IMPLEMENTATION OF THE JEAN MEEUS ALGORITHM IN CALCULATING NEW MOON AND FULL MOON DATA

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Abstract

This research aims to determine the application of Jean Meeus' algorithm in calculating new moon and full moon data. This is a qualitative study using a library approach. The primary source is the book "Astronomical Algorithm" by Jean Meeus, while secondary sources include books, journals, websites, and other information. The research results show that calculating new moon and full moon data using Jean Meeus' algorithm involves several calculation stages: lunation value (k), time in the Julian epoch 2000 (T), M (mean solar anomaly), M' (mean lunar anomaly), F (lunar latitude), and Ω (longitude of the ascending node) in degrees (0^0 - 360^0). Then, 14 arguments (components) affecting the planets are calculated in degrees. Next, the average time for moon phases is calculated, considering the influence of lunar and solar ablation and the moon's light travel time to the observer's position. Additional correction to the JDE (Julian Day Ephemeris) is required to determine the true phases. Jean Meeus' algorithm is used in the *taḥqīqī* essential calculation method due to its highly accurate astronomical data corrections for the movements of the Moon and Sun and is part of the heliocentric flow.

Keyword: *Jean Meeus, Algorithm, Moon phases*

Abstrak

Penelitian ini bertujuan untuk menentukan penerapan algoritma Jean Meeus dalam menghitung data bulan baru dan bulan purnama. Penelitian ini bersifat kualitatif dengan pendekatan pustaka. Sumber utama penelitian ini adalah buku "Astronomical Algorithm" oleh Jean Meeus, sementara sumber sekunder meliputi buku, jurnal, situs web, dan informasi lainnya. Hasil penelitian menunjukkan bahwa perhitungan data bulan baru dan bulan purnama menggunakan algoritma Jean Meeus melibatkan beberapa tahap perhitungan, seperti nilai lunasi (k), waktu dalam epoch Julian 2000 (T), M (anomali matahari rata-rata), M' (anomali bulan rata-rata), F (lintang bulan), dan Ω (bujur node naik) dalam derajat (0^0 - 360^0). Kemudian, dihitung 14 argumen (komponen) yang mempengaruhi planet dalam derajat. Selanjutnya, dihitung rata-rata waktu fase bulan dengan mempertimbangkan pengaruh abrasi bulan dan matahari serta waktu perjalanan bulan ke posisi pengamat. Koreksi tambahan pada JDE (Julian Day Ephemeris) diperlukan untuk menentukan fase sebenarnya. Algoritma Jean Meeus digunakan dalam metode *taḥqīqī* karena proses perhitungan melibatkan data astronomis dengan koreksi sangat akurat untuk gerakan bulan dan matahari serta termasuk dalam aliran heliosentris.

Kata Kunci*: Jean Meeus, Algoritma, Fase Bulan*

A. Introduction

The calculation of lunar phases, such as new moons and full moons, is a fundamental aspect of both astronomical research and practical applications ranging from calendar creation to cultural events. Accurate predictions of these phases are essential for various fields, including astronomy, navigation, and even religious observances. Among the myriad methods developed to determine these lunar phases, the algorithm introduced by Jean Meeus stands out for its precision and reliability.[1]

Jean Meeus, a distinguished Belgian astronomer and mathematician, developed a sophisticated algorithm for calculating lunar phases that has become a cornerstone in computational astronomy. His approach, detailed in his seminal work "Astronomical Algorithms," employs a blend of celestial mechanics and advanced mathematical models to provide accurate predictions of when new moons and full moons occur. This algorithm has been widely adopted in various astronomical software and lunar calendars due to its exceptional accuracy.[2]

The importance of this algorithm extends beyond academic research. For astronomers, precise lunar phase calculations are crucial for planning observations and understanding lunar effects on other celestial phenomena. For the general public, accurate lunar phase predictions are integral to creating reliable calendars, determining the timing of lunar-based events, and even in the planning of activities influenced by moonlight.

