Celestial Navigation Plugin for OpenCPN

Introduction

The plugin facilitates celestial navigation by providing visual verification of measurements. 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 Celestial Navigation form when the plugin is opened, contains all of your sights. Track up to approximately 30 sights. Select *New* to enter a new sight. Duplicate an existing sight. *Edit* to view and make changes to an existing sight or make changes to a sight you just duplicated. *Delete* a sight or Delete *All sights*. You can track up to approximately 30 sights in the form. If the form freezes up, you probably exceed the limit. *Delete* a few sights. First time, Select *New* to input a new sight. To make a Sight Circle of Position (COP) or Line of Position (LOP) visible on the charts, in the first field select/unselect the "eye" icon.

Taking Sights

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

- Altitude: angle above the horizon (typical)
- 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 that are visible in either the Northern or Southern Hemisphere plus Polaris.

  - Before taking a sight, adjust your sextant to remove errors. Know your Index Error. And know your Height of Eye above sea-level. These are important inputs of your sights in Celestial Navigation Plugin.
  - During the day, the Sun is an excellent body for a sight. The Moon is also an excellent body when above the horizon during the day. Venus is often bright and visible during the morning or evening. It too can make an excellent body during daylight.
  - Before Sunrise or Sunset, make a plan and select stars and planets that will be visible above your horizon between Sunrise Nautical to Civil Twilight or Sunset Civil to Nautical Twilight.

- Choose bodies with perpendicular positions at the fix point. In the northern hemisphere, Polaris provides excellent latitude, while the Sun or Moon give good longitude.
- Complementary bodies help ensure accuracy. If bodies move in the same plane, the error in latitude may be significant, especially near the equator. The azimuths of observed bodies should differ by at least 30 degrees to enhance the accuracy of the fix.

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. In the form *Certainty level* affects the width of the plotted line of position.

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 more visible as you zoom into the chart or it can be 10 or larger for visibility when zoomed out.

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

- **Use of 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 values to adjust the COP position for current sights.
- **Time** is synchronized with the system clock when a new sight is selected. A good quartz watch with UTC and local time is best. Be sure to manually adjust Time to correspond with the exact 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, enter dead reckoning for distance and bearing to shift the COP. Shifted sights are not used for calculated position fixes with the **Fix** button but can be visually determined. Once shifted, sight is no longer used for a position fix but can still be visually determined.

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 that value for many years. Bob Bossert prefers leaving Clock Offset to "0" and Including Watch Error in individual sight “Time” setting.

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: Select color and transparency appearance (do not affect the results).

Parameters Tab: Slightly affect accuracy, generally the same for all sights. 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 When there are two or more sights taken, you can compute a fix for location (use at least 3 sights). With only two sights, the program might converge on the wrong location, so enter the closest dead reckoning latitude and longitude.

The regression uses the least squares to find a position at sea level. Although it could technically work at various altitudes, this is not implemented.

For shifted sights or magnetic north azimuth sights, the math is complex and not implemented. Currently, fixes can only be computed from altitude shots, but true north azimuth may be supported in the future.

The Fix is from visible sights. The red Fix X shows only when Fix is open.

Reduce Errors

Pitfalls: Sight not appearing. It is easy to have large errors in position with celestial navigation, accuracy is difficult. If you do not see a sight on the chart, ensure the visible (eye) icon appears in the Sight List, then zoom out and pan the whole earth to determine it's location. Altitude shots close to 90 degrees cover a very small area and may be difficult to find.

Multi-Body Sights: To minimize position errors, it is recommended to take a 3-body sight (e.g., Sun, Moon, and Venus) within a 20-minute timeframe. Ensure the celestial bodies are adequately spaced apart. Input the sights and their times into the plugin, which will create a triangle with the **Fix** point at the center. If your vessel is in motion, advance the Line of Position (LOP) of the first and second sights to align with the third sight's position based on the (DR) bearing and distance traveled, using the **DR Shift Tab**. When taken within 20 minutes, it is considered a fix; otherwise, it is regarded as a Running Fix.

Importance of 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 over time. Navigators use the precise time of observation to calculate their location. If the watch or chronometer isn't synchronized with UTC, errors will occur in the calculations. Clock

Offset or individual adjustment in each Sight's Time for Watch Error will align it with the precise Universal Time (UTC).

Watch Error: Monitor the quartz watch against Marine Radio frequencies to determine its accuracy for the day. The navigator records and tracks the watch's error trend (e.g. fast by 5 seconds every 30 days) to estimate the daily error. When taking a sight, read the watch and adjust the time based on the noted Watch Error, then convert the adjusted time to UTC.

Personal Bias Error: To determine their average personal bias error, navigators load numerous sights (at least 100) over time. 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 reporting of Cel Nav Plugin accuracy and precision against the Commercial Edition of Nautical Almanac. (During upgrades or annual or every other year.
2. Calculate (NA versus Plugin) using 3 statistics (see below)
3. Results are summarized on the Cel Nav webpage.
4. Users will know the accuracy and precision to expect from the data.

Established Accuracy Goal

1. Mean and Standard Deviation of the Differences. A Target standard deviation of .1 nm or .1 minutes.
2. Percent of observations with 0 difference. (NA data is no finer than .1 minutes. Plugin data normalized to be .1 minutes for purpose of comparison).
3. Percent of observations greater than .1 minute or less than .1 minutes. (in practice after rounding plugin data, it would be .2 minutes).