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FIRST STEPS TOWARDS OBTAINING CULTURAL ASTRONOMY SOFTWARE

Eduardo Rodas-Quito[1] and Javier Mejuto[2]

[1]Universidad Nacional Autónoma de Honduras (eduardo.rodas@unah.edu.hn)
[2]Universidad Nacional Autónoma de Honduras (javier.mejuto@unah.edu.hn)

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ABSTRACT

A new software tool is introduced in this paper. It renders the local horizon for a terrestrial observer and the sky tracks of celestial objects that are of interest in cultural astronomy, with sufficient precision for historical times, by using open-source software tools and geographical data. Unlike popular planetarium software in which the researcher must know in advance the approximate date that an astronomically interesting event may have occurred, this tool allows the researcher to find the dates that events of cultural interest happened in the past and provides a basic visual representation of how they could have been observed from a location of interest. Celestial events such as the rising and setting of the Sun, Moon and planet Venus can be graphically compared to specific azimuthal orientations in order to determine possible astronomical intentionality. The software has been tested by the authors in their own research work, who were able to save resources such as travel time and expenses, since there was no need for further visits in astronomically interesting dates to the site.

KEYWORDS: Cultural Astronomy, Python, Software

1. INTRODUCTION

Research in the Mesoamerican cultural region has proved that many structures were designed based on astronomical considerations (Šprajc, 2004). One of many examples are the latest archaeoastronomical projects in Copan where several alignments involving stelae and structures have been identified. These orientations can be related to Sun and Venus horizon events with ritual and/or mythical significations (Pineda de Carias et al., 2009; Zablah, 2009). In the last two decades, with the emergence and fast development of advanced Informatics Technology, archaeoastronomical studies have benefited with the use of different pieces of software. One of the most popular is Stellarium planetarium software with remarkable features such as: a very friendly Graphic User Interface (GUI), a realistic rendering of the sky and the capability to incorporate horizon pictures and sceneries which could be related to astronomical phenomena (Zotti & Wolf, 2017). In its origin, this software was not designed for cultural astronomy use, but as new versions have become available, some capabilities have been added to it, like the *archaeotracks* option which shows the tracks of some celestial bodies through the sky or the possibility to insert local horizon or 3D virtual reconstructions images of archaeological structures, relating them to the perceived landscape (Zotti, 2016). Despite these added capabilities, some issues remain, like trying to pinpoint the dates of specific events in the past. The user must know beforehand the dates for making the simulations or invest a lot of time finding the nearest candidate (if it is possible to occur at the desired location, in the first place). Besides that, if use of the local horizon and sceneries characteristics is needed for the study, additional specialized techniques must be used, for which the researcher must have some additional skills. An example of this is the plugging of 360-degree panorama photos taken on-site into the planetarium software. This requires the user to take the picture, make corrections for localizing the True North and cardinal points, obtaining and learning to use image processing software and the means to incorporate the resulting image into the planetarium software, with the inherent errors introduced in each step of the process. Also, there is the problem of changing the observing location within an archaeological site, which results in a change in the horizon that can be seen. If this situation is not foreseen by the researcher, this new view cannot be immediately adopted, having to wait until a new visit to the site is made. In order to overcome this problem, software tools that automate the process of generating the local horizon according to a specific location can be used, like HeyWhatsThat (2018) web service or the Horizon (Smith, 2013) GIS tool. However, the need to adapt the generated horizon to the planetarium program persists, thus requiring an extra effort from the user.

Thus, a specifically designed tool for archaeoastronomy that could render the tracks of selected sky objects as seen from the site of interest as well as the local horizon in an automated way, both at the same time, would be very helpful for those who are studying or planning to make studies about orientations in archaeological sites, in a quick and effective way. This has been the motivation for developing software which represents local horizons and movements of celestial object. It has been accomplished by using free software libraries and freely available digital elevation data obtained through remote sensing, making it easier to obtain accurate and reliable results in an archaeoastronomical study.

