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HILAAL-CTM: Algorithm to Determine and Visualize the First Visibility of Lunar Crescent Using Contrast Threshold Model

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ABSTRACT

Introduction: The determination of the beginning of the Hijri month depends on the visibility of the new moon after conjunction

Objectives: This study develops an algorithm based on a contrast threshold model to determine the first moment of new moon visibility at selected locations in Malaysia.

Methods: Key factors influencing new moon visibility, such as atmospheric attenuation, light pollution, twilight sky brightness, and human eye sensitivity, are also considered in this model.

Results: This algorithm can generate windows of opportunity that provide the best time for new moon sighting.

Conclusions: The study also validates the model by comparing it with observational data from several locations, including Aceh, Indonesia, and Tindouf, Algeria, for the determination of the beginning of Ramadan 2025. The findings indicate that this algorithm can aid in aligning the rukyah (moon sighting) method with scientific models, thereby contributing to the unification of the Islamic calendar.

Keywords: New Moon Visibility, Algorithm, Contrast Threshold, Best Times

INTRODUCTION

A number of religious communities in the world use the first visible lunar crescent after its conjunction to determine their religious calendar. Muslims use the visibility of the lunar crescent to determine the date of the holy fasting month, Eidul Fitri, and Eidul Aidha (Mohd Nawawi et al., 2024). The Orthodox Judaism, or the Karaite Jews, relies on the visibility of a lunar crescent to determine the Rosh Chodesh and religious holidays such as Passover and Yom Kippur (Leaman, 2022). Some ethnic groups in Africa observe the lunar crescent's visibility to determine their calendar. Among them, the Serer people of Senegal celebrate the Raan Festival, which takes place annually on the second Thursday after the appearance of the new moon in April (Patterson, 2022). Similarly, the Bariba people of Benin observe the Gaani Festival, a significant cultural event that follows the lunar calendar (Anagonou et al., 2023). The Borana Oromo people of Ethiopia rely on the Borana calendar, which is based on the appearance of the new moon in conjunction with seven particular stars or constellations (Duressa, 2022). In Ghana, the Dagomba people celebrate Bugum Chugu (Baba Zakaria et al., 2024). This festival is held on the ninth day of the first month of the Dagomba lunar year.

The success of a lunar crescent visibility is based on various astrophysical factors. Several important astrophysical factors must be considered in determining lunar crescent visibility (Schaefer, 2000). These include atmospheric extinction, lunar surface brightness, light pollution and twilight sky brightness, and human eye sensitivity (M. S. Faid et al., 2023). Researchers studying lunar crescent visibility, have linked the Moon's brightness to the width of the crescent during observations. The wider the lunar crescent, the higher its brightness. The greater the intensity of the

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Moon's brightness, the easier it is for the human eye to detect it. Consequently, lunar brightness is one of the most crucial factors in crescent moon visibility. All crescent visibility criteria incorporate the width of the lunar crescent in their models (M. S. Faid et al., 2023; Loucif et al., 2024).

Atmospheric extinction the loss of light from celestial objects as it passes through Earth's atmosphere due to scattering and absorption of light (Ilyas, 1994). It occurs due to particles, aerosols, and humidity in the Earth's atmosphere. The presence of high concentrations of aerosols and moisture in the atmosphere obstructs the passage of celestial light to Earth, making the observed object appear dimmer. Schaefer found that for every increase of 0.25 in atmospheric extinction, the brightness of the Moon's surface decreases by 1.5 magnitudes, making it nearly three times dimmer (Schaefer, 1990). This highlights the importance of studying atmospheric extinction. Since atmospheric extinction affects lunar brightness, nearly all crescent visibility criteria take it into account. This may be done through lunar altitude, the time interval between sunset and moonset, or through theoretical extinction values (Al-Rajab et al., 2023; M. S. B. Faid et al., 2024).

Twilight sky brightness refers to the illumination of the sky due to scattered sunlight during the periods after sunset and before sunrise, when the sun is below the horizon but still illuminates the atmosphere. Twilight sky brightness is a crucial factor in lunar crescent visibility, as observations typically occur during twilight. A brighter twilight sky reduces the contrast of the lunar crescent, making it harder to see. Bruin was one of the first researchers to incorporate twilight brightness effects into crescent visibility calculations (Bruin, 1977). He replaced the twilight sky brightness parameter with the solar depression angle below the horizon. In addition to the solar depression angle, the azimuthal difference between the Moon and the Sun can also serve as a proxy for twilight brightness (M. S. Faid, Shariff, et al., 2024; Taher & Abdulla, 2024).

