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Measuring and Modelling Crescent Image Contrast with a DSLR Camera

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Abstract

The Hijri calendar is synonymous with hilal (young crescent moon) observation. Nowadays, hilal observation is expanding to various circles using instruments that are easily obtained and widely available on the market. The configuration that is often chosen uses a portable telescope and DSLR camera to produce images. Several theoretical models on the visibility of celestial objects at twilight, including the crescent moon, have been developed by several researchers. This has prompted the study of crescent image contrast and testing of more and more data. This study contains alternative processing of crescent moon images from DSLR cameras to measure the contrast value of observations (C_{obs}) and approximated by theoretical models. (C_{mod}).The final result of this research is a model of the hilal contrast limit at a certain elongation and can be applied for those who are interested in testing the contrast limit according to the specifications of the instrument and observation procedures used.

Kata kunci : Hilal, DSLR Camera, Contrast, Model

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A. Introduction

The Moon is the Earth's only natural satellite. The Moon is often seen and observed with a different disc shape each day. The daily difference in appearance observed from the Earth is a cycle that repeats itself over the course of an entire year. The daily difference in appearance observed from Earth is a cycle that repeats itself over the course of an entire month. Monthly cycles and changes in the Moon's appearance are common phenomena, and are even used as time markers and dating systems in various calendars, one of which is used by Muslims (the Hijri calendar).

The Hijri calendar system uses the synodic period of the moon as a reference. The synodic period is the time it takes for the Moon to return from one lunar phase to another (about 29 days). The lunar phase refers to the appearance of the part of the Moon illuminated by the Sun's light when viewed from the Earth. It varies from 100% (full moon) to 0% (new moon).

Hilal is the crescent observed after conjunction, usually after sunset (twilight). Hilal is the parameter for the beginning and end of a month in the Hijri calendar. It is therefore not uncommon for hilal observations to be very busy, especially to determine important days or prayers in Islam, such as determining the start of fasting in the month of Ramadan, Eid al-Fitr and Eid al-Adha.

Recently, the practice of Hilal observation in Indonesia is not limited to Islamic organisations and the Ministry of Religious Affairs of the Republic of Indonesia. However, with the development of astronomy throughout the country, many are interested in observing the new moon every month on a regular basis, both academics, communities and lay people. The instruments and observing techniques used in the practice of hilal observation also vary.

Since 2010, the Meteorology, Climatology and Geophysics Agency (BMKG) has been conducting Hilal observations at several locations in Indonesia. The observations use portable telescopes and Digital Single Lens Reflex (DSLR) camera detectors, which can be accessed directly through BMKG's web opponent every month[1]. The use of DSLR cameras in hilal observations is one of the efforts to optimise the instruments available and is expected to be affordable for those interested, as they are easily obtainable and widely available on the market, with capital costs that are not too expensive. This opens up the possibility of obtaining more and

[1] Badan Meteorologi Klimatologi dan Geofisika, Sistem Informasi Observasi Hilal Indonesia, (2023) <https://hilal.bmkg.go.id/> [accessed February 15, 2023].

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more hilal image data and can be an asset for studying them in depth.

DSLR cameras use a CMOS (Complementary Metal Oxide Semiconductor) sensor with a colour array filter that collects red, green and blue light in separate pixels (Bayer matrix). The light measured is directly visible light (380-730 nm). The spectral sensitivity of light in CMOS has a red, green and blue (RGB) colour filter that can be separated using image processing software. DSLR cameras used as detectors in HILAL observations are expected to detect variations in the brightness of an object[2].

Observing the hilal is not an easy task. The young hilal will be close to the sun, giving the observer a short time to observe the hilal. In addition, observations made at dusk will make the Moon's light appear almost the same as the background sky. Astronomers have been studying the hilal since Babylonian times[3].

Schaefer has developed a model for the visibility of celestial objects at twilight[4]. This study opens up the possibility of conducting a contrast study of hilal (crescent moon) images and testing with more and more data.

This research opens up the possibility of conducting a contrast study of hilal (crescent) images and testing with more and more data.

This research includes an alternative method of processing DSLR Hilal image data (on each red, green and blue channel) using modules in the Python programming language. The data processing produces the brightness of the moon and the brightness of the sky. These two brightnesses are used to determine the value of the observed hilal contrast (C_{obs}), with the definition of Sultan[5]. In addition, the author also modelled the hilar contrast (C_{mod}) by utilizing the visibility equations of celestial bodies found in Schaefer's [6].

