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Crescent Moon Visibility: A New Criterion using Deep learned Artificial Neural-Network

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Abstract
Many authors investigated the problem of the early visibility of the new crescent moon after the conjunction and proposed many criteria addressing this issue in the literature. This article presented a proposed criterion for early crescent moon sighting based on a deep-learned pattern recognizer artificial neural network (ANN) performance. Moon sight datasets were collected from various sources and used to learn the ANN. The new criterion relied on the crescent width and the arc of vision from the edge of the crescent bright limb. The result of that criterion was a control value indicating the moon's visibility condition, which separated the datasets into four regions: invisible, telescope only, probably visible, and certainly visible. This criterion was used on the dataset for ANN learning to compare its efficiency with the actual moon visibility events.

Keywords: Crescent Moon Early Sighting, Machine Learning, Neural Networks, Pattern Classification.

رؤية الهلال: معيار جديد باستخدام شبكة عصبية اصطناعية بالتعرّف العميق

زياد طارق علاوي
قسم هندسة الحاسبات، كلية الهندسة، جامعة بغداد، بغداد، العراق

الخلاصة
قام العديد من الباحثين بفحص مسألة رؤية الهلال الجديد بعد الاقتران حيث اقترحوا معايير عديدة حاولت علاج هذه المشكلة. يقدم هذا البحث معيارًا جديدًا لرؤية الهلال مبنيًا على آليات التعلم العميق وتمييز الأنماط باستخدام الشبكات العصبية الاصطناعية، حيث تم جمع مجموعة بيانات من مصادر مختلفة وتم استخدامها لتعليم الشبكة العصبية. يعتمد ذلك المعيار على عرض الهلال وقوس رؤيته اعتبارًا من طرفه اللامع، أما ناتج هذا المعيار فهو قيمة نظام تحدد ظروف رؤية الهلال حيث تم تقسيم مناطق الرؤية الى أربعة أقسام: غير مرئي، التلسكوب فقط، مرئي احتمالًا، مرئي بالتأكيد. وتم استخدام هذا المعيار على مجموعة بيانات خاصة بالشبكة العصبية لمقارنة كفاءته مع أحداث رؤية الهلال الواقعية.

1. Introduction

Building a criterion for early visibility of the new crescent moon has been an essential astronomical issue investigated by many ancient scholars and scientists. Since the era of the Babylonians in the 6th century BC, there have been many criteria for moon sight visibility. For

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instance, the Babylonians used moon age and lag to predict the possibility of seeing the crescent moon. At the dawn of the Islamic golden age from the 8th through the 11th centuries CE, Muslim scholars contributed many criteria to moon sighting. Most of them were mentioned in [1]. That article covered about a millennium of research concerning this topic. In [2], the author mentioned the most recent results of moon sighting criteria such as Fotheringham [3], Maunder [4], Danjon [5], Bruin [6], McNally [7], Ilyas [8], Fatoohi [9], Schaefer [10], Yallop [11], Al-Mostafa [12], Odeh [13], and Sultan [14].

In recent years, the growth of machine learning (ML) technologies has led to several significant technological advances. ML algorithms have demonstrated their efficacy in various disciplines, including pattern recognition. Many researchers use artificial neural networks (ANNs) to find patterns because they can analyze and understand patterns hidden in the data they perceive. They can also self-train with new data to improve their results and correct mistakes. They can predict the outcome of every input not in the datasets, which makes the ANNs flexible in case some data is missing or wrong. Numerous studies on ML using ANNs have been conducted to recognize and classify patterns [15, 16, 17, 18].

This study proposed a new criterion based on the arc of vision and the crescent width. This criterion is based on the results of training an artificial neural network to recognize patterns. The proposed ANN in [2] was used to develop a new and straightforward moon sight criterion based on the borderlines arising from the ANN's overall response. Criterion design was performed after training the ANN with the datasets that came from observational data provided by Schaefer [10], Yallop [11], Odeh [13], and Alrefay et al. [19]. The proposed criterion was tested with the observational dataset and gave promising results. Furthermore, the world record for the youngest crescent moon was simulated and compared with an observational region-colored world map.

This study is divided into six sections: Section 2 illustrates the associated research work. Section 3 shows the essential parameters for moon sighting, along with the training dataset. Section 4 demonstrates the outcome of ANN training and discusses the obtained results. Section 5 proposes and tests the moon sighting criterion using the world's youngest, naked-eye observed crescent moon. Section 6 concludes this study.

