Celestial Navigation through Zenith Image Analysis

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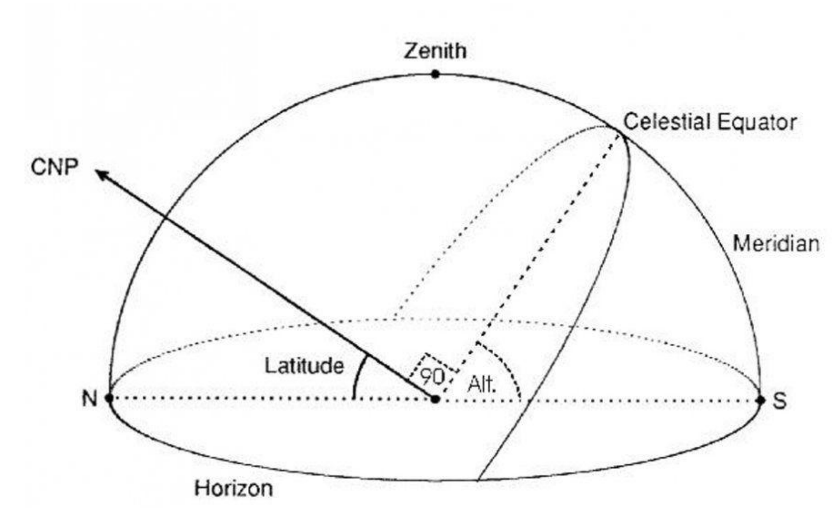
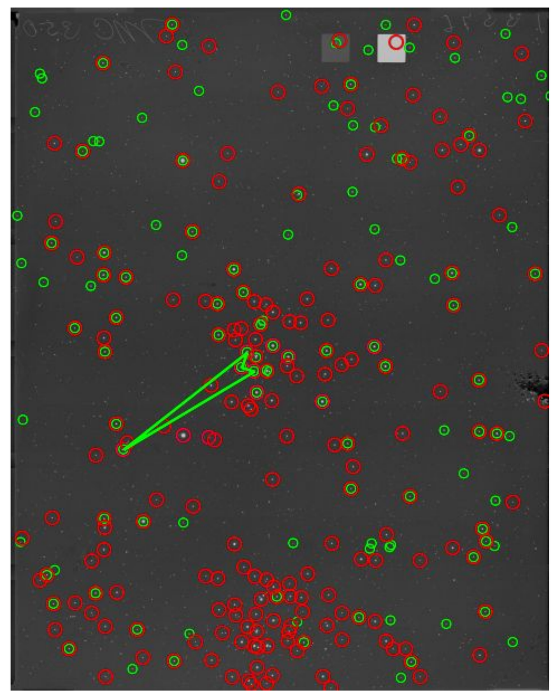
Background

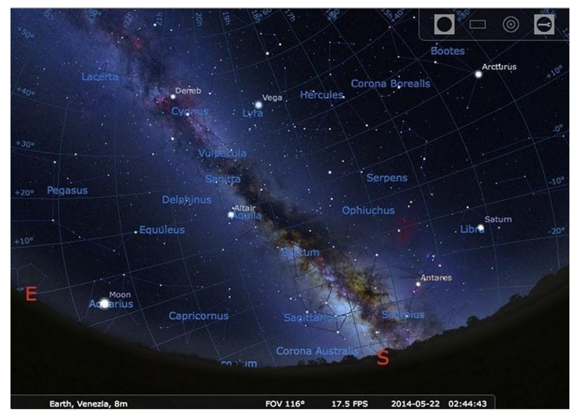
- Navigation in the general sense is almost synonymous with use of a Global Positioning System (GPS).
- GPS systems are noticeably flawed due to weak signals, physical blocking by large buildings, and inability to penetrate surfaces (Klausberg, GPSWorld 1990). These issues are exacerbated in warzones with the possibility of jamming.
- Celestial navigation is passive, functional across the globe, and independent of a GPS.
- The main objective of this project is to develop and explore a new method of celestial navigation that makes use of the geometric properties of zenith images.

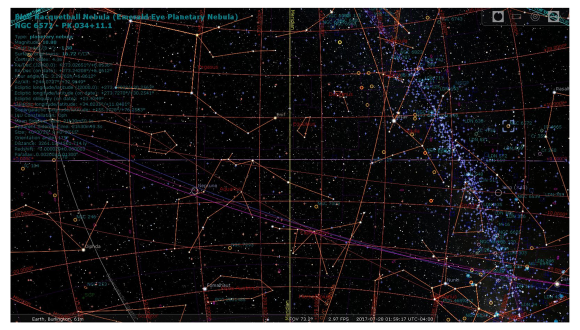


Tools

- The project depends on three applications, two of which are open-source software.
- The first is Astrometry.net, an online program that finds right ascension and declination using an image of a starfield (Dustin Lang *et al* 2010 *AJ* **139** 1782).
- Next is an algorithm for finding GAST using Unversal Coordinated Time (UTC) that was adopted from the United States Naval Observatory (USNO, computing GAST).
- Lastly the project made extensive use of Stellarium, a free astronomy simulator, in testing and development.