The observed hilal contrast values (C_{obs}) are matched with the hilal contrast model (C_{mod}) by determining the best model. The final result of this research is a limit model of the hilal contrast that can be observed at a certain elongation using the best parameters that have been obtained previously.

[2] J. E. Hoot, 'Photometry With DSLR Cameras', *Society for Astronomical Sciences* (2007), 67-72 (71).

[3] B. E. Schaefer, 'Astronomy and The Limits of Vision', *Vistas in Astronomy*, 36 (1993), 311-361 (339).

[4] Ibid, p. 311.

[5] A. H. Sultan, 'Best Time for the First Visibility of Lunar Crescent', *The Observatory*, 126 (2006), 115-118 (117).

[6] B. E. Schaefer, Op. Cit., p. 315-321.

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B. Research Method

In this research, the author used hilal image data as primary data and studies the brightness of celestial objects found in the literature to build a hilal contrast model. Based on the type of analysis used, this research involves quantitative research.

The data used in this study are 9 hilal images observed using portable telescopes and DSLR cameras. The images were taken on 31 August 2019 at the Astronomy Study Programme of Bandung Institute of Technology, starting when the sun set below the horizon. Detailed instrument specifications and observing procedures used in this study were presented by Faadillah[7].

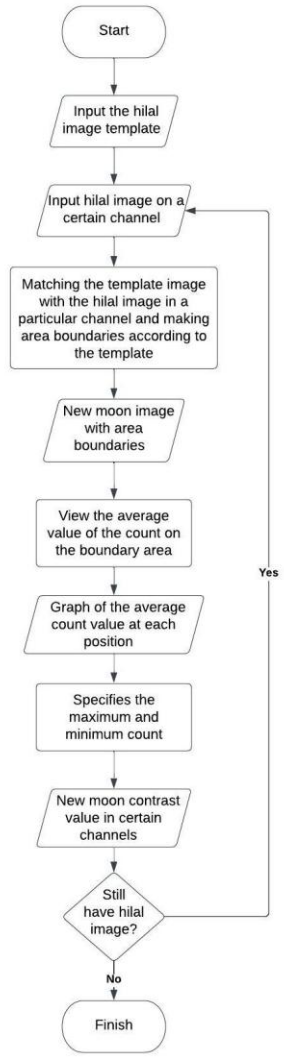

Figure 1. Flowchart of hilal image data processing.

The Hilal image is processed to determine the Moon Brightness Value and the Sky Brightness Value, resulting in the Hilal Observation Contrast Value (C_{obs}).Image processing is performed using the Python programming language, and the processing procedure follows the flowchart shown in Figure 1.

Each image is first decomposed into red, green and blue channels. Each channel

[7] M. Hasan Faadillah, 'Studi Kontras Citra Bulan Sabit dengan Kamera DSLR' (final project - unpublished, Institut Teknologi Bandung, 2020).

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is then measured for image brightness at a specific region boundary based on the template image used.

The use of area boundaries in the image is intended to ensure that the selected location gives almost the same state in each image. The image brightness value is generated by calculating the average number of counts at each pixel. The process and results of the image measurement are shown in Figure 2.

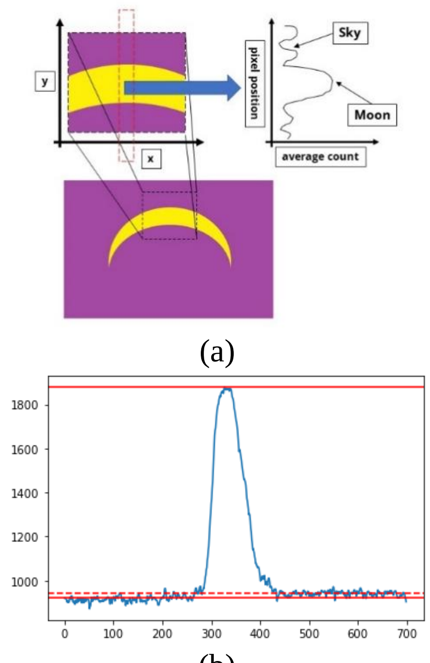

Figure 2. (a) Schematic data processing and (b) processing results.

