Celestial Navigation Plugin for OpenCPN

Introduction

The plugin facilitates position of boats using Celestial Navigation (no GPS), and a Marine Sextant. It expands on the concept of Line of Position (LOP) by incorporating measurement error and displays true positions, typically as circles (COP). Notably, it allows sights based on bearing as well as altitude.

- Accuracy Goals, Precision and Testing Also see the statements below at the bottom.
- Abbreviations, Definitions and Measurements (Stelian, this should be a link to the html page) For terms and definitions used below.

The Sights form is the first form when the plugin is opened. It contains your sights. Select New to enter a new sight. Duplicate an existing sight. Edit to view and make changes to an existing sight. Delete a sight or Delete All sights. To show a sight's Circle of Position (COP) on the charts, select/unselect the "eye" icon. There is no limit to the number of sights. But the more sights, the slow it takes to open the plugin. The Sights are stored in a document, "sights.xml". You can archive old sights by making a copy and renaming the file.

Taking Sights

Sight Tab Sight Measurement (Hs) is an angular measurement of an astronomical body using a sextant. It can be one of these types:

- Altitude: Angle of the body above the horizon (most common method)
- Azimuth: angle to north; non-standard due to measurement difficulty use the angle to north. Azimuth sights are not regularly taken, because it is difficult to measure more accurately than 1 degree which normally results in errors above 100 nautical miles.
- Lunar: angle from the moon to another body for clock correction

Celestial Body: You can select Sun, Moon, Venus, Mars, Jupiter, Saturn, Mercury, and 57 Navigation Stars plus Polaris that are visible in either the Northern or Southern Hemisphere

Limb: For altitude or lunar shots of the Sun and Moon, choose lower limb unless obscured; then use upper limb. For lunar sights with the sun, select upper for outer limbs, lower for inner limbs, center if both are upper or lower.

Sight Measurement (Hs): Enter your sextant reading. Integer degrees in the degrees field, and decimal minutes in the minutes field. Your sextant can only measure 0.1 minutes of arc.

Minutes of uncertainty determines the width of the plotted circle or line of position COP/LOP, except that it will never be shown on the chart less than .5mm wide for visibility reasons. Minutes of uncertainty can be small, like 0.1 or less, which is very visible as you zoom into the chart. Or it can be 10 or larger when zoomed out.

FIND. When you press this button, the sight you input is reduced using the Law of Cosines. Law of Cosines is used to compute Altitude (Hc), the altitude you would have measure by your sextant if you were truly at your DR position. It also calculates, Azimuth (Zn) or Bearing to the body from your DR position. Finally Intercept and direction is computed. The distance your DR or Assumed Position is towards or away from the body. Azimuth can be True or Magnetic. The DR position defaults to your Boat Position's Lat and Longitude. However, you can change that location to be the DR position when you took your sight. The Lat/Lon is in decimal degrees where North is positive, South is negative. East is positive. West is negative.

Date and Time Tab: Must match the exact moment of sight measurement.

- **DR Shift Tab**: If the sight was taken earlier, and the position has changed, do not change the date and time values. Instead, use the DR Shift Tab and enter dead reckoning Distance and Bearing to adjust the COP position for current sights.

- **Time** defaults with the system clock when a new sight is selected. But Time needs to be UTC, not local or system clock time. A digital watch or quartz watch with UTC and local time is best. Be sure to manually adjust Time to correspond with the exact UTC moment the sight was taken, see Watch Error below.

- **Recording**: In preparation, set the stopwatch and record UTC time. When the sight is taken, say "Mark", so the assistant can record stopwatch time and the sight body and altitude, or if you are solo, try using a recording timer app on your cell phone with a wired microphone.

- **Time Certainty** default is 0 seconds which shows a signal darker line in the COP. A time Certainty of > 0 shows two darker lines, equivalent to that many seconds apart.

DR Shift Tab: If the boat has moved since you took your sight, enter dead reckoning distance and DR Track to shift the COP. Shifted sights are not used by the **Fix Button.** But you can determine your FIX, a Running Fix, visually. And then drop and label a Mark on your chart.

Clock Offset Tab: Clock Offset or Correction adjusts and redraws all stored sights (shown or not). It can be used to set DeltaT, although the plugin calculates celestial objects value using current DeltaT formulas. Many traditional navigators prefer to leaving Clock Offset to "0" because they included compensating for watch error in individual sights when entering UTC.

Sean suggests adjusting the global "Clock Offset" until COP converge to determine local clock accuracy. No matter how Watch Error is adjusted, do it consistently to ensure precise navigational calculations based on celestial observations.