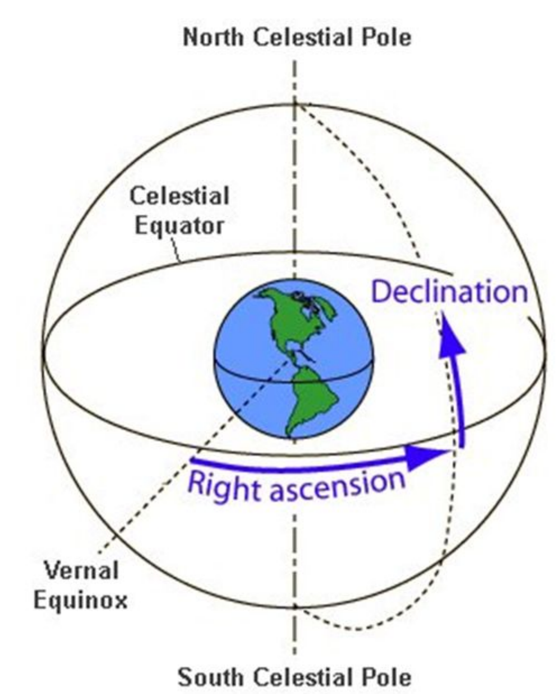


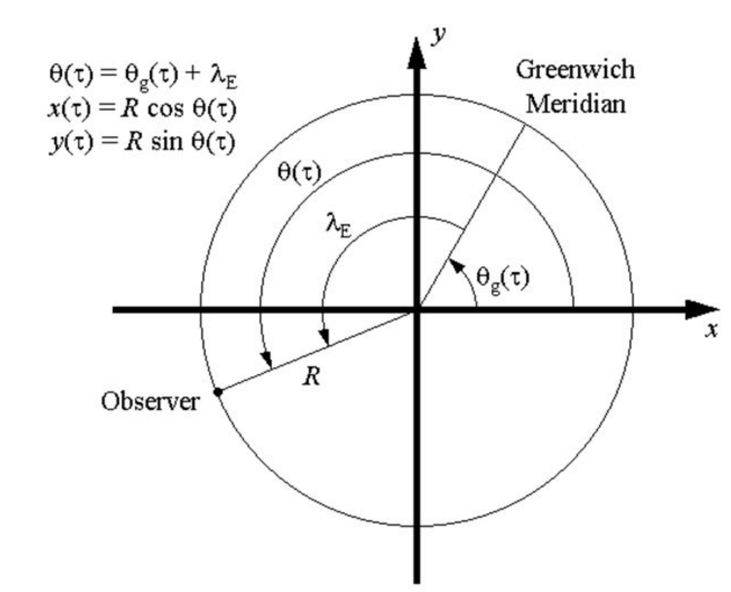




Process

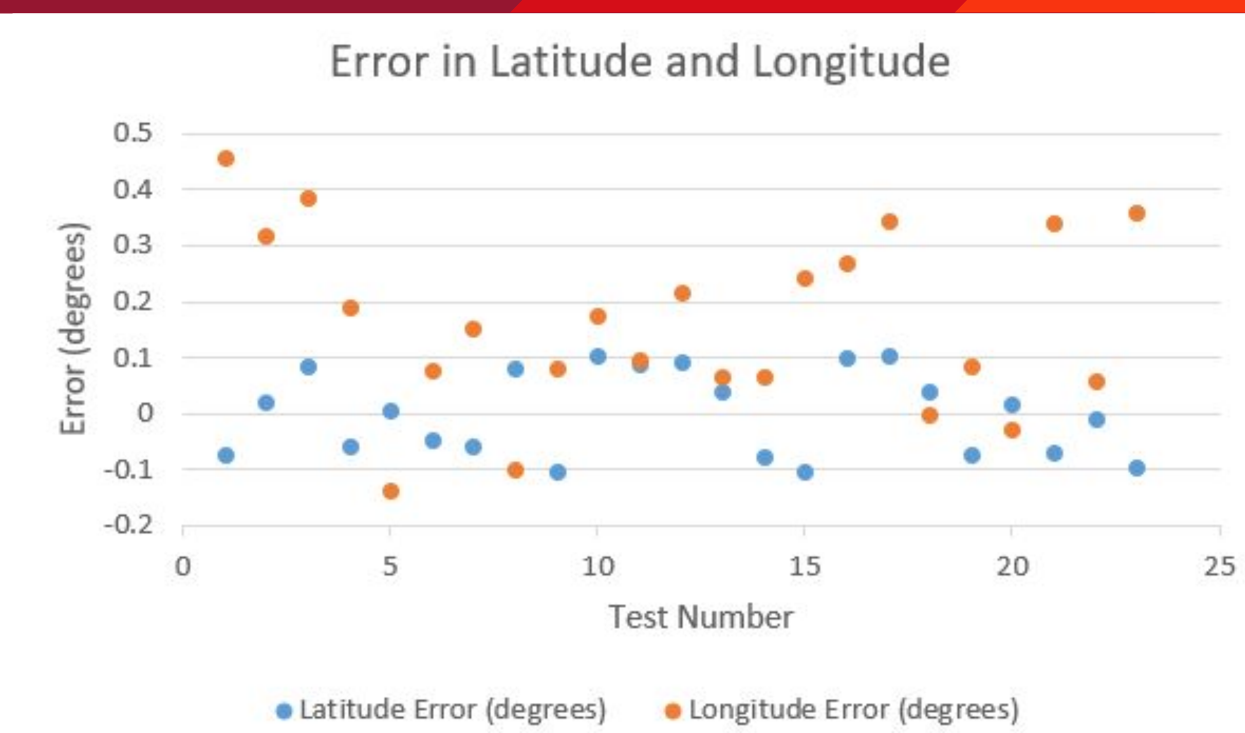
- The fundamental idea behind this project is the combination of right ascension, RA, and Greenwich Apparent Sidereal Time, GAST, to arrive at longitude, and the conversion of declination into latitude.
- Declination is the angle above the celestial equator, which is functionally identical to the terrestrial equator, it is thus equal to geometric latitude.
- RA is the angle between a point and the vernal equinox. GAST is the hour angle between the vernal equinox and the prime meridian. Thus, the sum of the observer's zenith RA and the current GAST equals the angle between observer and the prime meridian: longitude.





Results

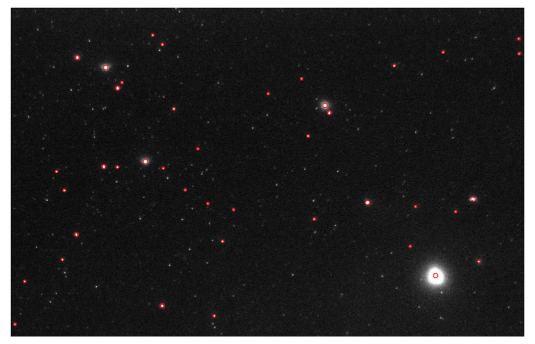
- The method was translated into Python code now freely available on GitHub, then run on a series of Stellarium screenshots.
- The screenshots were taken without the effects of atmosphere refraction or cloud cover, at various points around the globe and at various times throughout the year using predictive modeling.