The maximum value in the image is the magnitude of the Moon, (B_m) while the minimum value to the left of the image (solid line) is the magnitude of the sky (B_{sky}).Therefore, the contrast value can be determined from these two brightness values. The contrast value used in this study is Sultan's definition of contrast, found in equation (1)[8].

$$C = \frac{B_m - B_{sky}}{B_{sky}}, \qquad (1)$$

Each of the B_m and B_{sky} values obtained from each image was substituted into equation (1) and resulted in the observed contrast values (C_{obs}). Table 1 presents the results for each channel.

Table 1. The contrast value of observations on each channel

C_{obs} (*Red*)	C_{obs} (*Green*)	C_{obs} (*Blue*)
0.026	0.017	0.010
0.029	0.022	0.012
0.027	0.026	0.018
0.040	0.040	0.027
0.045	0.059	0.034
0.072	0.107	0.068
0.169	0.233	0.059
0.661	0.627	0.164
1.039	0.887	0.155

The calculation of the model uses several equations, namely the lunar brightness equation, the sky brightness equation and the contrast equation. Lunar magnitude can be expressed in magnitude (logarithmic) and foot-candles (linear). The relationship between magnitude (m_v) and foot-candles is given by the equation (2).

[8] A. H. Sultan, Loc. Cit

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$$m_v = -16.57 - 2.5 \log{(I^*)}\,, \quad (2)$$

$$I = I^* \times 10^{\frac{-kX}{2.5}}\,, \quad (3)$$

I^* is the brightness of the object without atmospheric influence and I is the brightness influenced by the atmosphere. k is the extinction coefficient and X is the air mass.

The approximation of the mass water value in the case of hilal observation is the mass water value for objects that have altitude (h) $< 20°$ close to the horizon derived by Rozenberg[9].

$$X = [\cos{(Z)} + 0.025\, e^{-11\cos{(Z)}}]^{-1}, \quad (4)$$

$$Z = 90° - h_m\,, \quad (5)$$

where Z denotes zenith distance.

Krisciunas and Schaefer derived a Moon brightness calculation model with an accuracy of between 8% and 23%[10]. The apparent magnitude of the Moon, m_v, is given by equation (6)[11].

$$m_v = -12.73 + 0.0026|\alpha| + 4x10^{-9}\,\alpha^4, \quad (6)$$

where α is defined as the Moon phase angle in degrees. The relationship between the Moon phase angle and the angular distance between the Moon and the Sun or elongation (ϵ) is $\alpha = 180° - \epsilon$.

The moon is an extended source that has a surface brightness (B_m) in nanoLambert units and has a relationship with the brightness without atmospheric influence (I^*).

$$I^* = 2{,}95 \times 10^{-7} \int B_m\, d\Omega\,, \quad (7)$$

where Ω is solid angle in steradians[12]. Using the definition of solid angle, the illuminated area of the Moon's disk is $(0{,}5\,\pi\, r^2) \times (1 + \cos{\alpha})$, where r the Moon's radius and using the Moon's angular radius $(d\theta)$ $\approx 15'$, the approximation of Moon's surface brightness value (B_m) is obtained,

$$B_m = \frac{I^*}{2{,}95 \times 10^{-7} \times \frac{1}{8}\left(\frac{15\pi}{60 \times 180}\right)^2 \times (1 + \cos{\alpha})}, \quad (8)$$

The above equation is an approximation value and ignores several effects including:

1. Refraction will change the altitude position (h).When near the horizon, the altitude will only change by a maximum of half a degree, so the brightness value will only change by a small amount.
2. The position of the moon used in this model is the centre. The calculation will be more accurate if the position chosen is the illuminated part of the moon. However, this can be ignored as the maximum difference in the position selected is only a quarter of a degree.

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[9] G. V. Rozenberg, , *Twilight: A Study in Atmospheric Optics*, (New York: Springer Science Business Media, 1966) p. 157.

[10] K. Krisciunas dan B. E. Schaefer, 'A Model of the Brightness of Moonlight', *Pub. Astron. Soc. Pacific*, 103 (1991), 1033–1039 (1036)

[11] B. E. Schaefer, Op. Cit., p. 320.

[12] Ibid, p. 319.