Config Tab: Changing color and transparency appearance does not affect the results.

Parameters Tab: This is where Index Error, Height of Eye, Temp/Pressure of the sight is entered. Generally the same values for the sights at a given time. Change settings to change the default for new sights, settings will be remembered for the next new sight.

Calculations Tab: Shows altitude sight calculations for user verification and program collaboration.

Computing a Fix

Sight Tab > Fix button. The fix is determined from the sights with COP made visible (excludes the hidden COP sights). Need two or more sights with COP shown. The algorithm first seeks the Fix nearest Your Boat. If it doesn't find it, enter the closest dead reckoning latitude and longitude, and try again. When a Fix is found, a large red X is displayed on the chart while the Fix Button is open.

The regression uses the least squares to find a position at sea level for altitude type of sights. It was not implemented for shifted sights, sights taken at above sea level altitudes, and true north azimuth type of sights.

Common Problems.

Circle of Position or sight is not appearing. If you do not see a COP on the chart, ensure the visible (eye) icon appears in the Sight List, then zoom out and pan the earth to find it. If you are looking for a COP of a body, use a Star Finder to determine Altitude at your desired time and location. Or, try Hs of 75 degrees. Hs of 90 degrees is almost a point. That point is the Latitude and Longitude of the GP of the body (Calculation form will identify the Body's Lat and Longitude).

The Hc and Azimuth (Zn) is way off from what you expected. The default Hc and Zn is calculated using your Boat position. Did you Move your boat to your DR location? Is your DR location correctly shown on your OpenCPN chart?

Reduce Errors:

Adjustable errors. Adjust your sextant to remove all possible errors.
Index Error. Reverify your index error using the horizon IE is part of your sight measurement.
Height of Eye. Measure your height of eye above sea-level. This is part of your sight measurements. Natural Horizon sights are supported only. Dip Short is not yet supported.
Run of Sights: For each body, take a run of 3 to 6 sights every minute or so. Then input the entire run into the Celestial Navigation Sights form. Look at the Circle of Positions for these sights. Throw out the sights that look like errors. If they all look good, consider calculating an average sight and use that for your Estimated Position, Running Fix, or Fix.
Multi-Body Sights: To get your best possible location, try to take a 3-body sight within 20 minute timeframe. The Sun, Moon, and Venus sometimes makes a good 3 body during the day. Ensure the celestial bodies are adequately spaced apart. A two body should be 45 to 135 degrees apart. For a three body the 3rd outer bodies should be over 30 and less than 120 degrees from the other two bodies. Input the sights into the Celestial Navigation Sights form and make visible the best of each body's COP. The three body COPs will make a triangle. The fix would be in the center of the triangle. If your vessel was in motion, advance the Line of Position (LOP) of the first and second sights to align with the third sight's position using the (DR) track and distance traveled. The DR Shift Tab will do it for you. When the sights are taken within 20 minutes, it is considered a fix. Otherwise a running fix.
Running Fix: If the bodies were taken hours apart and are 45 to 135 degrees apart, it could be considered a Running Fix, the next best thing to a Fix. But you need to maintain a careful DR plot. The morning Sun and afternoon Sun make a good Running Fix. You can plot the Running Fix using the DR Shift tab. But, first consider the impact of set and drift (e.g. current).

Correct Time: Celestial navigation uses the positions of stars, the sun, and the moon relative to the observer's position on Earth. Because the Earth rotates, these positions change every moment. Navigators use the precise time of observation synchronized to UTC to calculate their location.
Watch Error: Monitor the quartz watch against Marine Radio frequencies to determine its accuracy for the day. The navigator records and tracks their watch's error trend to estimate the day's watch error.
Personal Bias Error: To determine their average personal bias error, navigators track the history of their sights over time to determine their average personal bias error. For instance, a colleague from the US Navy is aware of his average error and adjusts his sights accordingly.

About the Author (Link to Sean's Webpage)

Navigation in principle

Of course, if you already know where you are, there is no point in trying to determine it from the formulas above. But when you actually navigate, the odds are you don't know quite where you are, so how do we use the above formulas?

We draw what is called a position line or Sumner line. Although the modern position line is not quite a real Sumner line but it is close enough.

