3480
2021-Apr-07 10:02 *m 121.6011 42.5145
2021-Apr-07 10:03 *m 121.8517 42.6806
2021-Apr-07 10:04 *m 122.1034 42.8463
2021-Apr-07 10:05 *m 122.3564 43.0115
2021-Apr-07 10:06 *m 122.6107 43.1762
2021-Apr-07 10:07 *m 122.8662 43.3404
2021-Apr-07 10:08 *m 123.1229 43.5042
2021-Apr-07 10:09 *m 123.3810 43.6675
2021-Apr-07 10:10 *m 123.6403 43.8303
2021-Apr-07 10:11 *m 123.9009 43.9927
2021-Apr-07 10:12 *m 124.1628 44.1545
2021-Apr-07 10:13 *m 124.4261 44.3158
2021-Apr-07 10:14 *m 124.6907 44.4767
2021-Apr-07 10:15 *m 124.9566 44.6370
2021-Apr-07 10:16 *m 125.2238 44.7968
2021-Apr-07 10:17 *m 125.4925 44.9560
2021-Apr-07 10:18 *m 125.7625 45.1148
2021-Apr-07 10:19 *m 126.0338 45.2730
2021-Apr-07 10:20 *m 126.3066 45.4306
2021-Apr-07 10:21 *m 126.5800 45.5877
2021-Apr-07 10:22 *m 126.8564 45.7443
2021-Apr-07 10:23 *m 127.1334 45.9003
2021-Apr-07 10:24 *m 127.4119 46.0557
2021-Apr-07 10:25 *m 127.6918 46.2105
2021-Apr-07 10:26 *m 127.9732 46.3648
2021-Apr-07 10:27 *m 128.2560 46.5184
2021-Apr-07 10:28 *m 128.5404 46.6715
2021-Apr-07 10:29 *m 128.8262 46.8240
2021-Apr-07 10:30 *m 129.1135 46.9758
2021-Apr-07 10:31 *m 129.4024 47.1270
2021-Apr-07 10:32 *m 129.6927 47.2776
2021-Apr-07 10:33 *m 129.9846 47.4276
```

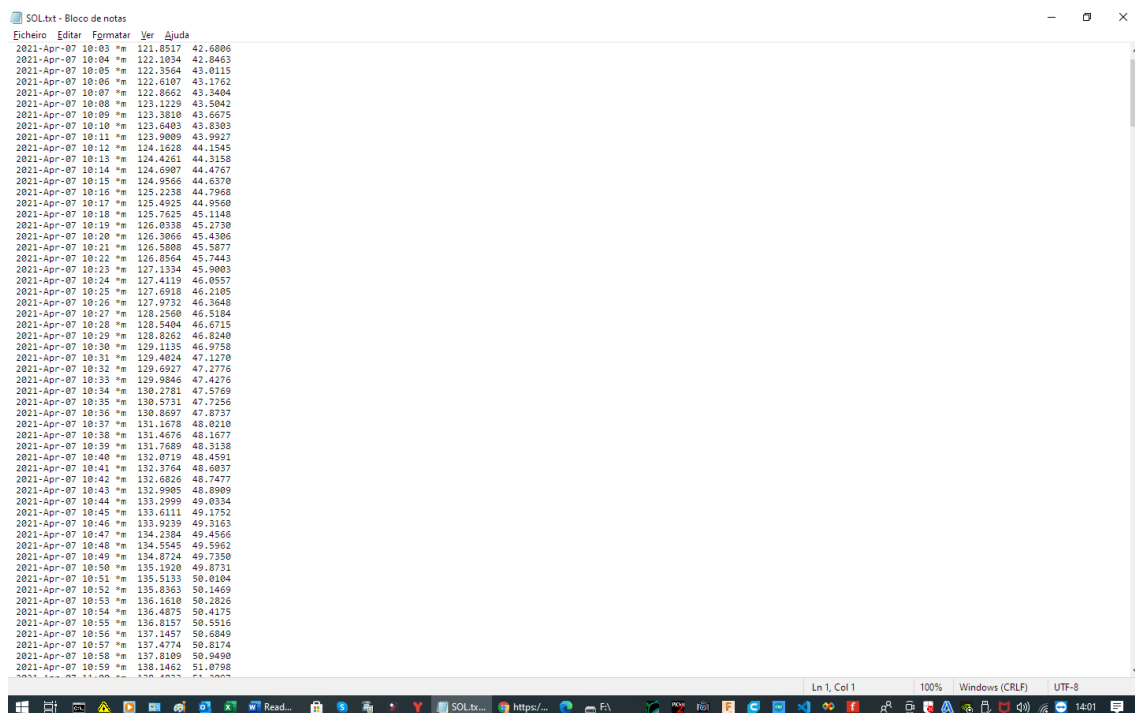
This will track the object between 10:00 and 10:30 AM UTC @ 21 Apr 07

Copy this and put on the SD Card inside a folder with the object name.