3. The distance between the Earth and the Moon is constantly changing. The Moon will appear larger and brighter when it is at perigee (the closest distance between the Moon and the Earth) than when it is at apogee (the farthest distance between the Moon and the Earth).

In the case of hilal observations made at twilight, the applicable sky brightness (B_{sky}) is the contribution of the sum of the night sky brightness (B_{night}) and the twilight sky brightness (B_{twi}). Simply approximating the sky brightness value with an accuracy of up to 20%[13].

$$B_{sky} = B_{night} + B_{twi} , \quad (9)$$

where B_{sky} has units of nanoLambert. B_{night} is defined as the brightness of the sky at night without the contribution of other light. The value has a value of 180 nanoLambert in the dark.

$$B_{night} = B_o \left[0,4 + \frac{0,6}{\sqrt{1 - 0,96 \sin^2 Z}}\right] 10^{-0,4kX} , \quad (10)$$

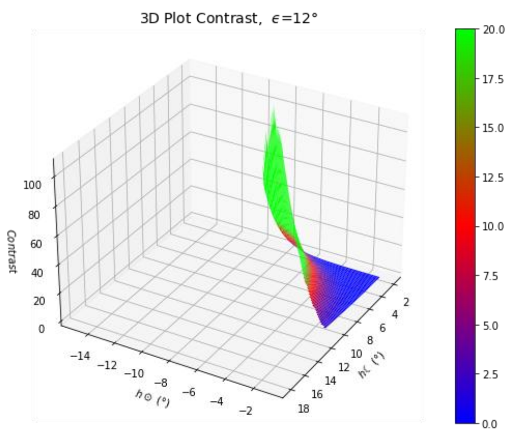
Meanwhile, B_{twi} is the brightness of the twilight sky, where there is still light (light and dark transition) due to the scattering of the Sun's light which has altitude of (h) below the horizon.

$$B_{twi} = M \left[10^{8,45+0,4h_s}\left(1 - 10^{-0,4kX}\right)\right] , \quad (11)$$

$$M = \max\left\{1, dex\left[\frac{\rho_s}{90^\circ} - 1.1\right]\right\}, \quad (12)$$

where ρ_s is the angular separation between the Sun and the sky under review, while h_s is the altitude of the Sun. The operation dex in astronomy is defined as $dex(y) = 10^y$.

Specifically in this study, the definition of the hilal contrast value used is the Sultan definition[14] mentioned in equation (1) or can be expressed as, $C = \frac{B_m}{B_{sky}} - 1$, by substituting the value B_m using equation (8) and the value B_{sky} using equation (9) the computation of the initial hilal contrast model will be obtained. Details about data processing and model computation can be found in Faadillah[15].



[13] Ibid, p. 321.

[14] A. H. Sultan, Loc. Cit

[15] M. Hasan Faadillah, 'Kontras Citra Bulan Sabit dengan Kamera DSLR: Pengukuran dan Pemodelan' (thesis - unpublished, Bandung Institute of Technology, 2023).

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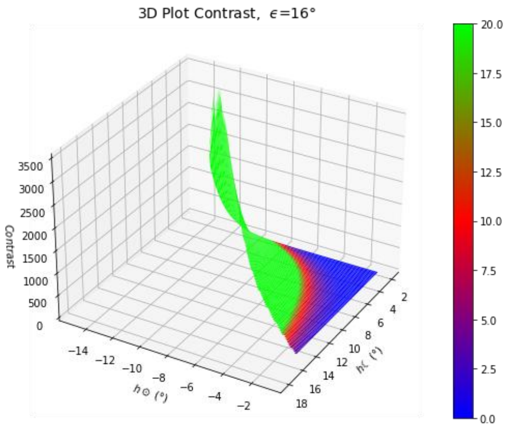


Figure 3. The results of the 3-dimensional plot of the model with a certain elongation (ϵ).This plot uses the values of $B_o = 180$ and $k = 0,4$.