2. Related Works

Recent studies have proposed moon sight criteria, such as Hassanzadeh [20], who found that the Danjon's limit should be 5°, agreeing with McNally. Also, he claimed that the crescent, whose elongation was less than Danjon's limit, could be seen through a 120 mm telescope. Utama et al. [21] used $ARCL$ and $ARCV$ to develop a criterion for moon sighting using an observation dataset held in Malaysia. He found that the minimum $ARCV$ was 8.4° and the minimum $ARCL$ was 7.1°. Naz Ahmed et al. [22] used circular regression models to establish a criterion for moon sighting and found that the minimum parameters were 7.28° for $ARCL$, 3.74° for $ARCV$, and 3.39° for moon latitude from the horizon.

The author proposed a pattern-recognizer ANN in his article [2] to predict the moon sighting conditions by training the ANN using a dataset of 578 collected results of real moon sighting campaigns and observations. The ANN managed to learn the dataset with an accuracy of 72% towards building a standard Hijri calendar for Iraq [2].

3. Research Method

3.1. Moon Sighting Elements

As discussed earlier, many criteria use different parameters. The most important parameters are listed below and illustrated in Figure 1:

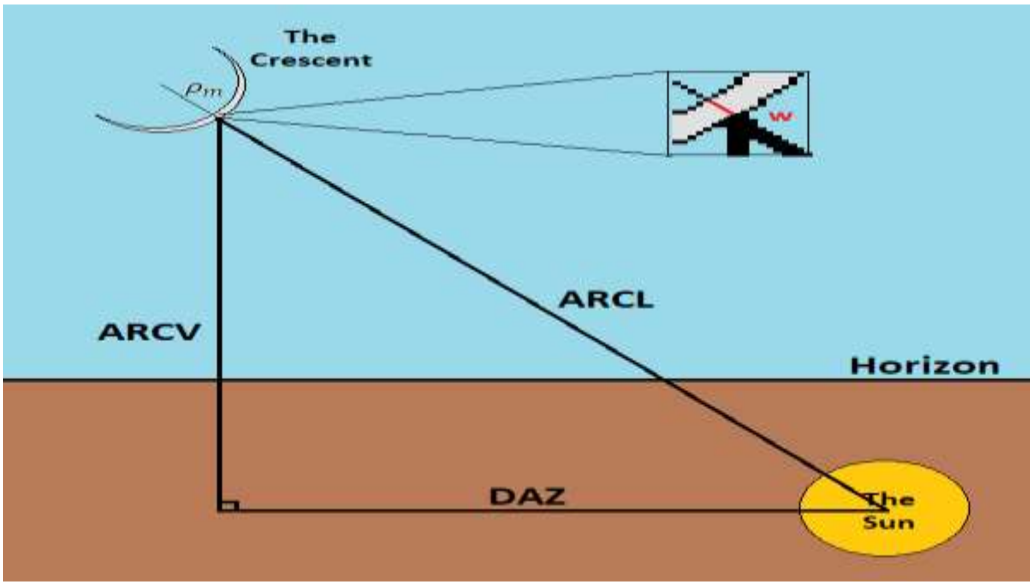


Figure 1: The essential parameters are presented according to the horizontal coordinates of the moon's nearest limb relative to the sun.

1- Arc of Light ($ARCL$): is the arclength between the sun and the bright limb of the moon, measured in degrees.
2- Arc of Vision ($ARCV$): is the difference between the altitude of the center of the sun and the altitude of the bright limb of the moon, measured in degrees.
3- Azimuthal Difference (DAZ): is the difference between the azimuth of the sun and the azimuth of the bright limb of the moon, measured in degrees along the horizon.
4- Radius of the moon's disk (ρ_m): is the arclength between the center of the moon's disk and the center of its bright limb, measured in arcminutes and varies between 14' at the moon's apogee through 17' at the moon's perigee.
5- Crescent Width (w): is the width of the moon's illuminated fraction from its central limb s measured in arcminutes. Its value depends on the radius of the moon and the fraction of illumination, which depends on the $ARCL$.

There is a general formula relating $ARCL$, $ARCV$, and DAZ as follows:

$$\cos ARCL = \cos ARCV \cos DAZ \quad (1)$$

For $ARCL$ less than 20°, one could use a more straightforward formula:

$$ARCL^2 = ARCV^2 + DAZ^2 \quad (2)$$

The crescent width is calculated using the equation below:

$$w = \left(1 - \cos\left(ARCL + \frac{\rho_m}{60}\right)\right)\rho_m \quad (3)$$

If $ARCL$ is less than 20°, that equation can be simplified with accepted accuracy:

$$w = \left(\frac{ARCL + \frac{\rho_m}{60}}{81}\right)^2 \rho_m \quad (4)$$

The parameters $ARCL$, $ARCV$ and w will be the training parameters of the ANN in the same manner as in [2].