This could be the starting point for a comprehensive software that should be useful for the many tasks a cultural astronomer faces when doing field work and interpreting the gathered data, by reducing the workload and time invested in the preliminary part of the process while the efforts can be focused to analysing the data to get the best conclusions from them.

2. METHODOLOGY

In order to get specifically designed software for Cultural Astronomy, the following points were taken into account: (a) possibility of inputting the exact location of the observing point; (b) handling of elevation data that includes the location of the observing point from a geographical information database; (c) possibility of calculating the elevations of the local horizon from the elevations data; (d) ability to make a graphical representation of the calculated horizon; (e) the ability to represent graphically the celestial objects tracks when performing their apparent movement through the sky; (f) ability to represent visually the monumental or architectonic orientations of structures towards the local horizon and (g) possibility of visual detection of coincidences between structure orientations, celestial object tracks and local horizon heights. This kind of analysis is important since the local horizon plays a fundamental role in the determination of the correct astronomical orientations in archaeological structures, as can be seen in Figure 1.

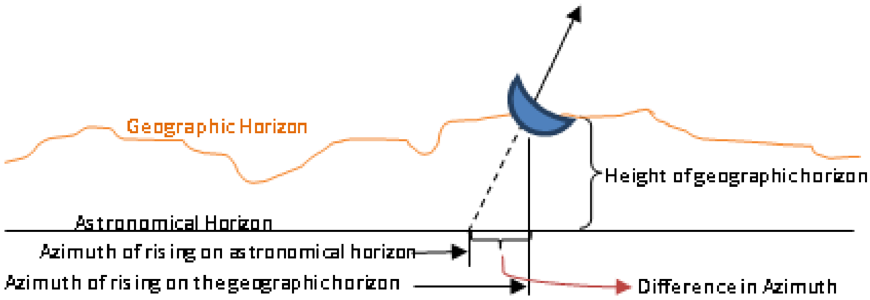

Figure 1. Differences in azimuth caused by local horizon.

With this in mind, software was developed in the Python programming language, one of the most widely used computer languages used today in academic work in Astronomy as proven by the existence of several specific libraries for the calculation of topocentric positions of celestial objects. The Python version used here is 2.7, the most widely used Python version when the software development phase began. For the astronomical calculations, this software relies on functions obtained from the libraries of the PyEphem (2018) package, which uses routines for astronomical computations taken from the XEphem (2018) program by Mr. Elwood Downey, which are based on the VSOP87 planetary theory developed at the Bureau des Longitudes (Bretagnon & Francou, 1988). Additionally, some special events have been calculated using the algorithms from Meeus (1998).

Inputs required by the software are:

- Date
- Geographical coordinates of the observer: latitude, longitude and altitude
- Azimuth of the orientation to be evaluated

With this set of data, the software returns a series of outputs which are displayed either numerically or graphically.

Numerically displayed data are:

- Coincidences between orientation of structure and rising or setting of the Sun.
- Closest lunar standstill that will occur to the entered date.
- Closest Venus extreme declinations to the entered date.
- Closest Sun Passage through the Zenith to the entered date.

Graphically displayed data is:

- Track of the Sun through the celestial sphere.
- Track of the Moon through the celestial sphere.
- Track of Venus through the celestial sphere.
- A line representing the entered azimuthal orientation.
- Local horizon profile.

The software has a graphical user interface which displays buttons for each of the numerically or graphically displayed data calculations. For the graphical representation we have followed Zotti & Groeller (2005). A sample drawing by the software is shown in Figure 2.

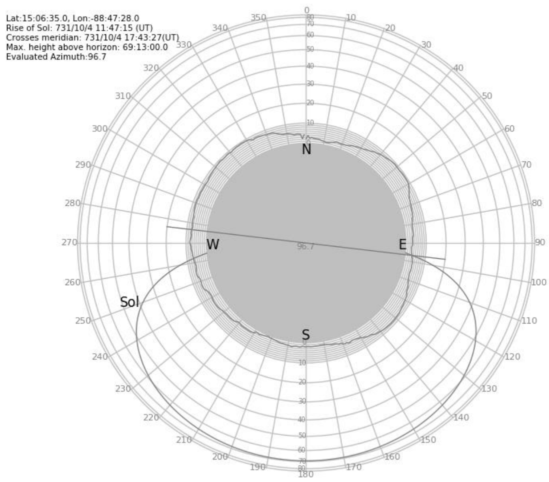

Figure 2: Graphical representation of the track of a celestial body, relating it to an orientation and the local horizon.