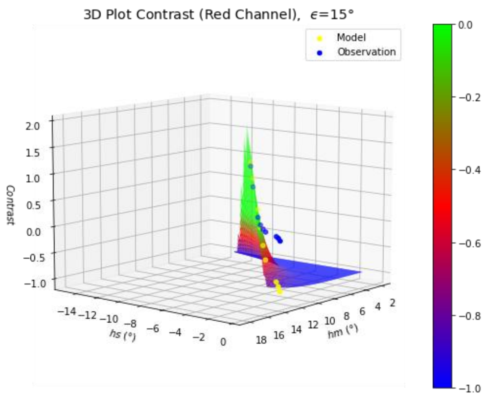
The computational result of the model is a 3-dimensional plot, $C_{mod} = C(h_s, \epsilon, h_m)$, contrast values that depend on the Sun's altitude (h_s), elongation (ϵ), and Moon's altitude (h_m) are presented in Figure 3. Figure 3 uses the values of $B_o = 180$ and $k = 0.4$, the plot shows that the contrast value tends to increase as h_m goes higher and h_s goes lower. The regions that have contrasting values also increase as the value of ϵ increases.

After obtaining the contrast model computation $C_{mod} = C(h_s, \epsilon, h_m)$ and processing data from the observation contrast C_{obs}, then determine the best contrast model parameters. The best contrast model parameters are the parameter values (B_o and k) that can make the contrast model (C_{mod}) close to the observation contrast value (C_{obs}). Parameters B_o and $k$are searched using an optimization algorithm (Generalized Reduced Gradient (GRG) Nonlinear). The best contrast model parameters B_o and $k$provide results on each channel in Table 2.

Table 2. Best B_o and k contrast model parameters on each channel.

	Red	*Green*	*Blue*
B_o	180,242	180,243	180,247
k	1,117	1,121	1,165

The resulting B_o and k parameters are used to create the best contrast model. The comparison of the contrast model $C_{mod} = C(h_s, \epsilon, h_m)$ and the observation contrastC_{obs} in each channel is visualized in Figure 4.



(a)

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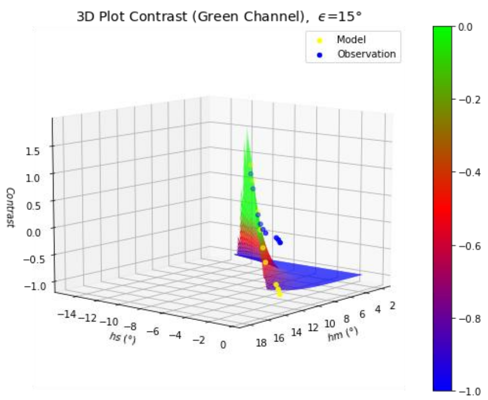
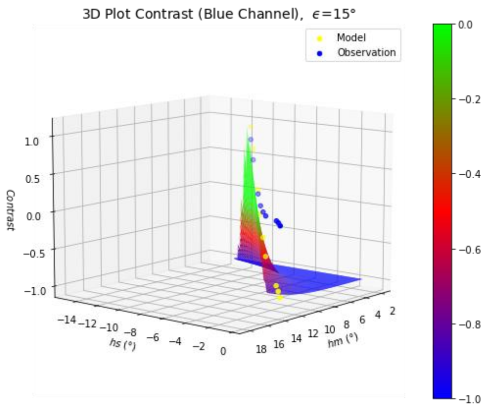


(b)



(c)

Figure 4. Visualization of the difference between model and observation data in each channel. (a) Red, (b) Green, and (c) Blue.

C. Results and Discussion

Results

The research results are in the form of a crescent-shaped image contrast threshold model. This model is in the form of crescent image contrast contours shown in Figure 5. The dashed line is the trajectory of the position of the Moon's elevation and the Sun's elevation, which move together with almost constant elongation.

Discussion

The crescent image contrast limit model is derived from a contrast model using the parameters B_o and k that successfully approximates the observed contrast value (C_{obs}). B_o and k are seen as very complex factors from the use of instruments and observation procedures, including weather conditions at the observation location. The values of B_o and k will be different, if different instrument specifications, observation procedures, and observation locations are used. Therefore, the resulting crescent image contrast limit model is only valid for certain specifications.

Visualizing the comparison of C_{obs} value and C_{mod} value in Figure 4, the C_{mod} value successfully optimizes the C_{obs} value in the maximum contrast value region. As for the minimum contrast value region, it has an error percentage of almost 40%. This is because parameters B_o and k are obtained using limited observation data. The parameter value will get better with more observation data. So that the C_{mod} value can optimize C_{obs} in all contrast value regions with a small percentage error.

