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Detection of Qur'anic Ikhfa Patterns in Digital Images Using Binary Similarity Distance Measures (BSDM) with 3W-Jaccard Formula

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ABSTRACT

Recitation rules in the Qur'anic script form various visual patterns. One of the selected rules for this study is the Ikhfa pattern. Ikhfa is a recitation rule pronounced subtly when the nun sukun (نْ) or tanwin (ـٌ ,ـٍ ,ـً) is followed by one of 15 specific letters, namely: ta' (ت), tsa' (ث), jim (ج), dal (د), dzal (ذ), za' (ز), sin (س), syin (ش), shad (ص), dhad (,yduts siht nI .(ك) fak dna ,(ق) faq ,(ف) 'af ,(ظ) 'ahz ,(ط) 'aht ,(ض the primary challenge is the difficulty of automatically detecting the Ikhfa pattern in both digital and printed Qur'anic texts. This challenge arises from the subtlety of the recitation rule, which makes it difficult to distinguish from other recitation patterns. To address this, the Ikhfa pattern is detected using image processing techniques, and pattern classification is performed using the Binary Similarity and Distance Measures (BSDM) method. The results indicate that the pattern detection system, employing BSDM with the 3W-Jaccard formula, achieved a detection rate of 83.84%. This suggests that the 3W-Jaccard formula is an effective approach for detecting similar recitation patterns. One advantage of the 3W-Jaccard formula is its ability to recognize patterns with a relatively small amount of reference data, making it highly suitable for implementation in the detection system.

I. Introduction

Acoourding to Quraish Syihab, the Qur'an literally means perfect reading. Since humans first learned to read and write several hundred years ago, there has been no literature that can match the pure interpretation of the Qur'an. The Qur'an combines letters and words to create a statement that is neatly arranged so that it is called the Qiraah collection. The Qur'an is the lafadz of mashdar qira'a which comes from qara'a which means to read. "The word of Allah which has miraculous value which was revealed to the prophet Muhammad SAW through the intermediary of the Angel Gabriel as, which is written in the mashahif, narrated to us mutawatir, which is read as worship, which begins with the Al-Fatihah the An-Nas letter" is the definition of the Qur'an agreed upon by scholars [1].

The ability to read the Qur'an should be the first step in making the Qur'an a guide to life [2]. Linguistically, the Qur'an means something that is read or the act of reading. Reading the Qur'an correctly is an obligation for reciting the Qur'an in accordance with phonetic standards [3].

One of the tajwid rules to consider when reading the Qur'an is dead nun (نْ) or tanwin (ـٌ , ـٍ , ـً), which is divided into several categories, one of which is the rule of Ikhfa. Ikhfa means concealing certain letters in the following letter. Haqiqi refers to actual concealment. Ikhfa haqiqi means softly pronouncing the sound of the dead nun (نْ) or tanwin (, ـٍ , ـً ـٌ). When the dead nun or tanwin meets one of the Ikhfa haqiqi letters, the Ikhfa reading occurs. The correct way to pronounce it is to expel the sound of the dead nun (نْ) or tanwin (ـٌ , ـٍ , ـً) from the nasal cavity until it sounds faint (like ng), then hum for two characters before transitioning into the next letter [4].

Ikhfa is a rule of recitation where the sound is pronounced softly when dead nun (نْ) or tanwin (ـٍ , ـٌـًـ , -) meets one of its 15 letters: ta' (ت), tsa' (ث), jim (ج), dal (د), dzal (ذ), za' (ز), sin (س), syin (ش), shad (ص), dhad (ض), tha' (ط), zha' (ظ), fa' (ف), qaf (ق), and kaf (ك). Understanding the rules of tajwid is important so that those who recite the Qur'an can read its verses correctly and in accordance with its teachings [5].

Every person who reads the Qur'an typically refers to a teacher who is an expert in makhraj and tajwid, known as an ustadz. The ustadz will monitor every rule being read and correct any mistakes in pronunciation. However, learning practices can often pose challenges. Unclear pronunciation makes it difficult for many students to understand and apply the rules of tajwid, especially the rule of Ikhfa. Traditional tajwid learning often requires direct supervision from a teacher skilled in tajwid, which is sometimes difficult to find in certain areas. Modern technology offers great potential to overcome this challenge, one of which is through the use of artificial intelligence (AI) technology and digital image processing [6].

With the rapid advancements in AI and image processing, object detection technologies like the Binary Similarity And Distance Measures (BSDM) method have shown excellent results in various applications, including text pattern recognition and small object detection. The Binary Similarity And Distance Measures (BSDM) method includes various formulas, such as 3W-Jaccard, Sokal Sneath, Sokal Michener, Bray & Curtis, Cosine, Mountford, Pierce, and other formulas to calculate the similarity between two objects based on binary characteristics and their similarity. This method is highly effective in ikhfa patterns, which require precision in identifying small and complex letters in the text of the Qur'an [7].

Using Binary Similarity And Distance Measures (BSDM), Ikhfa pattern identification can support independent tajwid learning, enhance pronounciation accuracy, and provide a more flexible learning experience. Recent research indicates that the BSDM method can detect Wajibul Ghunnah tajwid patterns in Qur'anic images, archieving an accuracy rate of 80 percent. The Sokal & Sneath formula whitin the BSDM method, as used in this study, demonstrates the ability to detect patterns with a relatively small set of references, making it suitable for integration into automated systems. Implementing an Ikhfa pattern detection system through images using BSDM can significantly improve the efficiency and accuracy of independent tajwid learning. It is hoped that with this system, users will be able to read the Qur'an corerectly without relying solely on teachers [8].