2.1. *Computing numerically displayed data*

For coincidences between orientations and sunrises or sunsets calculation, the closest previous solstice to the date entered by the user is found by using the ephem.previous_solstice PyEphem function. Starting at this date, the azimuth of sunrise (or sunset) is compared to the azimuth of the orientation under study, every consecutive day until a minimum difference is found between them. Then, a second date is found by repeating the same procedure, but starting from the next solstice and evaluating sunrises (or sunsets) backwards in time, by the use of the ephem.next_solstice PyEphem function. This same procedure is used for finding the date of the Passage of the Sun through the zenith but using the latitude of the site as the orientation to be evaluated.

For the closest lunar standstill, the procedure is based on the time that the Moon's ecliptical longitude reaches a ±90° position with respect to its ascending node, when this one is oriented to the vernal equinox (Meeus, 1997). Then, the behaviour of the azimuth of moonrises and moonsets is analysed (in one-sidereal-period steps) until a minimum (or maximum, depending on the case) value in azimuth is found.

For the closest Venus extreme declination, the azimuth of risings and settings are computed every two days, for five synodic periods of this planet (which is 2920 days, thus 1460 steps), saving the data of when maximums and minimums are achieved.

The dates of these events were compared to those obtained by using the JPL's Horizon web-service, which is based in the integration of thousands of planetary, lunar and sun positions, and provides very accurate positions for solar system bodies (Folkner, 2014). This comparison finds that the dates correlate well with the ones calculated with the Horizon web service.

The procedures to compute this data are available as buttons in a GUI and the results of the numerical computations are displayed below them, as shown in Figure 3.

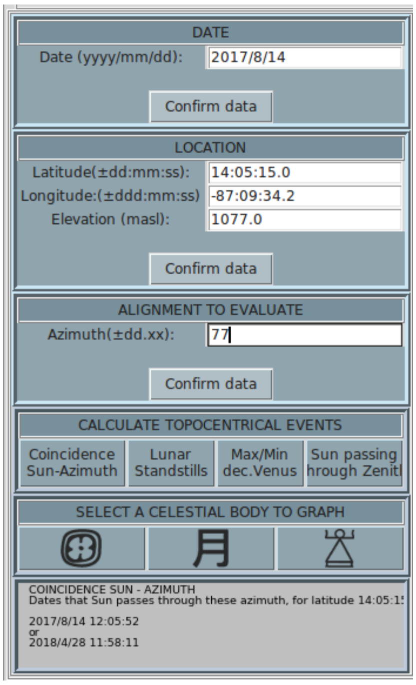

Figure 3: Interface to enter data and to display results of numerically displayed data

2.2. *Computing graphically displayed data*

For representing the local horizon, digital elevation data of the terrain surrounding the site was downloaded from the Earth Resources Observation and Science-Center (EROS) website, which provides information collected by the Shuttle Radar Topography Mission (SRTM). The data thus obtained is in 1° by 1° tiles with a resolution of 3 arc-seconds x 3 arc-seconds (or 90 m x 90 m at the latitude of the equator) (Farr et al., 2007). The use of this digital elevation model (DEM) is justified by the fact that many archaeological sites are located in places for which no previous lidar or other remote sensing studies have been performed, so, as a preliminary tool for archaeoastronomical study, this DEM is adequate due to its wide coverage of the Earth surface as well as its availability through the internet at no cost. With this approach, no information on human-made obstacles to the visibility of the horizon is considered, however, it is important to note that many archaeological structures with astronomical significance were built according to naturally occurring events where large obstacles (like hills or mountains) are the only ones involved. The size of these obstacles is usually larger than the 90m resolution of this DEM, so a very precise horizon profile is obtained by this method. Before using the information in the database, it was necessary to transform the data format from big-endian (hgt) to text format. Python has the Struct library, which provides the necessary functions for this task. Once this is done, the information is easier to handle in the generation of a preliminary rendering of the local horizon. Then, the horizon may be drawn by using the proper algorithm, for which many methods have been devised. The authors developed their own, easy for debugging the code while still suitable for preliminary studies, which consists of the following steps:

- Identifying the point within the tile that corresponds to the observer's location.
- Finding the distance of the astronomical horizon, with equation:

$$d_a = R\cos^{-1}\left(\frac{R}{R+h}\right)$$

where R is the Earth's radius in meters, h is the height above sea level of the location in meters, d_a is the distance to the astronomical horizon, suitable for preliminary studies. In future versions this distance should be extended to include high mountains beyond the astronomical horizon.

- Trace imaginary lines radially from the observer's location, one for each degree in azimuth (360 in total), measuring the angular altitude of each point along the line, within the circle determined by the astronomical horizon, by using the equation:

$$\Theta_i = \tan^{-1}\left(\frac{h_i - h_o}{d_{io}}\right)$$

where Θ_i is the angle of point I as seen from the observer's location, h_i is the height (above sea level) of the point being evaluated, h_o is the height (above sea level) of the observer's location and d_{io} is the distance between the observer's location to the point being evaluated. This equation is suitable only for a flat surface, thus, an immediate improvement is to implement the formula for a curved surface.

- Select the point with the largest angular altitude along the line. This is repeated for all the lines being traced.
- Graph all the angular altitudes in an angular altitude vs. azimuth graph.

By using this method, we obtained the results seen in Figure 4. Compared to the real one, it can be seen that the resulting graphic is very close to the real horizon obtained through photography (Figure 5).

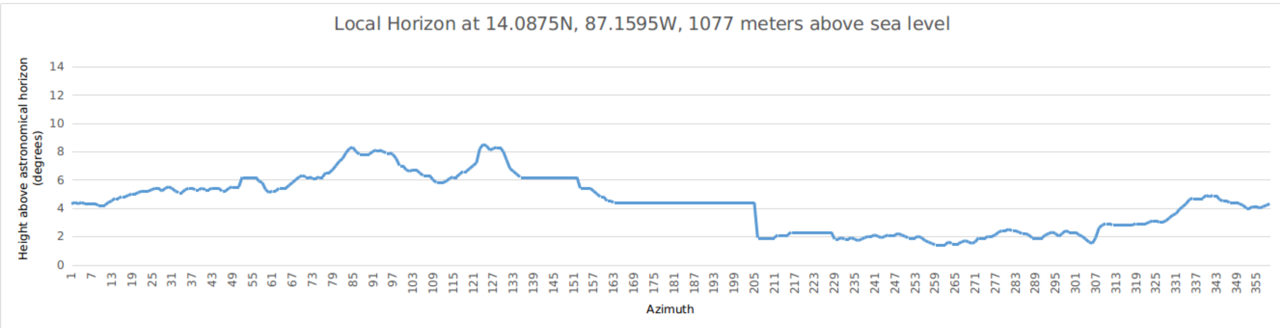

Figure 4: Computed local horizon at the Spatial Sciences Faculty in Honduras

Figure 5: Real horizon at the Spatial Sciences Faculty in Honduras

Once this information as well as the horizontal coordinates of the astronomical body under study at the entered date are available, they are converted into polar coordinates and then visually represented, as shown in Figure 2. This way the researcher is able to determine whether the entered orientation coincides with the track of the celestial object as close as possible with the line of the horizon by making a simple visual evaluation, thus inferring a probable astronomical alignment which would be worthwhile to study in a more detailed way with other, more sophisticated tools that take into account other aspects, e.g. anthropogenic obstacles of the horizon.

