Astronomical Observation Planner

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Abstract. One of the tasks of robotization of astronomical observations is the creation of programs for the optimal distribution of time depending on the position of the Sun (efficient use of twilight time), the position and phases of the Moon. An important requirement for this program is the autonomy of its work, independent of external Internet resources. To solve this problem, an autonomous astronomical calendar was developed that makes it possible to estimate the time of sunrise and sunset, the moon (as well as its phases), the onset and end of twilight. This subroutine is the first step in automating the planning of astronomical observations. The next important step is to develop software that will be able to plan observations in an optimal way. The targets for observations are discussed, for these purposes the necessary initial parameters are indicated, which make it possible to form a schedule of observations at telescopes in an automatic mode.

Introduction

In 2021, the implementation of program to create a Virtual Observatory [1] based on the Fesenkov Astrophysical Institute. One of the program's objectives is to automate the observational process of astronomical sources at the institute's telescopes located at the Assy-Turgen observatory and other observation sites. An important software component in the system being created is the so-called observation planner (OP). This component will allow sorting and creating the most optimal telescope operation plan for a particular night from the resulting list of objects and their coordinates and observation time. The program should take into account the moments of sunrise-sunset, the duration of morning and evening twilight, the moonrise-set and its phases, and the influence of the gradient from the lunar sky illumination. All program calculations should be carried out without external Internet resources.

The interpreted high-level language PHP was chosen as the primary programming language for creating the planner, as it is the most suitable for integrating software into the Internet portal of the Virtual Observatory and for user interaction.

The development of OP is carried out in several parts. In the first part, software was created for numerical calculations of sidereal time, the position of the Sun and Moon, and the calculation of their moments of sunrise and sunset and twilight for a specific date and place of observation. The results of the first stage are presented in the form of an Astronomical calendar and posted on the portal of the Astrophysical Institute [2] (Fig. 1). Where any user can get the specified data for any point on the earth's surface (at the specified geographical coordinates).

In the second part of creating the OP, algorithms will be implemented to calculate the brightness of the sky background depending on the phase and the angular distance between the Moon

and the observed source. It will make it possible to exclude from observations dim objects that are close (by angular distance) to the bright Moon. Also, the source sorting algorithm will be implemented at this stage.

Fesenkov Astrophysical Institute

Astronomical calendar

Coordinates of a place

(Default the center of Almaty)

	Deg	Min	Sec			Deg	Min	Sec	
Latitude:	43	15	0	North ∨	**Longitude:**	76	57	0	East ∨

Time zone from UTC: [+∨] [6]

Height above sea leve: [0]

Input a year and choose a month

Year [ ] [-----Month-------- ∨]

Interested data

○ Siderial time (local)   ○ Rise, set of the Sun, twilights   ○ Rise, set of the Moon, phases

○ Equinoxes and solstices

Input a number as in the picture

6574

[ ]

[Calculate]

Figure 1 – Interface of developed on-line Astronomical calendar. Available on the link: https://fai.kz/calendar/calendar_eng.php

Chapter 1. Basic parameters calculation and algorithms.

To calculate the moments of sunrise and sunset of the Sun and the Moon, the following algorithmic steps are implemented (Fig.1):

Step 1. Calculating the equatorial coordinates of the Sun and Moon at a specific point in time:

1.1. Calculation of the position of an object in its orbit at a specified point in time. Since the Sun and Moon are not point sources, here, the coordinates of an object are the coordinates of the center of the solar (or lunar) disk.

1.2. Translation of own orbital coordinates into ecliptic coordinates.

1.3. Calculation of corrections for the change in the inclination of the equatorial plane to the ecliptic plane at a specified point in time. As well as corrections for precession and nutation of the Earth's axis.

1.4. Translation of the object's ecliptic coordinates into equatorial coordinates, considering the corrections specified in 4. At the output, we obtain geocentric equatorial coordinates at the specified epoch.

Step 2. Transformation of the geocentric coordinates of the Sun and the Moon into topocentric coordinates (corresponding to the place of observation):

2.1. Calculation of the geocentric parallax of an object, taking into account corrections for latitude and height (above sea level) of the observer's position.

2.2. Transformation with the help of corrections 2.1. from geocentric to topocentric equatorial coordinates.

Step 3. To calculate the moments of sunrise and sunset of the Sun and the Moon, the algorithm of successive approximations was used.

