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Solar eclipse monitoring for solar energy applications

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Abstract

In recent years, the interest in using solar energy as a major contributor to renewable energy applications has increased, and the focus to optimize the use of electrical energy based on demand and resources from different locations has strengthened. This article includes a procedure for implementing an algorithm to calculate the Moon's zenith angle with uncertainty of $\pm 0.001°$ and azimuth angle with uncertainty of $\pm 0.003°$. In conjunction with Solar Position Algorithm, the angular distance between the Sun and the Moon is used to develop a method to instantaneously monitor the partial or total solar eclipse occurrence for solar energy applications. This method can be used in many other applications for observers of the Sun and the Moon positions for applications limited to the stated uncertainty.

Keywords: Solar eclipse; Moon position; Solar position; Solar energy

1. Introduction

The interest in using solar energy as a major contributor to renewable energy applications has increased, and the focus to optimize the use of electrical energy based on demand and resources from different locations has strengthened. We thus need to understand the Moon's position with respect to the Sun. For example, during a solar eclipse, the Sun might be totally or partially shaded by the Moon at the site of interest, which can affect the irradiance level from the Sun's disk. Instantaneously predicting and monitoring a solar eclipse can provide solar energy users with instantaneous information about potential total or partial solar eclipse at different locations At least five solar eclipses occur yearly, and can last three hours or more, depending on the location. This rare occurrence might have an effect on estimating the solar energy as a resource.

This article includes a procedure for implementing an algorithm (described by Meeus (1998)) to calculate the Moon's zenith angle with uncertainty of $\pm 0.001°$ and azimuth angle with uncertainty of $\pm 0.003°$. The step-by-step format presented here simplifies the complicated steps Meeus describes to calculate the Moon's position, and focuses on the Moon instead of the planets and stars. It also introduces some changes to accommodate for solar radiation applications. These include changing the direction of measuring azimuth angle to start from north and eastward instead of from south and eastward, and the direction of measuring the observer's geographical longitude to be measured as positive eastward from Greenwich meridian instead of negative. In conjunction with the Solar Position Algorithm (SPA) that Reda and Andreas developed in 2004 (Reda and Andreas, 2004), the angular distance between the Sun and the Moon is used to develop a method to instantaneously monitor the partial or total

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solar eclipse occurrence for solar energy and smart grid applications. This method can be used in many other applications for observers of the Sun and the Moon positions for applications limited to the stated uncertainty.

SPA has the details of calculating the solar position, so only the Moon position algorithm (MPA) is included in this report. When the solar position calculation is included in this report, the SPA report will be the source for the SPA calculation.

This article is used to calculate the Moon's position for solar radiation applications only. It is purely mathematical and not meant to teach astronomy or to describe the complex Moon rotation around the Earth. For more information about the astronomical nomenclature that is used throughout the report, review the definitions in the Astronomical Almanac (AA) or other astronomy references.

2. Moon position algorithm

2.1. Calculate the Julian and Julian Ephemeris Day, Century, and Millennium

The Julian date starts on January 1, in the year −4712 at 12:00:00 UT. The Julian Day (JD) is calculated using the Universal Time (UT) and the Julian Ephemeris Day (JDE) is calculated using the Terrestrial Time (TT). In the following steps, there is a 10-day gap between the Julian and Gregorian calendars where the Julian calendar ends on October 4, 1582 (JD = 2,299,160), and on the following day the Gregorian calendar starts on October 15, 1582.

2.1.1. Calculate the Julian Day

$$\mathrm{JD} = \mathrm{INT}(365.25 * (Y + 4716)) + \mathrm{INT}(30.6001 * (M + 1)) + D + B - 1524.5, \tag{1}$$

where INT is the integer of the calculated terms ($8.7 = 8$, $8.2 = 8$, and $-8.7 = -8$, etc.). Y is the year (2001, 2002, etc.). M is the month of the year (1 for January, etc.). If $M > 2$, then Y and M are not changed, but if $M = 1$ or 2, then $Y = Y - 1$ and $M = M + 12$. D is the day of the month with decimal time (e.g., for the second day of the month at 12:30:30 UT, $D = 2.521180556$). B is equal to 0, for the Julian calendar {i.e. by using $B = 0$ in Eq. (1), JD < 2,299,160}, and equal to ($2 - A + \mathrm{INT}\ (A/4)$) for the Gregorian calendar {i.e. by using $B = 0$ in Eq. (1), and if JD > 2,299,160}; $A = \mathrm{INT}(\mathrm{Y}/100)$.

2.1.2. Calculate the Julian Ephemeris Day

Determine ΔT, which is the difference between the Earth's rotation time and TT. It is derived from observation only and reported yearly in the AA (Astronomical Almanac; US Naval Observatory).

$$\mathrm{JDE} = \mathrm{JD} + \frac{\Delta T}{86,400}. \tag{2}$$

2.1.3. Calculate the Julian Century and the Julian Ephemeris Century for the 2000 standard epoch

$$\mathrm{JC} = \frac{\mathrm{JD} - 2,451,545}{36,525}, \tag{3}$$

$$\mathrm{JCE} = \frac{\mathrm{JDE} - 2,451,545}{36,525}. \tag{4}$$

2.1.4. Calculate the Julian Ephemeris Millennium for the 2000 standard epoch

$$\mathrm{JME} = \frac{\mathrm{JCE}}{10}. \tag{5}$$

2.2. Calculate the Moon geocentric longitude, latitude, and distance between the centers of Earth and Moon (λ, β, and Δ)

"Geocentric" means that the Moon position is calculated with respect to Earth's center.

2.2.1. Calculate the Moon's mean longitude, L′ (in degrees)

$$L' = 218.3164477 + 481267.88123421 * T - 0.0015786 * T^2 + \frac{T^3}{538,841} - \frac{T^4}{65,194,000}, \tag{6}$$

where T is JCE from Eq. (4).

2.2.2. Calculate the mean elongation of the Moon, D (in degrees)

$$D = 297.8501921 + 445267.1114034 * T - 0.0018819 * T^2 + \frac{T^3}{545,868} - \frac{T^4}{113,065,000}. \tag{7}$$

2.2.3. Calculate the Sun's mean anomaly, M (in degrees)

$$M = 357.5291092 + 35999.0502909 * T - 0.0001536 * T^2 + \frac{T^3}{24,490,000}. \tag{8}$$

2.2.4. Calculate the Moon's mean anomaly, M′ (in degrees)

$$M' = 134.9633964 + 477198.8675055 * T + 0.0087414 * T^2 + \frac{T^3}{69699} - \frac{T^4}{14,712,000}. \tag{9}$$