In addition to using limited observational data, the equations used to build the model are approximations of values that ignore some things, so that the Moon brightness calculation model used has an

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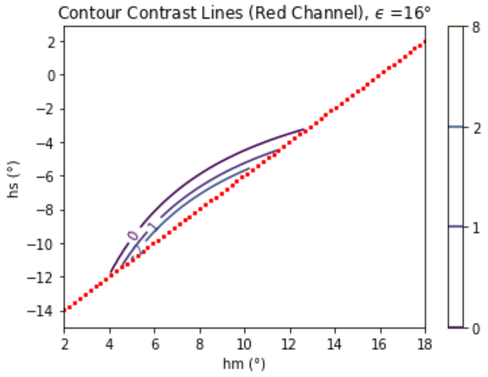
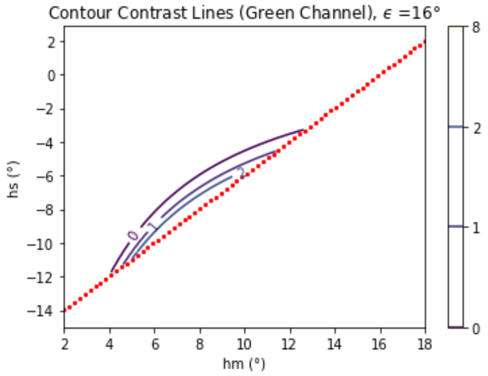
accuracy of between 8% to 23%[16] and the sky brightness calculation model used has an accuracy of 20%[17]. Therefore, high accuracy equations are needed to build a better model.

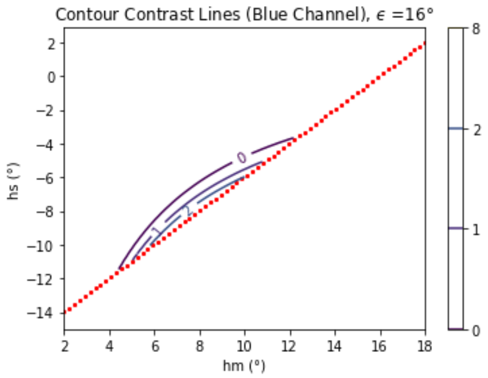
The definition of contrast used in this research is the definition of hilal contrast according to Sultan, $C = \frac{B_m}{B_{sky}} - 1$. The contrast will be positive if the Moon's brightness value is brighter than the sky's brightness value ($B_m > B_{sky}$). A positive contrast value indicates that the moon is observable. In addition, the contrast will also be negative if the Moon's brightness value is fainter than the sky's brightness value ($B_m < B_{sky}$). A negative contrast value indicates that the moon cannot be observed because the light is too dim. The contrast will be 0 if the Moon brightness and sky brightness values are the same, $B_m = B_{sky}$. At a contrast value of 0, the hilal cannot be observed yet because the brightness of the hilal is the same as the brightness of the sky. This value is the limit/transition of whether the moon can be observed or not.



(a)



(b)



(c)

Figure 5. Contrast contour values on each channel with fixed elongation. (a) Red, (b) Green, (c) Blue

Figure 5 shows the contrast contour values at $\epsilon = 16°$ using the B_o and k parameter values for each channel. The contrast value limit for the hilal to be observed is 0 and has a maximum value at certain h_m and h_s positions. The dashed line

[16] K. Krisciunas dan B. E. Schaefer, Loc. Cit.
[17] B. E. Schaefer, Op. Cit., p. 321.

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is the altitude trajectory of the Moon and Sun moving together with constant elongation. The Moon will move towards the horizon and the Sun will move away from the horizon. Along the trajectory (dashed line), the contrast value will show the minimum contrast limit for the moon to be observed and will have the maximum contrast (as the best contrast) before the contrast value drops to the contrast limit.

D. Conclusion

A crescent image contrast model viewed as a function of the Sun's altitude (h_s), elongation (ϵ), and Moon's altitude (h_m) or mathematically written as $C_{mod} = C(h_s, \epsilon, h_m)$ was successfully created by utilizing the equations of Moon brightness, sky brightness, and crescent contrast. This contrast model is then matched with limited observational data to obtain the best B_o and k parameter values. The obtained B_o and k values are used to model the limit of crescent image contrast under certain instrument specifications and observation procedures.

This research can be applied to those who are interested in testing the limit of contrast according to the specifications of the instrument and observation procedures used.

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