3.2. ANN Architecture

The architecture of the ANN is depicted in Figure 2.

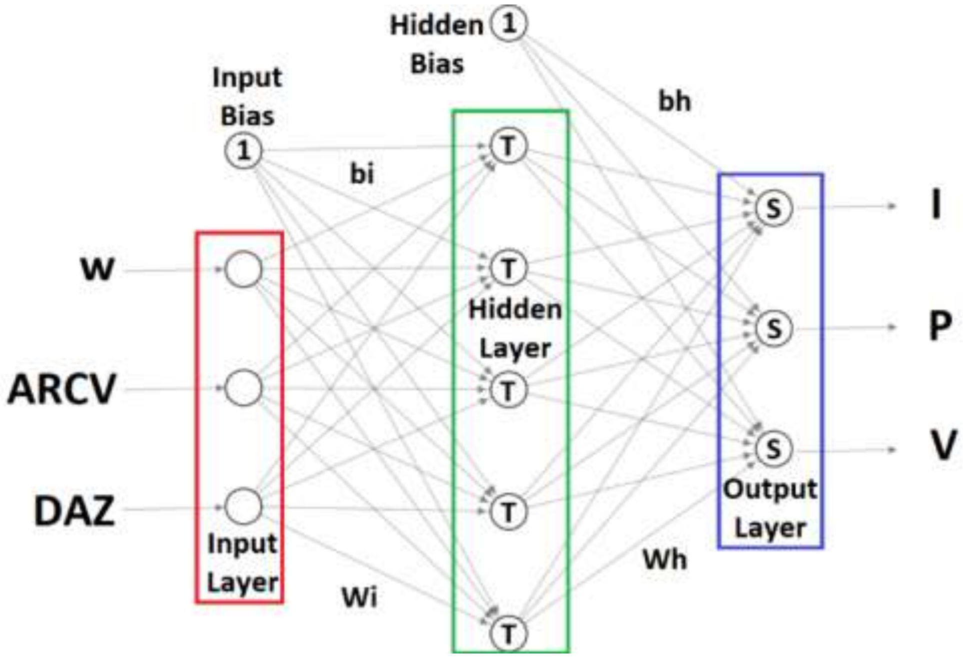


Figure 2: ANN architecture [2].

The ANN was built in three layers. The input layer (within the red box) consists of three input neurons. Each receives a single input parameter and is connected to the subsequent layer using weight and bias matrices.

The hidden layer (inside the green box) consists of five neurons that receive scaled input values. The letter (T) in the picture represents the tansig( ) function, and the activation function of the hidden layer [2]. All hidden neurons are interconnected with output neurons using weight and bias matrices.

The output layer (within the blue box) has three neurons. Output neurons represent the lunar observational zones. The letter (S) in the picture represents the softmax( ) function, the activation function of the output layer. If the result of the output neurons was unity or close to unity, its output will cohere with the observed outcome.

The ANN was trained through the Bayesian Regularization backpropagation (BRA) algorithm [2].

3.3. Dataset Used in ANN Training

Visibility characteristics of the crescent moon were computed at the best time when the altitude of the sun was 4° below the horizon on the day of observation, according to Ilyas [8]. The significant moon parameters were computed (the age of the moon Age, the width of the crescent w, $ARCL$, $ARCV$, and DAZ) [2]. Observational data (Sight Date, Longitude, and Latitude) [2], and observed crescent moon conditions were used to derive the parameters. These aims were utilized through the learning of the ANN.

The dataset used for ANN training consisted of 1024 entries obtained from Schaefer and Yallop (S), Odeh (O), and Alrefay (A). Table 1 presents a subset of the data set.

Table 1: A provided sample of the Observation Dataset by several authors

C	H. Y.	M.	Sight Date	Best Time (UT)	Lat	Lon	Age	W	ARCL	ARCV	DAZ	SOA	A
O	1422	12	12 February 2002	16:30	43.9	18.4	8.8	0.08	5.58	0.85	5.51	I	I
A	1435	10	27 July 2014	16:10	26.35	43.95	17.44	0.18	8.77	1.6	8.64	I	I
O	1423	2	13 April 2002	19:20	30.5	−9.7	23.96	0.26	10.57	9.14	5.33	I(T)	P
S	1361	12	8 December 1942	21:48	40.7	−74	19.8	0.34	11.32	9.78	5.74	V(F)	P
A	1419	7	21 October 1998	14.37	24.6	46.45	28.44	0.37	12.68	11.37	5.63	N	V
S	1393	2	5 March 1973	23:53	40	−85	23.75	0.38	12.24	12.2	0.97	V(V)	V

This table has 14 columns; its parameters are identical to the table in [2]. The exception is for the first column, which contains the letter (A) for Alrefay et al. dataset.