Light pollution is brightening of the night sky caused by streetlights and other man-made sources, which has a disruptive effect on natural cycles and inhibits the observation of stars and planets. It is often overlooked but important factor in crescent moon observations is light pollution. Light pollution is caused by excessive artificial lighting from sources such as streetlights, buildings, billboards, and improperly shielded lamps (M. S. Faid et al., 2019; Nawawi et al., 2024). Light pollution brightens the night sky, reducing the contrast of celestial objects, making them difficult to observe. This significantly affects optical and radio astronomical observations, including crescent moon visibility. Studies have shown that a 2-magnitude increase in light pollution makes crescent moon observations five times more difficult (Shariff et al., 2017; Utama et al., 2023).

Due to a complicated nature of a lunar crescent sighting, it is challenging to determine the exact time of visibility for a lunar crescent at any given location and time. The parameters for lunar crescent visibility are valid only within a restricted range of latitude and longitude and are not relevant every day of the year. It is essential to ascertain the precise timing of visibility to correctly observe the moon crescent (M. S. Faid, Nawawi, et al., 2024; Safiai et al., 2024). The windows of opportunity, referred to by Yallop as Best Time, signal to the observer when to concentrate on the observation while disregarding all distractions (Allawi, 2022; Safiai, 2024; Yallop, 1998). And at the same time, it will provide the judge to determine the validity of a lunar crescent sighting. Therefore, it is paramount to determine the exact time or windows of opportunity, for a lunar crescent sighting. This paper aims to provide an algorithm with visualization to determine the windows of opportunity for a successful lunar crescent sighting. The developed algorithm is named as HILAAL-CTM which acronym for Hijri Lunar Algorithm for Astronomical Luminosity - Contrast Threshold Model.

METHODS

Contrast threshold is applied for the algorithm development. The contrast threshold calculation between lunar brightness and twilight sky brightness is as follow.

$$Twilight\ Sky\ Brightness\ in\ Candela, twi_{cd} = 10\frac{12.58 - twi_{mag/sec^2}}{2.5}$$

$$Logharithmic\ scale\ for\ Twilight\ Sky\ Brightness\ in\ cd, logtwi_{cd} = twi_{cd} \times 10 \times \log\frac{100}{Zlp + 1}$$

$$When, Zlp < 18\ mag/sec^2 \qquad (1)$$

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$$C_{th} = \left[\left(\frac{\left(r_1 logtwi_{cd}^{-\frac{1}{4}} + r_2 \right)^2}{A} \right)^{\frac{3}{5}} + \left(k_1 logtwi_{cd}^{-\frac{1}{4}} + k_2 \right)^{\frac{3}{5}} \right]^{\frac{5}{3}}$$ Where, $r_1 = 6.505 \times 10^{-4}, r_2 = -8.461 \times 10^{-4}$ $k_1 = 7.633 \times 10^{-3}, k_2 = -7.173 \times 10^{-3}$ $A =$ semidiameter of lunar crescent in minutes	2
$$C_{th} = \begin{cases} \mathrm{C} + 10, & if\ contrast\_threshold\ is\ NaN\ or\ complex \\ C_{th} + 10, & otherwise \end{cases}$$ $$\text{Visibility} = \begin{cases} \text{Yes}, & if\ C_{th} > C \\ \text{No}, & otherwise \end{cases}$$	3

The input of the code is as follow. Lat & Long. Latitude and Longitude of the given location. Positive latitude for north, negative latitude for south. Positive longitude for East, negative longitude for West. Day, Month, & Year. Day of the observation. Must follow the local time zone. Ele & TZ. Ele is Elevation of the observation site in metre. TZ is time zone of the location based on its corresponding latitude and longitude. K. k is the atmospheric extinction coefficient. The atmospheric extinction coefficient is differed from one location to another and varies according to season of the month. Light Pollution Mag Sec. The value of light pollution in mag per seconds squared unit. The general value of light pollution can be determined either using value from Sky Quality Meter Instrument (SQM)

The output able to determine the windows of opportunity for a lunar crescent sighting as portrayed in Figure 1.