- The simulation software, Stellarium, introduced significant error. The internal clock on the program only calculated UTC to the minute, potentially creating up to 2.5 mile errors in the estimate. Tests also showed a lack of predictive ability in the program, with a series of tests done twenty years in the future doubling the average error.

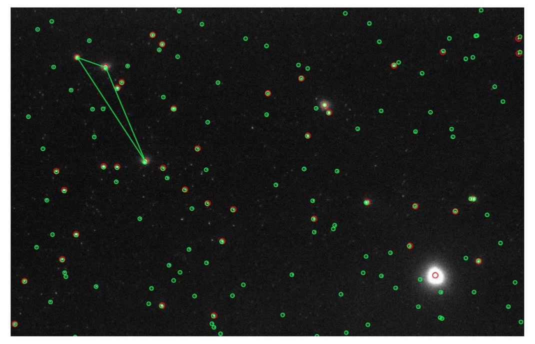


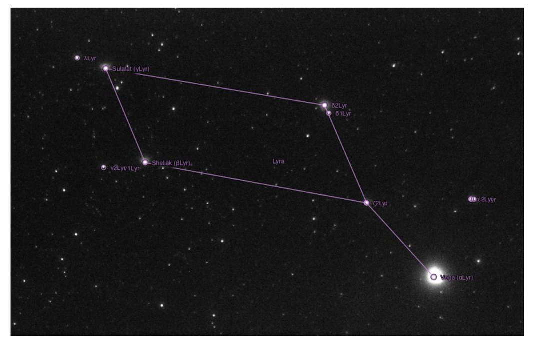
	Mean Value	Absolute Mean Value	Mile Error
Latitude Error	~0	.06735	4.65
Longitude Error	.16207	.18500	12.8

Real Life Testing

- Astrometry.net offers a downloadable version of the application, which was used to speed up the process and allow better integration with the project's codebase.
- Using a special 16mm 1/1.8" lens mounted to a ZWO ASI178MM monochrome camera pointed approximately towards zenith, or the point directly overhead.
- These photos demonstrate the Astrometry.net algorithm identifying the stars in the photograph then outputting the appropriate stars and constellations.
- Results from these tests give errors at approximately 16 miles as the crow flies, placing close to that of the simulation results.