3.1. Calculation of topocentric coordinates at the beginning of the day of interest (see steps 1–2).

3.2. Through formulas for transforming coordinates from equatorial to horizontal. We find the local sidereal time of the moments of sunrise and sunset of the object. That is the fulfilment of the condition that the object's height above the horizon of the place of observation is equal to zero ($h = 0$).

3.3 Let's convert the local sidereal time of the object's sunrise and sunset into local civil time.

Note: The coordinates of the Sun and Moon change significantly even at short intervals due to their relative proximity to the Earth (unlike the coordinates of distant stars). It means that in step 3.3 we will only get an approximate sunrise/sunset time. Since, upon reaching time 3.3, the Sun and the Moon will have time to move in their orbit. So, the next step is to repeat some of the points above.

3.4. Let's go to step 3.1. - we calculate the topocentric coordinates again, but for the time points obtained in step 3.3. Then we go to step 3.2. and get a new approximation of the local sidereal time for the moments of sunrise and sunset of the object. We again convert to civil time (step 3.3.) and get the updated civil time of sunrise and sunset moments. We repeat these iterations until we reach the desired accuracy.

3.5. We calculate corrections for the refraction of the Earth's atmosphere near the horizon and corrections for the spatial disk of the Sun (Moon). Since the moments of sunrise (set) correspond to the time when the upper (lower) edge of the disk touches the horizon plane. We make corrections to the moments of sunrise and sunset obtained in step 3.4. We get the local civil time of sunrise-sunset (Moon).

To calculate the position of the Sun, a numerical solution of the Kepler equation in the two-body problem is used. In this case, to simplify the calculations, we use the relativity of motion, considering the Earth to be stationary and located in the focus of the ellipse and the Sun moving along this ellipse. With known parameters (positions) at a certain point in time (in this case, at the

beginning of the epoch of 2000), you can get the position of the Sun at any point in time in the following way:

1) Having the initial positions of the Sun, we calculate the so-called average anomaly.

2) By numerically solving the Kepler equation by iteration, we obtain the value of the eccentric anomaly.

3) Through the formula connecting the eccentric and true anomaly, we find the latter, which corresponds to the orbital longitude of the Sun. Here we do not consider the influence of the Moon, planets, etc., since these things can be neglected to calculate the moments of sunrise and sunset.

Calculating the position of the Moon is a rather difficult task due to the significant influence (in addition to the Earth) of the Sun and nearby planets. An algorithm based on Brown's analytical lunar theory was implemented for these calculations. The following important amendments and additions are taken into account: the equation of the center, evection, variation, the annual equation, parallactic inequality, corrections for the influence of Venus, Mars and Jupiter, etc. To calculate the moments of moonrise and moonset, the horizontal equatorial parallax was also taken into account since the Moon is close to the Earth and moves in an elliptical orbit. As a result, its angular size changes when observed from the Earth.