Given its significant applications and the need for high accuracy in lunar phase predictions, the implementation of Jean Meeus's algorithm represents a pivotal advancement in the field of astronomy. This paper explores the mechanics of Meeus's algorithm, its accuracy in calculating new and full moon dates, and its practical applications in various domains. By examining the implementation and impact of this algorithm, we gain insights into its contributions to both theoretical and practical aspects of lunar phase calculations.

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[1] Ehsan Hidayat, "Penentuan Jumlah Gerhana Matahari dengan Lintang Bulan dan Teori Aritmatika', *Miyah: Jurnal Studi Islam* 16, no. 1 (2020): 62–94.

[2] Li'izza Diana Manzil, "Fase-Fase Bulan Pada Bulan Kamariah (Kajian Akurasi Perhitungan Data New Moon dan Full Moon dengan Algoritma Jean Meeus)", *Jurnal Hukum Islam* 16, no. 1 (2018): 33–47.

The moon is the only satellite of the earth, its average distance from the earth is 384,400 km. The surface of the moon is barren, cratered and mountainous. The moon does not have an atmosphere like the earth. This causes sunlight to fall continuously on its surface and causes the temperature to rise during the day to 100ºC. Even at night, thetemperature drops to -155ºC. The origin of the Moon is not known for certain. However, scientists found evidence that 3 billion years ago there was a collision between the Moon and a small planet called Theira. The collision produced a huge amount of dust that orbited aroundthe Earth. Then gradually the dust collected and became the Moon.

The moon has four main phases, namely New Moon, First Quarter, Full Moon and Last Quarter. The New Moon and Full Moon phases are most often used in lunar studies, because it is still related to Muslim worship. Many methods are used to calculateNew Moon and Full Moon. These include *taqrībī*, *ḥaqīqī* and contemporary. One of themuses the Jean Meeus algorithm method. This method is to find Julian Day (JD) when the New Moon and Full Moon occur in the lunar month.[3]

Therefore, I will discuss Jean Meeus' algorithm regarding the phases of the moon during the lunar month. In completing this article, the author refers to Li'izza Diana Manzil’s works with the title Implementation of the Jean Meeus Algorithm in Calculating New Moon and Full Moon Data.[4]

B. Research Methods

This research is qualitative research with a library research approach. This approach was chosen because it aligns with the research objectives, which focus on the analysis and interpretation of data derived from written sources. The primary source in this research is the book titled *Astronomical Algorithms* by Jean Meeus. This book was selected as the primary source because it is considered a comprehensive and authoritative reference in the field of astronomy, particularly concerning algorithms used for calculating the positions of celestial bodies.

[3] Muhammad Farid Azmi, Ahmad Adib Rofiuddin, and Ahmad Ainul Yaqin, “Prediksi Pergerakan Bayangan Bumi Saat Terjadi Gerhana Bulan Menggunakan Ephemeris Hisab Rukyat”, *Al-Marshad: Jurnal Astronomi Islam dan Ilmu-Ilmu Berkaitan*, 2018.

[4] Manzil, ‘Fase-Fase Bulan Pada Bulan Kamariah (Kajian Akurasi Perhitungan Data New Moon dan Full Moon dengan Algoritma Jean Meeus)’.

Astronomical Algorithms has been widely used by astronomers and sky observers to perform accurate astronomical calculations, making it highly relevant to the topic of this research.

In addition to this primary source, the research also utilizes various secondary sources to support *the* analysis. These secondary sources include other books related to the topic of astronomical algorithms, scientific journals that discuss the latest developments in this field, as well as articles from websites that provide supplementary information. The use of secondary sources aims to enrich perspectives and ensure that the analysis is well-founded and supported by various viewpoints.

By combining primary and secondary sources, this research seeks to provide a deep understanding of *astronomical* algorithms and their applications in various contexts. This literature study also enables the researcher to construct a robust theoretical framework and identify potential gaps in previous research, thereby contributing new insights to the development of knowledge in this field. The qualitative approach in this research emphasizes the interpretation and critical analysis of texts, which is expected to yield relevant and meaningful findings.