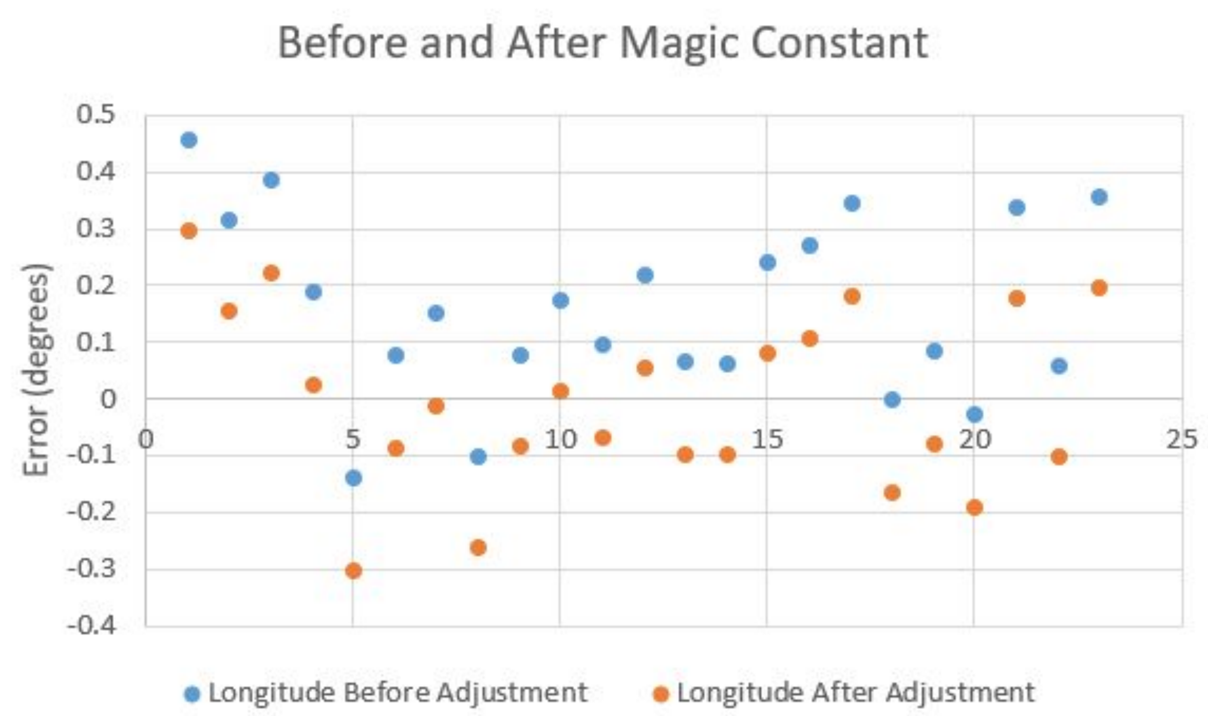






The Magic Constant

- While analyzing the results of the testing, latitude was shown to be scattered randomly around the target value as it should be. The calculated longitude, however, was instead scattered randomly around a value roughly three and a half miles east of the correct longitude. The value in degrees is 0.162.
- This magic constant indicates a clear bias in the code which has not yet been found.



	Mean Value	Error(miles)
Before	.16207	12.8
After	0	9.16

Conclusion

- The error in latitude averaged 4.65 miles, longitude optimally 9.16 miles, and so the total error averaged 10.3 miles.
- The method is too imprecise for use as the sole navigation system, but shows promise as a secondary verification tool on long-range missions such as open-ocean shipping or strategic Unmanned Aerial Vehicle (UAV) operations.
- The estimates are both easier and more accurate for latitude than longitude, possibly indicating a fringe use as a solution exclusively for north-south location.

Future Research Opportunities

- Determining the cause of the eastward drift in longitude estimates.
- Using a more accurate simulator or true test environment
- Exploring the difference in geodetic and geometric latitude
- Implement statistical modeling to increase accuracy such as the Extended Kalman Filter (EKF)
- Expand the range of analyzed photodata to include motion and direction of the camera