3. RESULTS

The first version of this software tool has been developed specifically to cover the needs of researchers in Cultural Astronomy and, in particular, for field work in Archaeoastronomy. This software has a modular design expecting that, with the passage of time and future versions, an increasing number of utilities and features will be added that will significantly increase both the usefulness of the program and the solution of bugs and limitations inherent to any software (e.g. we are currently working on how to calculate the values of the program variables when the archaeological site is located on one of the boundaries of the DEM tiles).

As can be seen in Table 1, our software, which we have called Chan U'Bih (Four Paths [of the Sun], in Maya language), covers the following tasks: graphical representation of celestial events, rendering of the local horizon, representation of the azimuth of archaeological remains and representation of tracks of celestial bodies through the sky. It makes all these tasks with no other third-party software involved. Comparison to other available software is made in Table 1.

Table 1: Comparison between main features of traditionally used software in Archaeoastronomy

Software Title	Graphical representation of celestial events	Rendering of the local horizon	Representation of azimuth of archaeological remains	Representation of tracks of celestial bodies through the sky
Stellarium	YES	YES*	YES*	YES
HeyWhatsThat	NO	YES	NO	NO
Horizon	NO	YES	NO	YES
Chan U'Bih	YES	YES	YES	YES

* In order to be able to do this, third-party software tools must be used to adapt them in this software.

Eventually, we will integrate other features of traditionally used software. We hope that through a close collaboration with all those developers who have been interested in designing computer tools for the specific work that is done in Cultural Astronomy we can fill the gaps in functionalities (as happens in other fields as Astronomy and Astrophysics). Needless to say, it is incredibly useful for the researchers and it would help to obtain more standardized results in the discipline.

For testing and evaluating purposes we used the software in the possible alignments in "El Puente" archaeological Park, a Maya site located in Western Honduras (15°06'35"N, 88°47'28"W, 478m above sea level), around 60 km north of the ruins of the major city of Copan (Nakamura & Cruz, 1993). The structures in and around a ceremonial complex have been restored, and the authors were asked by the staff of the Honduran Institute of Anthropology and History (IHAH) to explore their astronomical alignments and whether they were in relation with those identified in Copan (Zablah, 2009). Orientations between temples, stelae and structures' corners were evaluated using the software, drawing diagrams for each of them. No apparent astronomical orientation (regarding those of the Sun, Moon and planet Venus) were found. The complete analysis for all the candidate orientations can be found in Spanish (Rodas & Mejuto, 2016).

4. DISCUSSION AND CONCLUSIONS

There is an obvious lack of specific software for Cultural Astronomy that covers many tasks: databases, image recognition, pattern recognition, alignments and so on. Probably this cannot be covered by a single program, but the work presented here is another step towards developing comprehensive software for the discipline.

The software proved to be very useful in evaluating whether archaeological remains of structures have a relation to most common astronomical events, providing the following advantages:

- Reduce of unnecessary field trips to archaeological sites. Only one field trip is necessary to gather all the information required by the software.
- Resources like money and time are saved, while every possible astronomical event is evaluated at the same time, some of which are so rare that years would have to pass before the actual event can be seen.
- Astronomical events of interest to archaeoastronomical research that are not easily obtained through regular planetary software are calculated in a user-friendly way to regular users of this information, not for experts in computing.

Thanks to a combination of field work and software analysis that simulates rises and settings of the Sun, Moon and planet Venus while considering the local horizon, as described, it is concluded that this software accurately describes phenomena that occurred in the test site, allowing researchers to conclude in a relatively short time that the site itself does not have relevant orientations towards astronomical events. All this was done using the developed software which made it unnecessary to wait for all the astronomical phenomena to actually happen as it is read in the literature, as in Pineda et al. (2009).

More efforts must be made in this direction. Many researchers have missed at some point the existence of software that will facilitate the work for, or that would set standards in, any specific task in Archaeoastronomy. Our contribution will be available as free software (in both of its meanings: without any monetary cost and free to distribute or modify) for download with two clear objectives: obtain feedback of the users generating a community and obtain the greatest possible knowledge through the research that is carried out in sites with archaeoastronomical potential.

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