Like all good inventions, Sumner lines were discovered by chance by a fellow called, you guessed right, "Sumner", Thomas H. Sumner to be precise (maybe related to the late professor Julius Sumner-Miller). Sumner was a ship captain on his way from Charleston (South Carolina) to Greenock (Scotland). And he was worried because he had been sailing for several days in bad weather, the wind was blowing from the South East making Ireland a lee shore, and he had not been able to see the sun or any stars, the coast was getting near, and he did not know exactly where he was. Suddenly there was a break in the clouds, so he grabbed his sextant and snatched a quick sun sight, before the clouds covered the sky again.

Now he was wondering what to do with this information, so he played a "what if" game. He did not use the bearing formula above, because nobody had worked it out in quite that form yet, but he knew the altitude formula and he said "what if my latitude is... " and calculated the corresponding longitude and he plotted it on the chart, then he tried it again with another latitude, got another point on the chart. After doing that three or four times he suddenly realized that all the points he was marking on the chart seemed to fall on a straight line. Without thinking about it any more, he saw that the line needed pushing north by a few odd miles to lead straight over Small's light, so he turned north for those few miles, then turned to starboard until he was sailing parallel to that very first "Sumner line". His crew were a bit perplexed at that, wondering if the captain had gone mad, but when suddenly they arrived right at the very light, they thought he was a flaming genius. And so did the rest of the sailing community.

So why did the points fall on a straight line? They did not really but Sumner did not realize it at the time. The points Sumner was plotting were the points on earth from which any one would have seen, at the same moment as he did, the sun with exactly the same altitude. All those points are on a circle centered at the point on earth directly below the sun. Because this circle is usually huge, a small part of it appears straight on a Mercator projection chart.

So this is how we proceed in practice:

1. We assume we know where we are , we call this DR (for Dead Reckoning).
2. We calculate, based on the latitude and longitude of the DR, what the bearing and the altitude of the celestial object would be at the time of observation.
3. We draw the bearing line passing through DR.
4. We compare the actual measured altitude with what it would have been had we been at DR, the difference, in minutes of arc, is equal to the number of nautical miles that we have to move along the bearing line to find our position line. ie if the angle measured is greater than the calculated one by say 13' of arc, then we move towards the celestial object by 13 nautical miles, and if say the measured angle was less by 7' of arc than the calculated one, we would move away from the celestial object by 7 nautical miles.
5. Finally we draw a line at the right angle to the bearing line, passing by the point we have just found. This line is our position line and all we can tell is we are somewhere on this line.

Note the difference between our position line and Sumner's original one: our line is the tangent to the circle at the point nearest to DR, Sumner's was the circle. Sumner's line is in theory more accurate, but the circle is usually so large that the loss of accuracy is insignificant. Note also that in the tropics the circles can be extremely small, I remember reading about a P&O captain who used to obtain all his fixes without any calculation, he would take several observations when the sun was nearly dead overhead (say over a 15 minute period) for each time observation, he would plot the coordinates (GHA,DEC) of the Sun on his map then draw a circle of radius equal to (90 degrees - measured altitude). Since over the 15 minute period he would probably have collected 4 or 5 observations, he would draw 4 or 5 circles which would all intersect at one point. Simple but effective especially as in the tropics, position lines usually end up running all almost North-South giving good longitude information but lousy intercepts and large errors in latitude. The noon sight is damn important then.

If you wait a few hours, the sun will change position, and you will be able to repeat the operation and determine a 2nd position line which will intersect the first. Provided you haven't moved in the interval, you are at the intersection.

If you have moved (and the odds, are you would because it can be pretty boring sitting around doing nothing on a boat that's just bobbing up and down in the middle of the ocean), then all you need do is translate the original position line in the same direction, and the same distance as you have travelled. Your position will be at the intercept of the new line and the translated one. Sailors call this the SUN RUN SUN method.

The above information was edited from Eric De Man siranah.de

Accuracy Testing Procedures

1. Periodic report of Celestial Navigation Plugin accuracy and precision against the Commercial Edition of the Nautical Almanac. To be done during upgrades or as part of an annual or every other year review.
2. Calculate (NA versus Plugin) using 3 statistics (see below)
3. Results are summarized on the Celestial Navigation Plugin webpage.
4. Users will know the accuracy and precision to expect from the plugin.

Established Accuracy Goal

1. Mean and Standard Deviation of the Differences. Our target standard deviation is 0.1 nm or 0.1 minutes.
2. Percent of observations with 0 difference. Nautical Almanac data is no finer than 0.1 minutes. Celestial Navigation data will normalized to the same precision for purpose of apples to apples comparison.
3. Percent of observations greater than .1 minute or less than .1 minutes. In practice, these observation differences would be .2 minutes or larger.
4. 0.1 minutes is 600 feet.