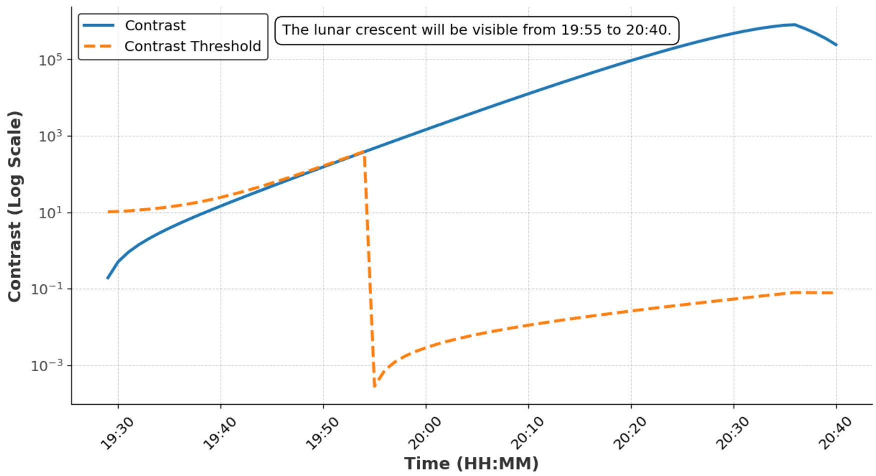

Figure 1: Windows of Visibility for Lunar Crescent Sighting

The plot contains the windows of opportunity, which contain text “The Lunar Crecent will be visible from time1 until time2”. Should the lunar crescent is not visible during the observation, the ouput contain text “Lunar Crescent is not visible”. Blue line indicates the contrast between sky brightness and lunar brightness, while orange line indicates the threshold of lunar crescent visibility. If the contrast is bigger than the threshold, then the lunar crescent will be visibility. However, if the contrast is less than the threshold, then the lunar crescent is not visible. The X Axis in the time of the observation, from sunset until moonset, while the Y-Axis is the value of contrast.

RESULTS AND DISCUSSION

The comparison of the time of visibility from various sites plays a crucial role in determining the lunar crescent sighting, as it depends on multiple factors such as atmospheric conditions, geographical location, and observer

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altitude. This algorithm is designed to accommodate these differences, ensuring a more accurate and reliable analysis of lunar visibility. By incorporating variations in astronomical, meteorological, and environmental factors, the algorithm enables a comprehensive comparison between different locations, providing valuable insights for researchers and scholars in the field of Islamic astronomy and moon sighting studies.

Light Pollution Factor

Pontian Johor is the designated site for lunar crescent observation in Malaysia. The site is obstructed by a community event taking place at night. Under typical circumstances, the light pollution measurement in Pontian is roughly 18 mag/sec^2; nevertheless, during these community events, the sky's brightness markedly increases, causing the SQM value to decrease to 10.13 mag/sec^2. The influence of the community event can be demonstrated as follows. During the light pollution reduction day in Pontian, with a SQM value of 18 mag/sec^2, the opportunity for lunar crescent observation extends to around 45 minutes, providing sufficient time to view the lunar crescent as shown in Figure 2. During a busy day in Pontian, with a SQM value of 10.51 mag/sec^2, the window for lunar crescent observation is approximately 35 minutes, hence necessitating a more precise timeframe for viewing the lunar crescent. This also signifies that on a busy day at the Pontian site, the lunar crescent is 20% more challenging to observe compared to a clear day in Pontian as shown in Figure 3.

Assessment of Lunar Crescent Visibility Validity from Various Site

Observation of Ramadhan Lunar Crescent Visibility on Aceh for 1st of Ramadhan 2025.

The lunar crescent observation for the first of Ramadhan is conducted on 28th February 2025. Observatorium Tgk. Chiek Kuta Karang Lhoknga is chosen as one of the prime sites for the lunar crecent, which has geographical coordinate of 5.46 north, 95.24east. The lunar crescent on 28th February 2025 is reported sighted on this location. Based on light pollution data mapping, the corresponding light pollution for this location is 21.49 mag/sec. Assuming the temperature is 27 celcius and relative humidity of 0.5, the window of lunar crescent visibility is as portrayed in Figure 4. Based on algorithm, the lunar crescent is predicted not sighted. This make the reported visibility of lunar crescent on this location to be arguable.

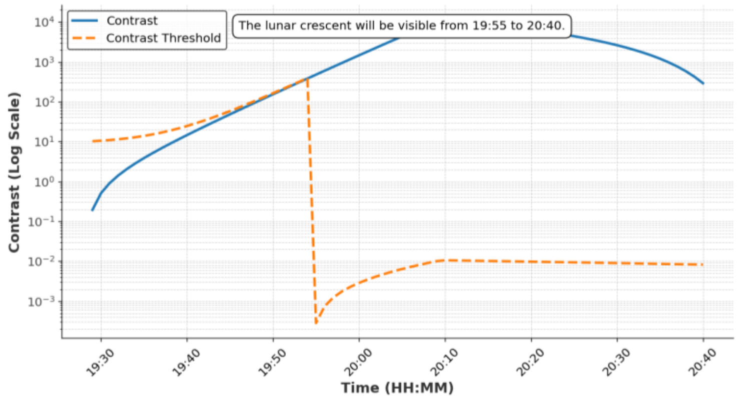

Figure 2: Opportunity Windows of Lunar Crescent Visibility at Pontian with SQM Value of 18 mag/sec^2