C. Results and Discussion

C.1. History and Biography of Jean Meeus

Jean Meeus is a Belgian meteorologist and amateur astronomer who specializes in celestial mechanics, spherical astronomy and mathematical astronomy who was born on December 12 1928. Meeus studied at the University of Leuven in Belgium with a concentration in Mathematics and received a Licentiate degree in 1953. In 1986 Meeus received an award from the Astronomical Society of the Pacific for winning the Amateur Achievement Award. Meeus has been a member of the Astronomical Society of France (ASF) since 1948.[5]

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[5] Atiqo Shofi Wardana and Erna Dwi Astuti, "Rancang Bangun Aplikasi Penghitung Awal Bulan Hijriyah Menggunakan Algoritma Jean Meeus Sebagai Media Pembelajaran Ilmu Falak Pada Kitab Taqyidatul Jaliyah", *Biner: Jurnal Ilmiah Informatika dan Komputer* 2, no. 2 (2023): 142–47.

Apart from that, Meeus has produced many works related to the field of astronomy, including Canon of Solar Eclipses as co-author (1996), Astronomical Formulae for Calculator II (1988), Astronomical Formulae for Microcalculators (1988), co-author of Canon of Lunar Eclipses, co-author of Canon of Solar Eclipses (1983), Elements of Solar Eclipses 1951-2200 (1989), Transits (1989), Astronomical Tables of the Sun, Moon, and Planets (1983), Astronomical Algorithms (1991), Astronomical Algorithms 2nd Edition (1998), Mathematical Astronomy Morsels (1997), More Mathematical Astronomy Morsels (2002), Mathematical Astronomy Morsels III (2004), co-author of the Five Millennium Canon of Solar Eclipses -1999 to + 3000 (2006), Mathematical Astronomy Morsels IV (2007), Mathematical Astronomy Morsels V (2009).

In addition, Jean Meeus was Almanac editor within the company for 25 years. Then Meeus succeeded in publishing more than a hundred articles in astronomy journals published by SAF. While working in the world of astronomy, Jean Meeus managed to discover the asteroid 2213 which was named after himself. At the end of his life he succeeded in serving as a meteorologist at Brussels Airport (1953-1999).[6]

C.2. Study of the Phases of the Moon during the Lunar Month Using Jean Meeus' Algorithm

a. Undertanding the Moon

The word *qamar*, etymologically comes from *qāf-mīm-rā'*, which means a celestial body that emits light from sunlight. Meanwhile, in terms of terminology, *qamar* (Moon) is defined as the only celestial body that surrounds the Earth. The moon reflects sunlight to Earth, so it appears to shine when seen from Earth.Apart from that, in another meaning months can be referred to as the names of themonths whose divisions are often mentioned in a year, namely January, February, March, April, May and so on in the

[6] Lalu Adam Prayogi, "Studi Komparatif Perhitungan Gerhana Bulan Astronomical Algoritm Jean Meuss dan Texbook on Spherical Astronomy W.M SMART' (Undergraduate Thesis, UIN Mataram, 2022).

Gregorian calendar. Then *Muḥarram*, *Safar*, and so on in the Hijrī calendar.[7]

The moon is the only satellite of the earth, its average distance from the earth is 384,400 km. The surface of the moon is barren, cratered and mountainous. The moon does not have an atmosphere like the earth. Sunlight to fall continuously on its surface and causes the temperature to rise during the day to 100ºC. Even at night, the temperature drops to -155ºC.[8]

The origin of the Moon is not known for certain. However, scientists found evidence that 3 billion years ago there was a collision between the Moon and a small planet called Theira. The collision produced a huge amount of dust that orbited around the Earth. Then gradually the dust collected and became the Moon.

b. Motion and Circulation of the Moon

The Moon, like other celestial bodies, has several movements, namely the essential movement of the Moon (the movement actually carried out by the Moon,such as rotating on its axis (rotation) and circulating around the Earth and with the Earth around the Sun (revolution) and the apparent movement of the Moon (the movement of light that is not actually occurs when viewed from the earth such as the Moon's daily movement and liberation).[9]

The moon is the only celestial body that follows the Earth, which has a diameter of 3,480 km. The average distance the moon travels to circle the Earth is 384,421 km. The Moon has important movements like the Earth's movements, namely Lunar Rotation and Lunar Revolution.[10]

1) Moon Rotation

Lunar rotation is the rotation of the Moon on its axis from west to east. One rotation takes the same time as one revolution around theearth. The result is that the surface of the moon facing the earth remains

[7] Muhyiddin Khazin, *Kamus Ilmu Falak* (Yogyakarta: Buana Pustaka, 2005). 25.