All records in the dataset with a crescent width of more than 2' (illumination > 6% or $ARCL$ > 30°) were excluded since the moon could not travel more than 30° in just two days, which are the sighting days of the lunar month.

The records in columns 9, 11, and 12 were utilized for ANN training to match column 14. Figure 3 shows a two-dimensional representation of the distribution of the dataset prior to ANN training ($ARCV$ vs. w). Every pixel refers to a separate observation and its color refers to the outcome of an experiment.

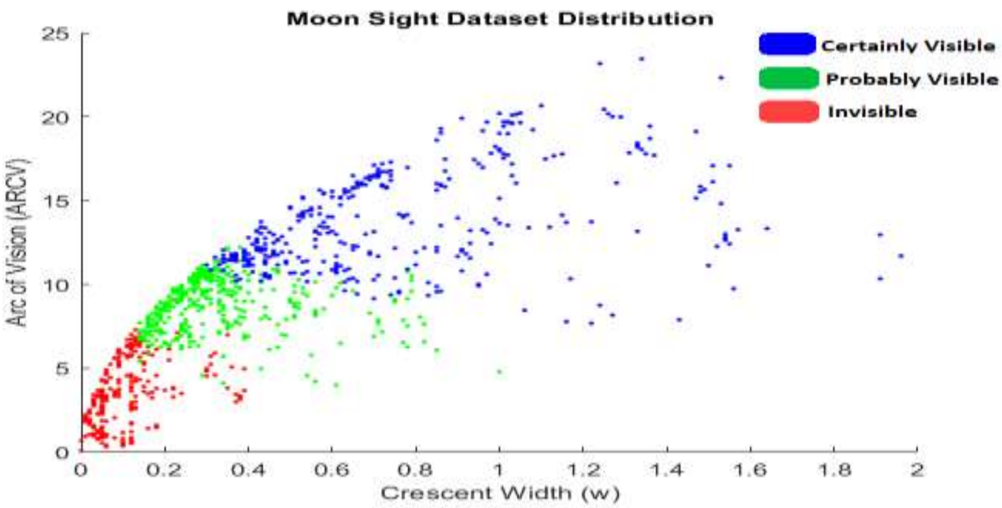
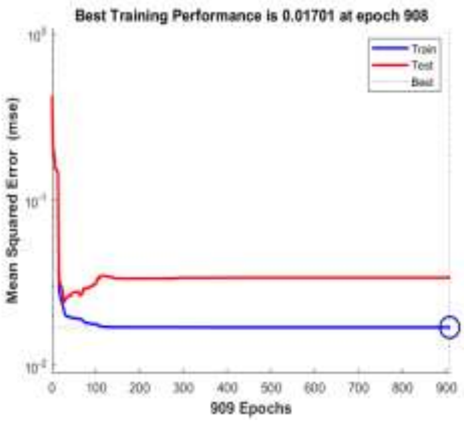


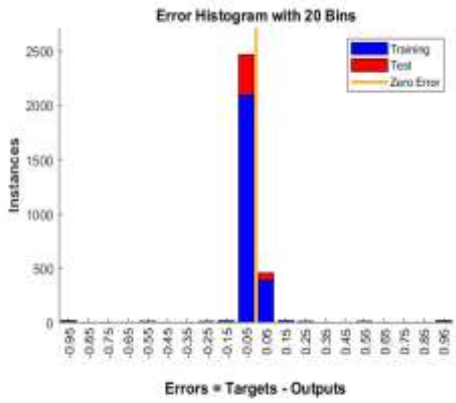
Figure 3: Training dataset distribution.

4. Results and Discussions

The 1024-entry dataset was utilized for training the ANN pattern recognizer using MATLAB® R2020b. After more than 900 training epochs across the whole procedure. The MSE after the training phase was 0.0107. Figure 4 depicts the training outcome.

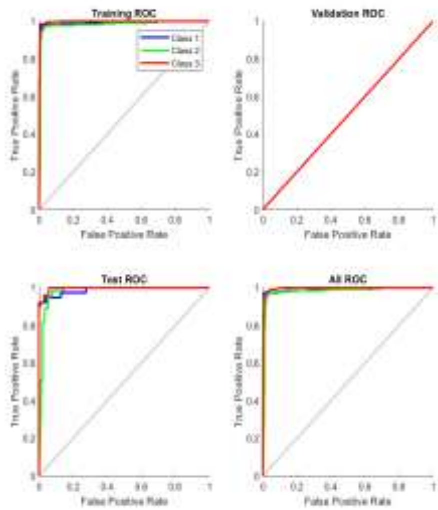


(a)



(b)

(c)



(d)

Figure 4: ANN training results: (a) MSE training = 0.0107; (b) Histogram of the Error; (c) Actual/Desired Output Confusion Table; (d) ANN ROC.