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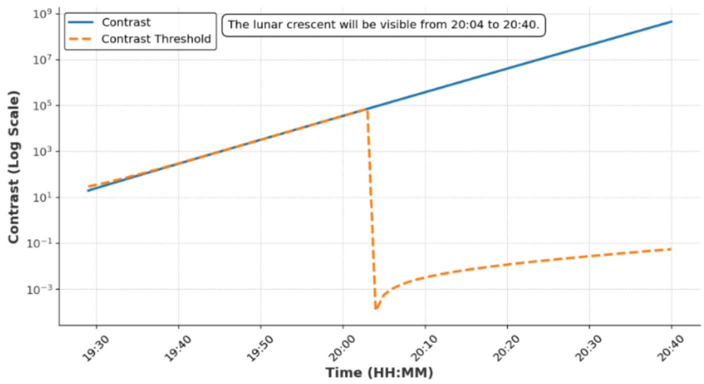

Figure 3: Opportunity Windows of Lunar Crescent Visibility at Pontian with SQM Value of 10.51 mag/sec²

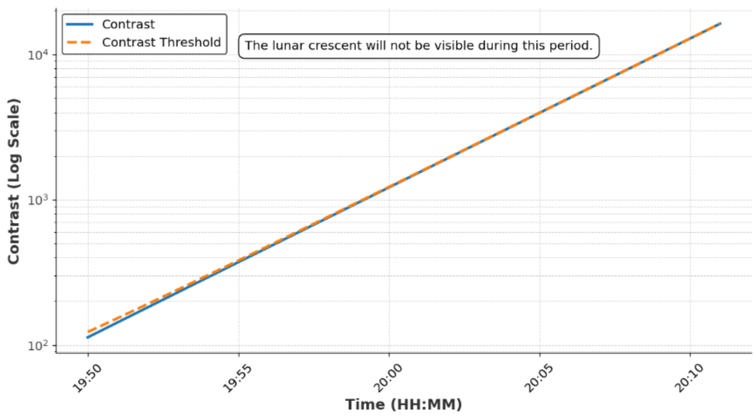

Figure 4: Opportunity Windows of Lunar Crescent Visibility at Acheh

Observation of Ramadhan Lunar Crescent Visibility on Tindouf, Algeria for 1st of Ramadhan 2025.

The lunar crescent observation for the first of Ramadhan is conducted on 28th February 2025. on Tindouf, Algeria is chosen as one of the prime sites for the lunar crecent, which has geographical coordinate of 27.639021677035377 North, 8.404182981115277 West, the lunar crescent on 28th February 2025 is reported sighted on this location. Based on light pollution data mapping, the corresponding light pollution for this location is 21.98 mag/sec. Assuming the temperature is 27 celcius and relative humidity of 0.5, the window of lunar crescent visibility is as shown in Figure 5. Based on algorithm, the lunar crescent is predicted sighted. This make the reported visibility of lunar crescent on this location to be validated.

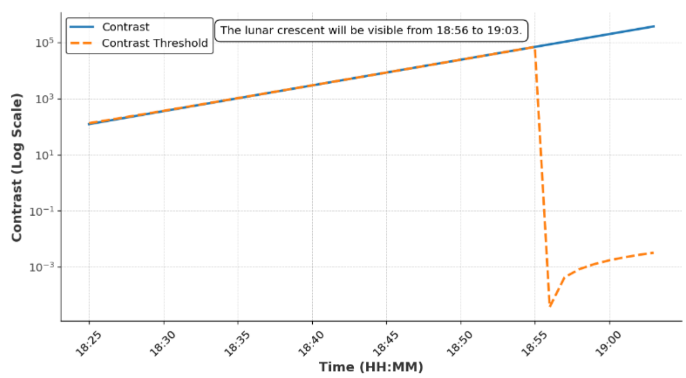

Figure 5: Opportunity Windows of Lunar Crescent Visibility at Tindouf

CONCLUSION

This study demonstrates that the contrast threshold model can be used to objectively determine the visibility of the new moon by considering various astronomical and environmental factors. Tests conducted at different observation locations indicate that the model's results align with actual moon sighting reports in several areas. However, discrepancies in locations highlight the need for a more detailed examination of environmental factors, including air humidity and the effects of light pollution. This model has the potential to be used as a support tool for astronomical institutions in making science-based decisions regarding the determination of the beginning of the Hijri month. Further research is needed to refine the model by incorporating additional parameters and validating it with a broader set of observational data worldwide.

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