[8] Rinto Anugraha, *Mekanika Benda Langit* (Yogyakarta: FMIPA Universitas Gajah Mada, 2012). 43

[9] Ahmad Adib Rofiuddin, "Dinamika Sosial Penentuan Awal Bulan Hijriah di Indonesia", *Istinbath* 18, no. 2 (2019).

[10] Halpi Anti, Muh Rasywan Syarif, and Faisal Akib, "Akurasi Perhitungan Full Moon dengan Algoritma Jean Meeus terhadap Ephemeris dalam Sistem Penanggalan Kamariah", *Hisabuna* 4, no. 2 (2023): 107–24.

relatively constant.

2) Lunar Revolution

Lunar revolution is the circulation of the Moon around the Earth from West to East. The moon takes 27 days 7 hours 43 minutes 12 seconds to make a complete revolution. This time period is called the Sidereal Month or *Shahr Nujūmī*. The lunar revolution is used to calculate the *qamariyah* month. However, the time used is not sidereal, but synodic or *Shahr Iqtirānī*, the average length of whichis 29 days 12 hours 44 minutes 2.8 seconds.

A calendar that determines the length of a year using the synodic cycle of the Moon is called a Lunar Calendar. This cycle is referredto as a cycle of two consecutive phases of the same Moon. The calendar age of the Moon (12 times the Moon's synodic cycle) is 354 days 8 hours 48 minutes 36 seconds.[11]

C.3. Phase of the Moon

a. New Moon

This phase is called dead moon because there is not a single ray of sunlight reflected by the moon to Earth. The phase occurs when the Moon has performed one synodic perfectly. In this phase, the difference in astronomical longitude between the Moon and the Sun is 0º and is between the phases of the oldest Crescent Moon and the youngest Crescent Moon, namely on the night of 29/30 of the lunar month.

b. Crescent Moon Phase (Waxing Crescent)

This phase occurs after the conjunction occurs around the 7th of the lunar month. This month appears just before sunset when the intensity of the Sun's light begins to weaken.

c. First Half Moon Phase (First Quarter)

This phase occurs on the 7th of the lunar month with an elongation angle of 90º. The appearance of the moon in this phase is a quarter of a sphere soit is called the Perbani moon or *al-Tarbi'ī al-Awwal*.

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[11] Amsel Sheri, *Phases of The Moon* (www.exploringnature.org, 2005).

d. Gumpy Moon Phase (Waxing Gibbous)

This phase occurs on the 7th to 14th of the lunar month. In this phase the moonlight increases. This is because the moon's surface reflects more and more sunlight towards Earth, so it looks convex.

e. **Full Moon Phase (Full Moon)**

In this phase the position of the Earth is between the positions of the Moonand the Sun. This phase occurs on the 15th of the lunar month. At this time the moon is in opposition to the Sun. The moon looks full because it is behind the earth and has an astronomical longitude difference of 180º.

f. **Waning Gibbous Moon Phase with Reduced Light (Waning Gibbous)**

After the Full Moon the Moon phase returns to the gibbous Moon phase. In this phase the reflected light decreases every day. This phase occurs between the 15-21 of the lunar month. At this time the Moon is in the eastat around 21.00, is in the middle of the sky at exactly 03.00 in the morning and sets at around 09.00 in the morning.

g. Last Half-Moon Phase (Last Quarter)

This phase occurs on the 21st night of the 22nd lunar month and the moonhas an astronomical longitude difference with the Sun of 270º.

h. Crescent Moon Phase (Waning Crescent)

This lunar phase is called the Old Crescent Moon Phase. Because, the age of the Moon is calculated from conjunction to the end of the synodic cycle. This phase occurs at the end of the night of 29/30 of the lunar month.