The training outcomes indicate that the ANN has learned the observation dataset remarkably (96.3%). Only 38 observations have deviated from the prescribed sighting conditions.

Figure 4a depicts the ANN's convergence progression. The inaccuracy reached its lowest point during epoch 908. Figure 4b depicts the difference between the actual and desired output, almost 0% for most ANN output values. In Figure 4c, the confusion tables reveal that 986 observations were accurate. However, 16 observations were overstated whereas the remaining 22 observations were undervalued. Figure 4d shows that the ANN has learned the three areas successfully.

A test dataset was produced to evaluate the pattern recognizer ANN efficiently, similar to the generated test dataset in [2], except for the crescent width which ranged between 0 through 2 rather than 4. Figure 5 provides a thorough examination of the observation dataset.
From the results of the training, one can find that the minimum crescent width for naked-eye visibility was 0.12' ($ARCL$ was around 6.86° or elongation was around 7.00°), which confirms Danjon's limit. The lowest crescent width for certain naked-eye visibility was 0.33' ($ARCL$ was about 11.55° or elongation 11.70° if DAZ=0), confirming Maunder's conclusions. If DAZ was

particularly wide, the width of the crescent may exceed 0.32' and be invisible to the human eye. When the crescent width w is greater than 1.2' ($ARCL$>22°), it is evident that the moon will be visible with the naked eye if $ARCV$>4°, confirming Ilyas's findings.

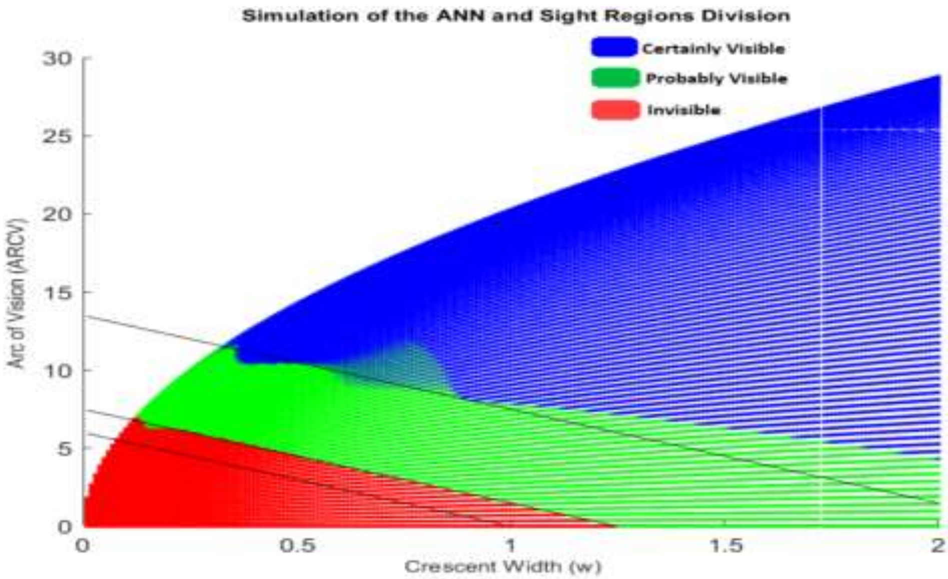


Figure 5: Pattern Recognizer ANN performance for arbitrary data.

5. Building a Proposed Criterion for Early Moon Sighting

Towards developing a new moon sight criterion using the results of the ANN, equations of the borders of the visibility regions were derived. As in the figure above, there are four regions: the red region represents two possibilities: 'invisible' and 'telescope only' conditions; the green region represents the condition of 'probably visible' by the unaided eye; the blue region represents the 'certainly visible' condition.

The formula of the q-test criterion was deduced using interpolation with a minimum mean-square error condition, and the final result of the criterion is shown in equation 8 and Table 2.