Like this SD Card shows some txt files where to paste the data:



Data is from SOL (Sun), so, open the folder SOL.txt (Sun.txt) and paste inside. Remember the first column must be a space!

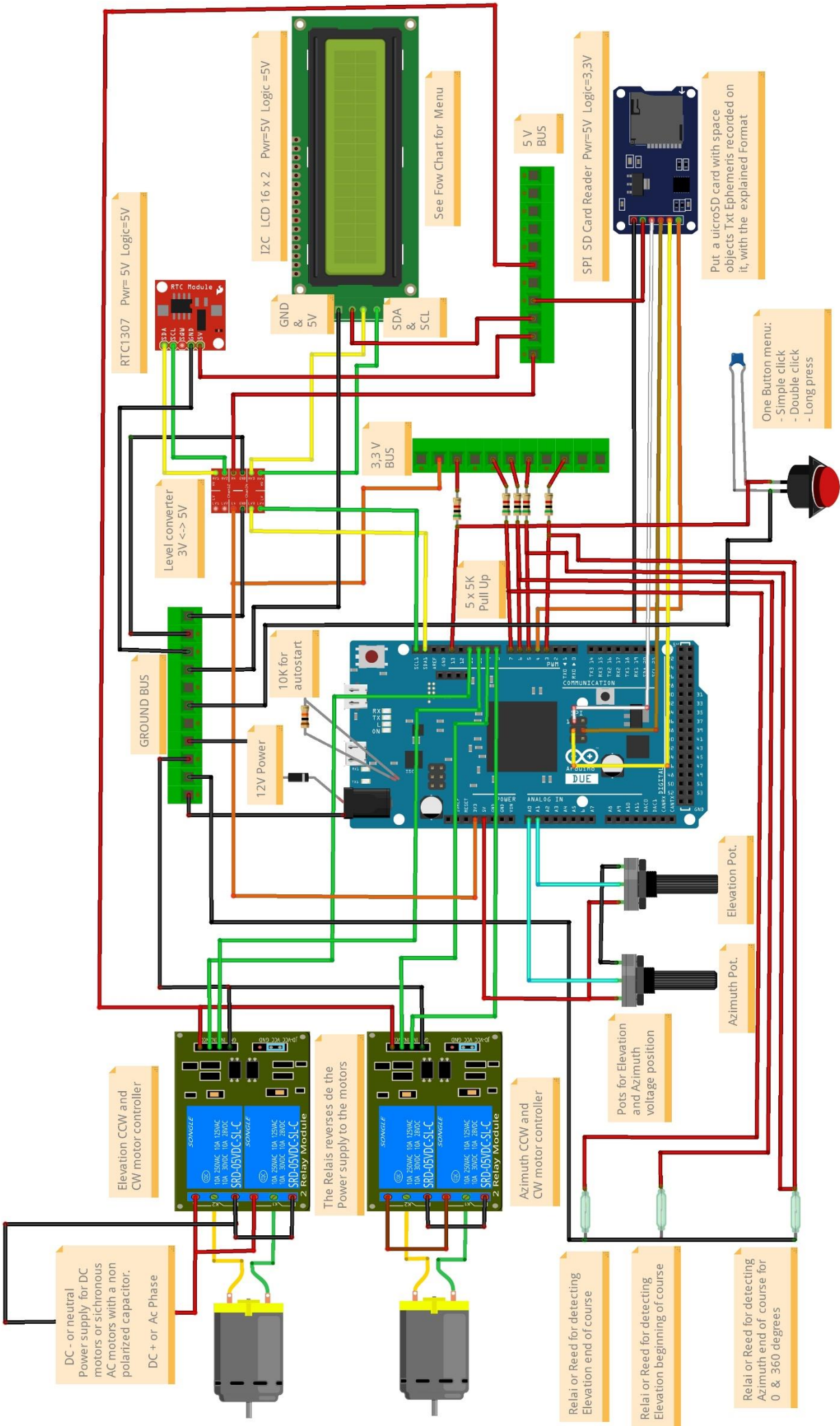


Save.