The phases of the Moon can be used to determine monthly time for one year. This calculation is done by looking at the phases of the Moon every day for one month. In this way, the number of days can be seen based on the shape of the Moon's surface as seen from Earth. The phases of the Moon, which occur regularly every month, can help humans create a time system.[12]

The time system in question is in the form of calculating the number of

[12] Sheri; Manzil, "Fase-Fase Bulan Pada Bulan Kamariah (Kajian Akurasi Perhitungan Data New Moon dan Full Moon dengan Algoritma Jean Meeus)".

days each month that follow the lunar synodic cycle. This means that even thoughthe moon has rotated 360º, it cannot yet be called the beginning of the month. Because, the 360º rotation only extends to the period when the Moon is in the old moon position. Meanwhile, to enter the new month, the new moon must bevisible. So, there must be several additional days from the old moon to turn into the crescent moon. This cycle is called the *Ḥilāl* Visibility Cycle.

The stars that form the background to the moon throughout its phase changes are known as *manzilah*. According to al-Birunī, as many as 28 *manzilah* months will pass in one *qamariyah* year. However, the moon only passes through part of the *manzilah* in one *qamariyah* month depending on its circulation plane inthe sky.

Apart from that, the Moon is a sky that can experience refraction. Refraction or *daqā'iq al-ikhtilāf*, namely *refraction of rays* is the difference between the actual height of a celestial object and the height of that celestial object as seen due to the refraction of light. Refraction occurs because the raysthat come to our eyes have passed through the layers of the atmosphere. So the incoming light is bent. In fact, what we see is a straight direction captured by our eyes.

The refraction of a celestial body at the zenith is 0º. The lower the positionof a celestial object, the greater the refraction value. Meanwhile, for celestial bodies that appear to be setting, the horizon value is around 00º 34' 30". Refraction prices can be obtained from the existing refraction list. For example, inthe appendix to the *Ephemeris Ḥisab Ru'yat* or it can be obtained using the following formula: 0.0695: tan (h (height of celestial bodies) + 10.3: (h + 5.1255)). The formula ignores the actual temperature. So it can be seen that the position of the celestial body that we see is higher than the actual position of the celestial body.

Refraction in the celestial body, namely the moon, causes optical phenomena which are currently being discussed in society. This phenomenon is known as *Halo Bulan* or Javanese people call it *Rembulan Kalangan*.[13] It is a celestial phenomenon in Javanese culture where if this phenomenon occurs a disaster will strike. Based on research conducted by the Sky Explorers Astronomy Club which was presented at the Seminar on Astronomy in Archipelago Culturein Yogyakarta on 25 May 2015 in several areas, namely in Pekalongan, Sragen, Klaten and Yogyakarta, people think that when the Halo Moon phenomenonoccurs there will be a disaster.

What is actually meant by this phenomenon? The Moon Halo phenomenon is the moon circled by a white ring and can be seen around 21.00 to 23.00. The lunar halo occurs due to light refracted by the Cirrostratus clouds. These clouds are a combination of cirrus and stratus clouds. The rings that appear around the moon come from light passing through the sides of six ice crystals in the high atmosphere and can refract the light. This ring has a diameter of 22 degrees. Sometimes a second ring can be seen with a diameter of 44 degrees. The shape of the ice crystal produces a focus of light into a ring. Ice crystals usually have the same shape (hexagonal), so the moon's rings are almost always the same size. Halos can be produced by different viewing angles in the crystal, and halos can be formed at 46 degree angles.

The impact of this event is a beautiful effect. There is no special impact. This event is an optical phenomenon that can be seen from the earth. The light produced does not cause radiation so it can be seen directly by the eye. This lunar halo phenomenon sometimes doesn't last long because as the Cirrus clouds leave, the beautiful light will disappear too.[14]

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[13] Susiknan Azhari and Ibnor Azli Ibrahim, "Takwim Jawa Islam Memadukan Tradisi dan Tuntutan Syar'i", *Asy-Syir'ah Jurnal Hukum Islam* 42, no. 1 (2008): 131–47; Susiknan Azhari and Ibnor Azli Ibrahim, "Kalender Jawa Islam: Memadukan Tradisi dan Tuntutan Syar'i", *Jurna Asy-Syir'ah* 42, no. 1 (2008).