Comparison of the moments of sunrises and sunsets of the Sun and the Moon obtained during the implementation of these algorithms with the data of the Astronomical Yearbooks for 1989, 2012, 2022 [5-7] give a time discrepancy of no more than 30 seconds, which indicates a sufficiently high accuracy.
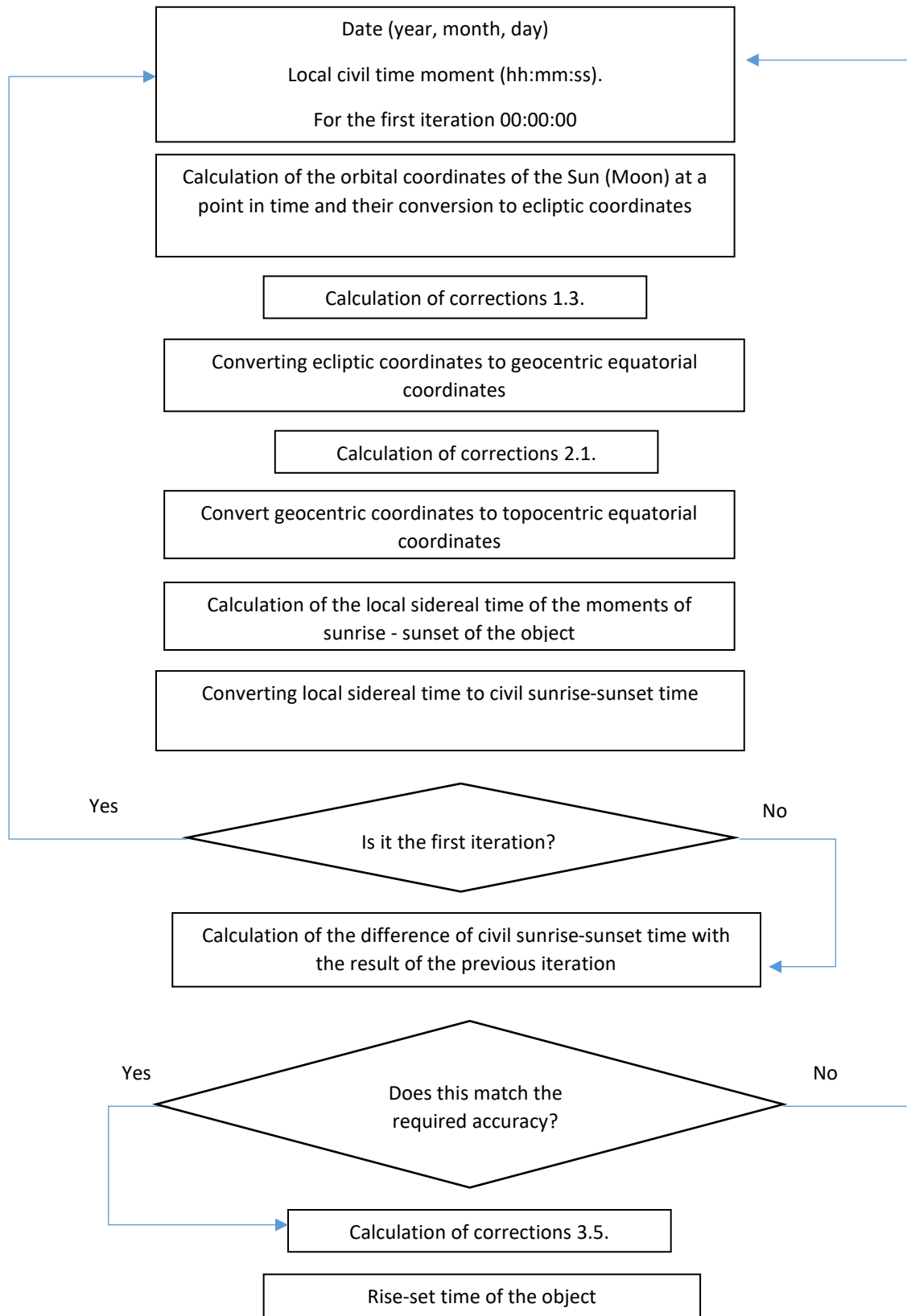
Figure 1 - Block diagram for rise-set time calculation for the Sun (the Moon).

Chapter 2. Sorting for objects

The program accepts as input a file with a list of objects containing the following information (about each object):

1) Object name

2) Right Ascension (RA)

3) Declension (DEC)

4) Magnitude in V filter

5) Exposure time of a single frame

6) Number of frames

In the first stage, the program rejects objects with incorrectly entered parameters. For example, when the data on the number of frames contains alphabetic characters instead of numbers or when the coordinates (DEC) indicate that the object cannot be observed at all at these latitudes. At the same time, an error log is formed, where similar objects are written with a description of errors.

In the second stage, calculations are carried out according to the time of the culmination of objects and then a preliminary sorting by this parameter is carried out. Objects with an earlier culmination time will be observed earlier.

In the third stage, the moments of sunrise and sunset are calculated, as well as three types of twilight (civil, navigational and astronomical) for the current and next day. Furthermore, the boundaries of the astronomical night are determined, indicating the beginning and end of observations.

In the fourth stage, the heights of objects are calculated at the beginning of the astronomical night. If the objects are descending and their height at the start of observations is below 20 degrees, then they are rejected.

In the fifth stage, the moonrise-set times and its phases are calculated, and the angular distances between the moon and the observed objects are calculated with estimates of the sky background illumination. At this stage, objects whose magnitudes are weaker than the sky background are rejected. For other objects in the list, their angular distance to the center of the lunar disk is displayed. The output is a sorted list of objects and an error log, which is then taken as input by the telescope control program.

Conclusions

At the moment, the first part of creating an observation planner has been fully completed - a block for calculating the position of the Sun and Moon, as well as the moments of their sunrise and sunset and the time of twilight, working in offline mode. Work is underway to complete the second block of the OP - the sorter of observation objects. The completed OP program will make it possible

to optimally distribute the operating time of astronomical instruments without human intervention. This software product will be an important element, without which full automation of the observational process of astronomical objects is impossible.

Acknowledgements

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