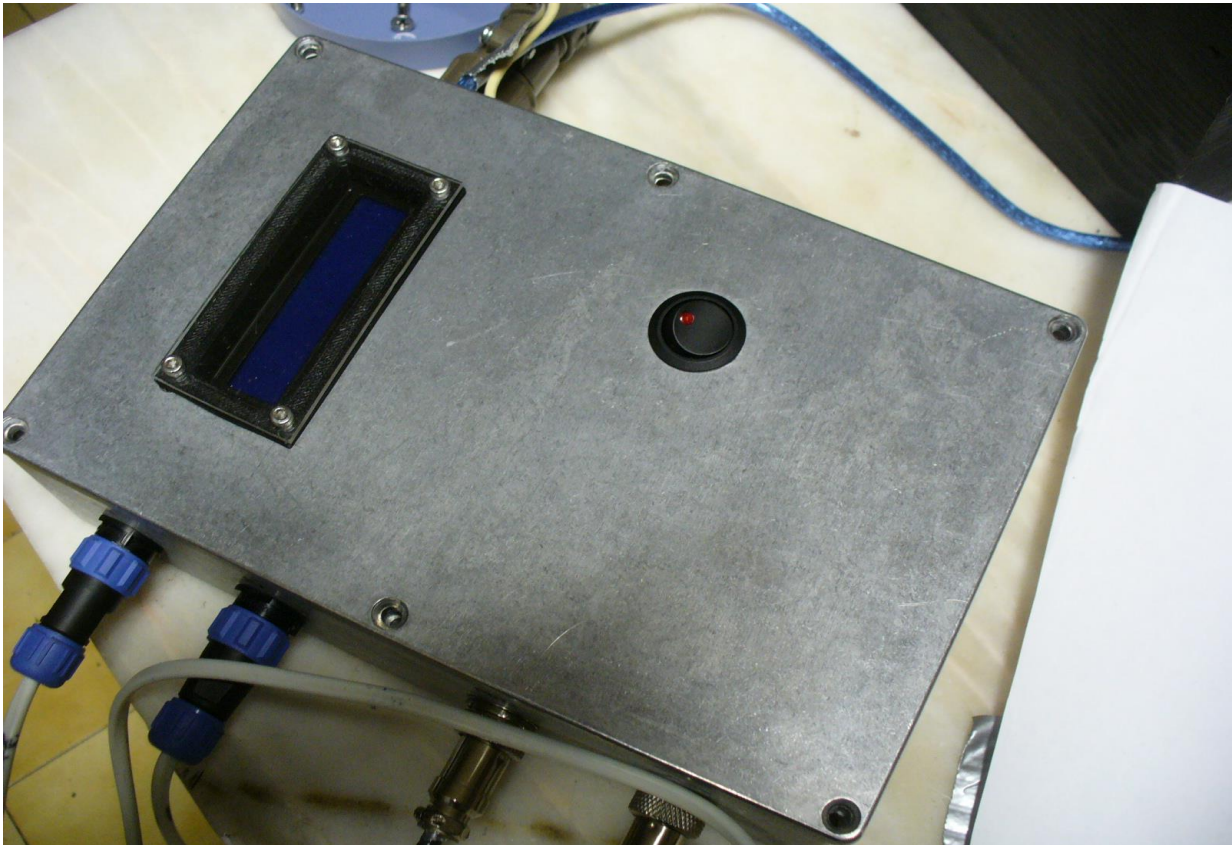
Do the same for all the objects you want to track on a specific day

Put the card in the Tracker and follow the menu to set the clock if needed, to select the object, and antenna offset. Wait for the automatic commands...