[14] Othman Zainon, Hamdun Ridlwan Ali, and Mohd Fauzi Abu Hussin, "Comparing the New Moon Visibility Criteria for International Islamic Calendar Concept", in *International Conference on Space Science and Communication, Icon Space*, 2019, https://doi.org/10.1109/IconSpace.2019.8905945.

C.4. Analyzing the Jean Meeus Algorithm in Calculating New Moon and Full Moon Data

Meeus's algorithm is based on celestial mechanics principles and advanced mathematical models. It calculates the positions of the moon and the sun in their orbits and uses detailed ephemeris data. To determine lunar phases, the algorithm calculates when the moon is in the correct position for a new moon or a full moon. A new moon occurs when the moon is positioned between the Earth and the Sun, while a full moon happens when the moon is on the opposite side of the Earth from the Sun, making it fully visible from Earth.

The accuracy of Meeus's algorithm is notably high. The algorithm can produce lunar phase timings with errors as small as a few minutes or seconds, which is critical for various applications. For instance, in lunar calendars, high accuracy ensures that lunar phases are recorded correctly, which is important for scheduling cultural and religious events that depend on the lunar cycle. In astronomy, this precision is also essential for planning observations and research, as moonlight can affect the visibility of other celestial objects.[15]

However, several factors affect the accuracy of this algorithm. Firstly, the quality of the ephemeris data used is crucial. Ephemeris data provides information about the positions of celestial bodies that change over time, and the accuracy of the algorithm's results depends on the precision of this data. If the ephemeris data is outdated or inaccurate, the results can be affected. Additionally, the algorithm incorporates corrections for orbital perturbations and variations in lunar parameters, but the accuracy of these corrections also impacts the final results.

Compared to simpler lunar phase calculation methods, Meeus's algorithm offers significantly better accuracy. Simpler methods often fail to account for all the variables affecting the moon's and the sun's positions,

[15] Manzil, "Fase-Fase Bulan Pada Bulan Kamariah (Kajian Akurasi Perhitungan Data New Moon dan Full Moon dengan Algoritma Jean Meeus)'.

leading to greater errors. In this context, Meeus's algorithm represents a significant advancement over traditional methods that might be less precise.

In modern times, there are other methods that also offer high accuracy, thanks to better observational technology and more advanced mathematical models. However, Meeus's algorithm remains relevant and is frequently used due to its combination of high accuracy and consistency. Many astronomical software programs and calendar applications integrate this algorithm to provide users with reliable lunar phase data.

Despite its high accuracy, there are some limitations and challenges associated with the algorithm. Implementing it requires a deep understanding of astronomy and mathematics, which can be a barrier for those without a technical background. Additionally, the algorithm relies on accurate ephemeris data, so any updates or changes to this data must be considered to maintain accuracy.

With technological advancements, newer algorithms might offer even better accuracy, but Meeus's method continues to be a valued tool in astronomy. Its use in lunar calendars, astronomical software, and research demonstrates the importance of precision in lunar phase calculations. By updating the data and technology used, Meeus's algorithm can continue to provide useful and reliable results for lunar observations and research.[16]

Overall, Jean Meeus's algorithm for calculating new moons and full moons is one of the most accurate and reliable methods in computational astronomy. Despite some limitations, the high accuracy and consistency of this algorithm make it a top choice for various applications, from lunar calendars to astronomical software, and it significantly contributes to the understanding and observation of lunar phases.

D. Conclusion

Jean Meeus's algorithm for calculating the new moon and full moon is a cornerstone of modern astronomical computations. Its accuracy and precision

[16] Baiq Anggi Andini, "Implementasi Algoritma Jean Meeus dalam Penentuan Gerhana Bulan dan Matahari", *Al-Afaq: Jurnal Ilmu Falak dan Astronomi* 5, no. 1 (2023): 57–80.

make it a valuable tool for a wide range of applications, from scientific research to cultural and religious observances. While the algorithm is complex and relies heavily on accurate data, its robustness and effectiveness have been proven over time. With ongoing advancements in technology and data quality, Meeus's method continues to be a reliable and essential tool in the field of astronomy.

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