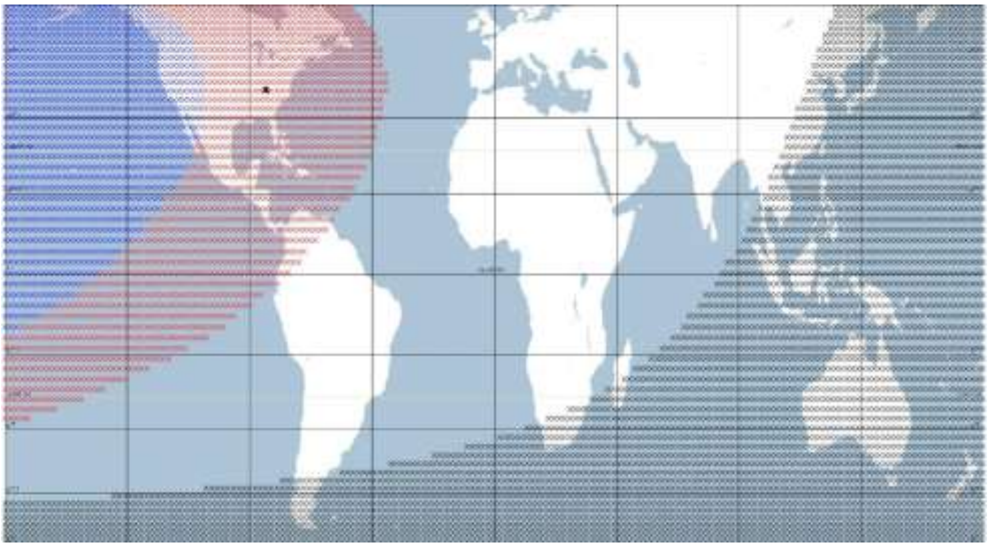
$$q_A = w + \frac{ARCV}{6} - \frac{5}{4} \quad (8)$$

Table 2: Crescent conditions for the proposed criterion according to the author

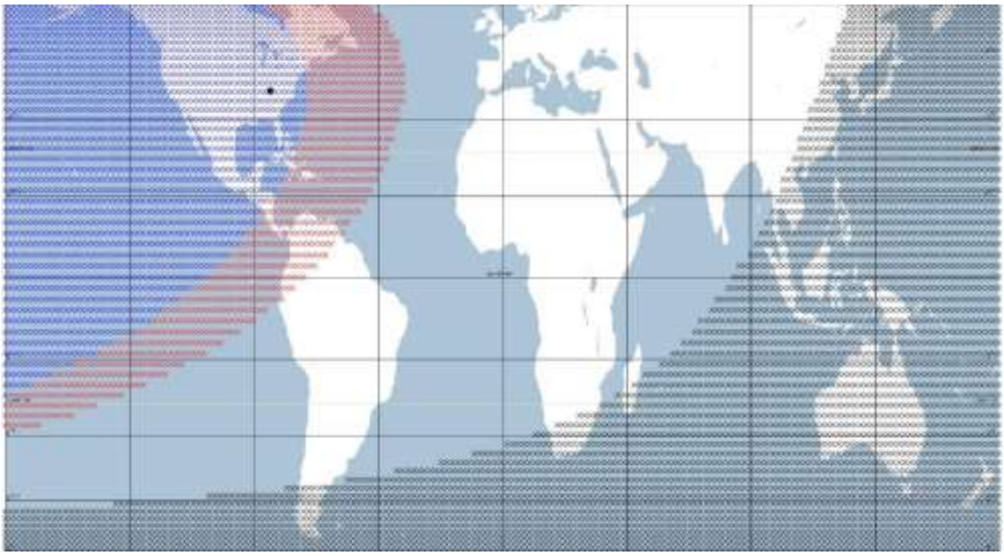
q **Value**	**Crescent Condition**
$q_A \geq 1$	Certainly Visible by the naked eye
$0 \leq q_A < 1$	Probably Visible by the naked eye
$-0.25 \leq q_A < 0$	Seen by Telescope Only
$q_A < -0.25$	Invisible

This criterion was tested on the event of the youngest and smallest elongated crescent moon observed by the naked eye. John Pierce observed it at Collins Gap, Tennessee, USA, on 25 February 1990 [10] [23].

Figure 6 shows the moon sight regions of the world on that day using the criterion of Odeh [13] and the criterion of the author. The observation site is marked in a black dot.



(a)



(b)

Figure 6: Moon sight regions of the world on 25 February 1990: (a) according to Odeh's criterion; (b) according to the author's criterion.

The black-shaded area on the world map indicates that the moon had yet to conjunct with the sun or had set before the sun, making it impossible to observe the moon in that region. The non-shaded area indicates that the crescent was invisible because its arclength was below McNally's limit (5.5°). The red-shaded area implies that the crescent moon could be seen by telescope only because its arclength was below Danjon's limit (7°). The blue-shaded region refers to the possibility of moon sighting by the naked eye or binoculars, and the green area confirms the certain unaided-eye visibility of the crescent moon. In Figure 6-a, the black dot was in the red region (Telescope Only) although the crescent was seen by the unaided eye. This implied that Odeh's criterion was inaccurate regarding that observation, whereas the black dot was located in the blue region (Probably Visible) in Figure 6-b near the borderline with the red region, i.e., the naked eye barely saw the moon. This means that the criterion of the author confirms that observation result. The $ARCV$ was 7.25°, and the crescent width was 0.14'. If Equation 8 is applied, the q value will be 0.1, confirming the moon sight's hardship.