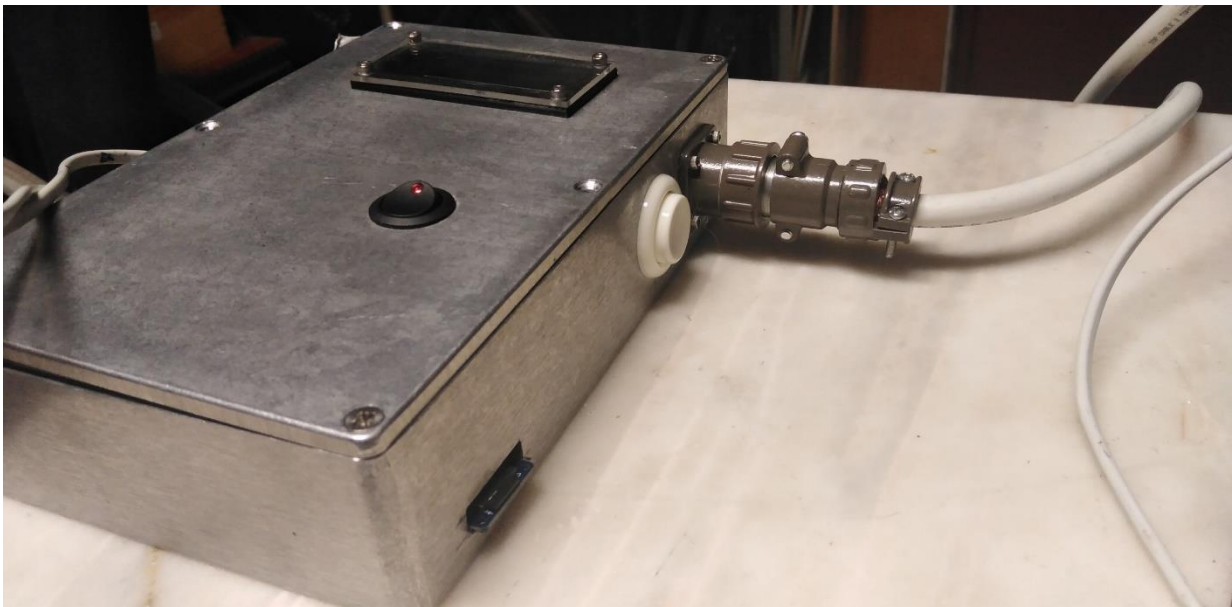
ARDUINO Diagram connections:



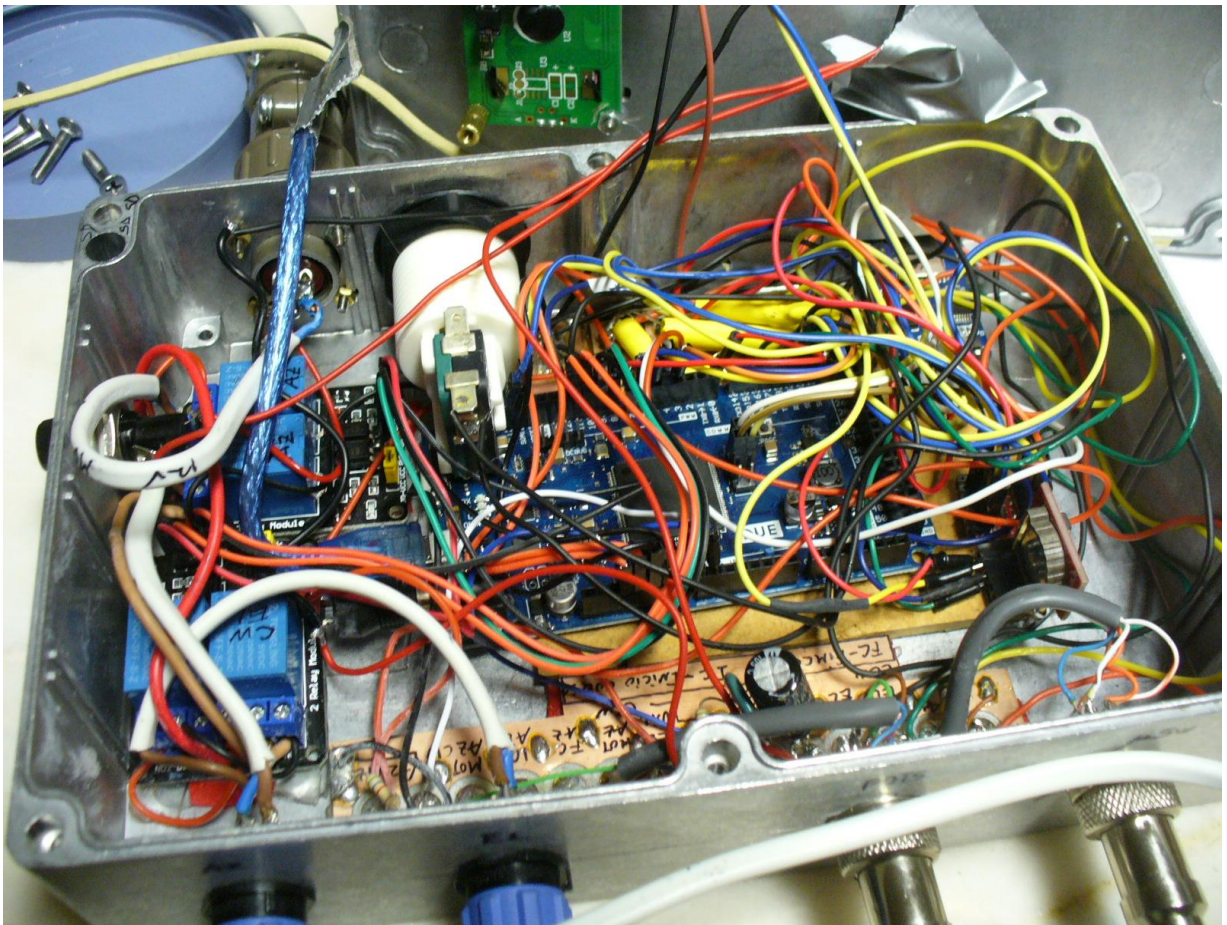




Panel, ON/Off switch AZ/EL and micro-switches connectors



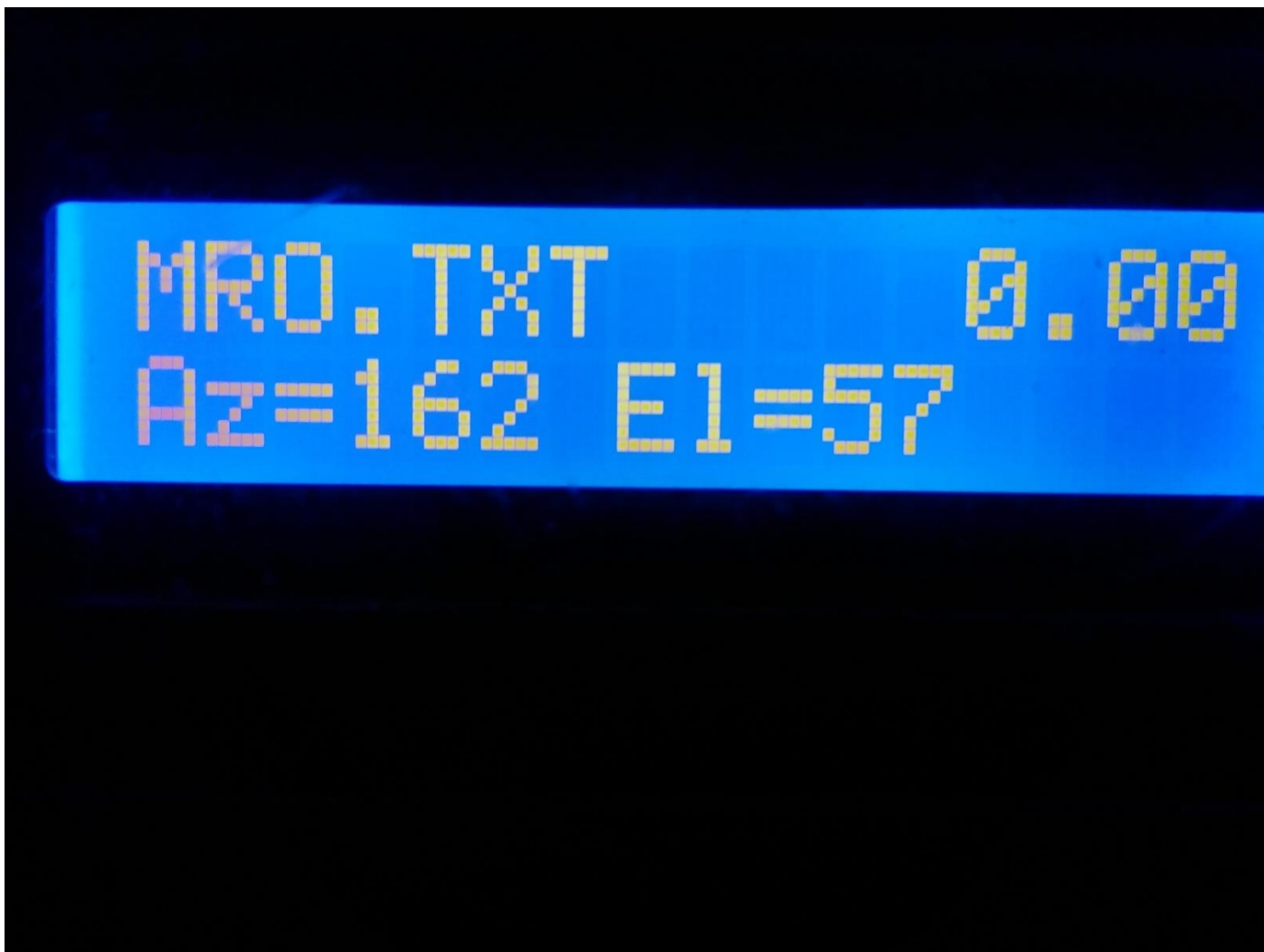
- Connector for ARDUINO 12 V and AC or DC Power for motors
- One robust button for Menu
- Micro-SD Card Slot



Inside the Mule Prototype



Date Time screen



OBJECT Name, OFFSET, Azimuth and Elevation @ the Time of previous screen



3D printing Elevation and Azimuth rotators to test the Tracker.

With this white plate and the rod shadow, it got a zero shadow in one hour of tracking the Sun.

More tests are now underway with a set of two-rotor type CDR Master Rotors @ 24 V AC and a 200 uF condenser without polarity to reverse the moving direction of the synchronous motors.

Good work and 73

CT4BB

Carlos