Figure 7 shows the shape of the crescent at the time of observation.

Figure 7: Shape and orientation of the moon at Collins Gap, Tennessee, on 25 February 1990.

The observation was carried out at a latitude of 1.5 km above sea level, which is why the naked eye could see the moon, although the crescent was too thin to be observed because the sky became clearer at higher altitudes.

6. Testing the Criterion Against other Challenging Sighting Records

6.1. Observations performed by A-Mostafa in the KSA:

Al-Mostafa in [24] claimed a positive observation of the youngest crescent moon using a telescope. The first observation was held near Riyadh, KSA on 14 March 2002. Figure 8 shows the moon sight regions of the world on that day, indicating the place of the sight in a black dot.

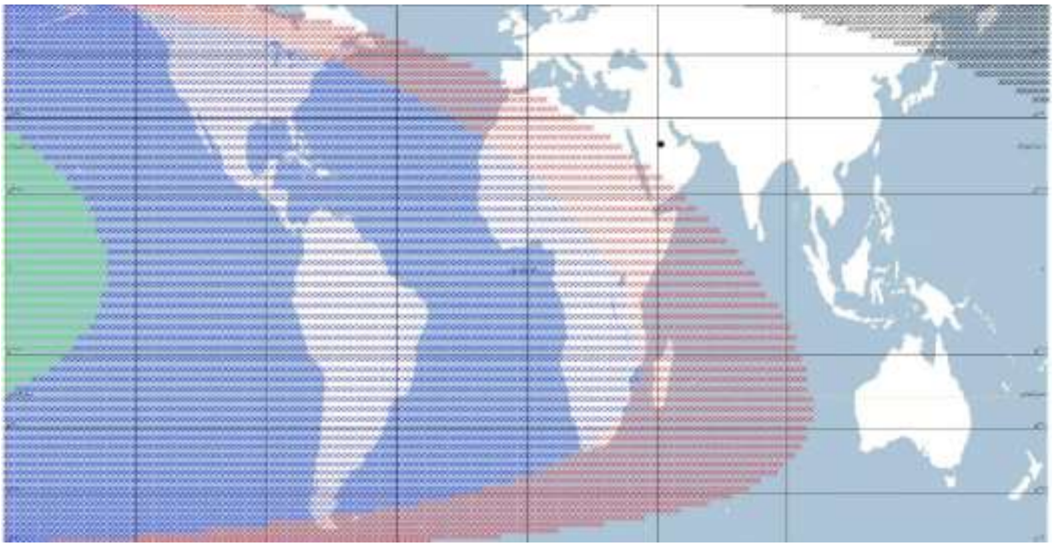


Figure 8: Moon sight regions of the world on 14 March 2002.

The black dot is located in the (Invisible) region close to the borderline with the (Telescope Only) region. This sight was fictitious as we will see in the next observation.

The second observation which was also claimed by Al-Mostafa in [25] was held on a top of a 1900m mountain near Medina, KSA on 14 September 2004. Figure 9 shows the moon sight regions of the world on that day, indicating the place of the sight in a black dot.

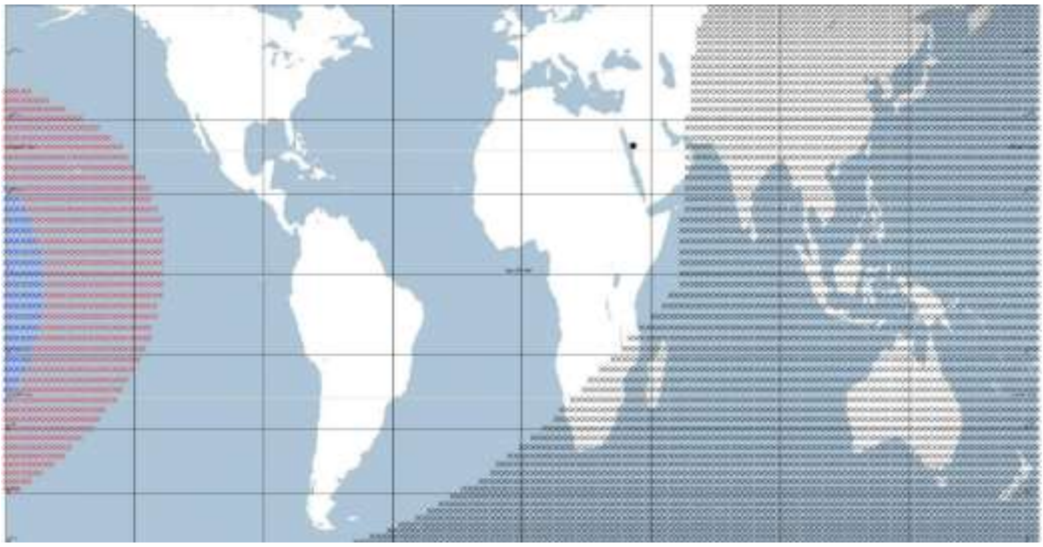


Figure 9: Moon sight regions of the world on 14 September 2004.

The black dot is located in the (Invisible) region near the border of the (Impossible) region. That observation was held after 1 hour only from the geocentric conjunction. The moon was 1° above the horizon at the time of sunset, and its elongation was just 2.6°. Al-Mostafa and his colleagues claimed that they saw the moon with their bare-naked eyes immediately after sunset and before seeing it through the telescope.

However, this observation was fictitious as the first one because they saw the whole disk of the moon slightly illuminated by the reflected light from the earth (the effect of "Earthlight"), and the thin atmosphere at that high altitude helped in that observation. They did not see any illuminated fraction of the crescent moon, because the moon cannot reflect any light from the sun to the earth at elongations below 5.5° [7].

6.2. Observations of the Crescent Moon for the beginning of Ramadan 1444 A.H.:

On 21 March 2023 17:24 UTC, a geocentric conjunction occurred which marked the beginning of a new lunar cycle dedicated to the holy month of Ramadan, 1444 AH. An observation was held near Razzazah lake, Karbala, Iraq, on the next day. The probability of naked-eye visibility was 86% (Probably Visible) according to the author's criterion, and the illuminated fraction of the moon was 1%. However, it was confirmed that the crescent was seen by naked-eye after the sunset, as well as most of the observation sights in the Arabian Peninsula, whereas the author could not observe it in Baghdad due to the city's pollution and the presence of clouds. Figure 10 shows the moon sight regions of the world on 22 March 2023 indicating the place of the sight in a black dot.

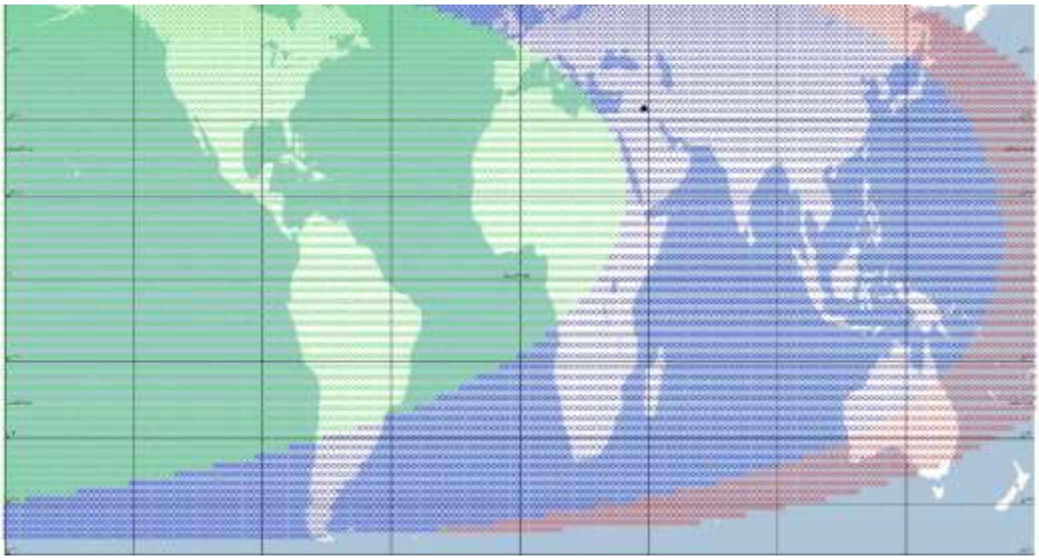


Figure 10: Moon sight regions of the world on 22 March 2023.

8. Conclusions

Implementing a moon sighting criterion has been of interest for about a century. Many advancements were accomplished in this area. In this study, a new criterion was proposed, designed through deep learning using ANN. The result of this criterion was promising to predict the possible conditions for moon sighting, providing the clarity of the sky. This criterion needs more observation records to prove its robustness and efficiency for prediction.

8. Acknowledgements:

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