II. METHOD

This study investigates the use of Binary Similarity and Distance Measures (BSDM) to detect the Ikhfa pattern in Qur'anic texts, sourced from digital Qur'an resources found online. The dataset consists of 7 randomly selected pages from Surah Al-Baqarah, stored in bitmap (.bmp) format. These images were carefully chosen to represent a variety of Ikhfa patterns, ensuring diversity in the dataset to aid in system testing and training.

The Principle of BSDM involves comparing binary vectors representing the characteristics of images. Each image is processed to produce a numerical representation in the form of a vector that encodes the binary pattern of the image. BSDM then calculates the similarity between two vectors by measuring the binary distance or pixel similarity between the two patterns. In the case of the Ikhfa pattern, BSDM utilizes local information from neighboring pixels to determine whether two images are similar, based on the comparison of binary features. The formulas used in BSDM, such as 3W-Jaccard, enable the system to effectively measure the closeness between two patterns, even with a limited amount of data.

The choice of BSDM is motivated by several key reasons. First, the method is particularly well-suited for small datasets, like the one used in this study. Other methods, such as CNN, SIFT, or HOG, typically require larger datasets and more computational resources. BSDM also offers high interpretability, allowing the detection results to be more easily understood and analyzed, while deep learning techniques tend to be more complex and require deeper expertise. Additionally, BSDM is more computationally efficient, making it a better fit for systems with limited resources.

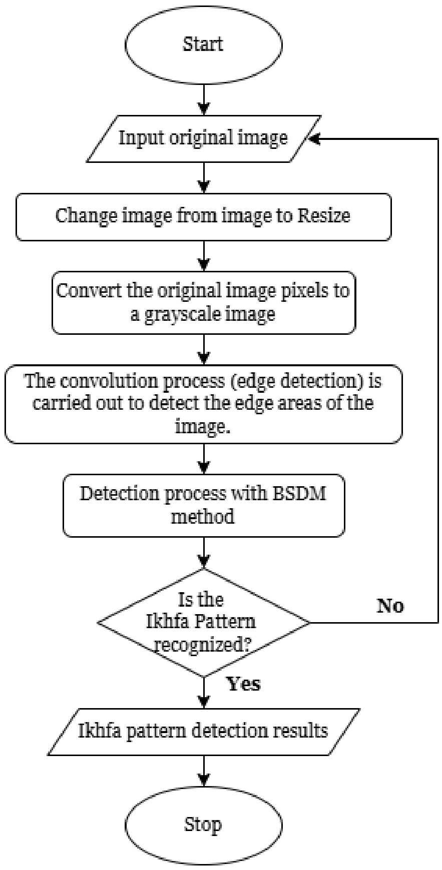


Figure 1. Overall System Flowchart

A. Image Processing

Digital image processing takes many forms, including low-level operations. During low-level operations, the image is transformed into one that is ready for modification [9]. The image structure is changed as a whole, producing a new image, vector, or single value. At this level, image operations are performed directly on a pixel-by-pixel basis, such as generating, warping, and histogramming [10]. At the intermediate level, the image is transformed into a data structure [11]. The image structure is partially altered because these operations only extract items that are considered important for processing, or ROIs (Regions of Interest). Area labeling, motion analysis, and others are examples of such operations [12].

A digital image represented by a function f(x,y), which consists of discrete brightness levels at specific spatial coordinates [13]. The light reflected from an object is what forms the image. The function f(x,y) has two key components:

1. Illumination (i(x,y)): this referes to the strength to the light source surrounding the object.
2. Reflectance (r(x,y)): this represents the amount of light the object reflects into our view.

Both i(x,y) and r(x,y) are functions, and they can be combined to form the overall image function f(x,y) through multiplication [14].

B. Grayscale Image

A grayscale image is an image with gray tones consisting of various shades of gray, created by mixing black and white [15][16]. Each shade is represented by an integer value ranging from 0 to 255, where 0 represents black, 255 represents white, and the values in between represent various intensities of gray [17]. The grayscale range typically includes 256 possible intensity levels. Often, 24-bit (RGB) color images are converted to grayscale images before undergoing further processing [18]. This conversion is done to simplify image manipulation, as it allows for operations to be performed on a single channel (intensity) rather than separately on each of the tree color channels (red, green, and blue) of the original image [19]. To further simplify a color image, which consists of three layers: R-Layer, G-Layer, and B-Layer. Ther first step in image processing is to convert it into a grayscale image. This approach allows the subsequent steps to still be treated as processes involving three layes, but now based on intensity values rather than color components [20].

C. Color Image

The color image, also known as a true color image or RGB image, is composed of tree color components: R (red), G (green), and B (blue). These components, when combined, create a wide spectrum of colors. Each color component is represented by 8-bits, with values ranging from 0 to 255 [21]. As a result, the total number of colors that can be represented is 16, 581, 575, or 255 x 255 x255 [22]. This color model can be describe as a three-dimensional vector space, commonly used in mathematics. In this context, x, y, and z are used to represent the coordinates of the color space. For example, a vector can be written as r = (x, y, x), where the RGB components of an image serve as the replacements for these coordinates [23].

For instance:

1. A color can be represented as RGB (30, 75, 255).
2. Black is represented as RGB (0, 0, 0).

D. Edge Detection Convolution Using Sobel

The term convolution refers to repeatedly applying a function to the output of another function. In the context of image processing, convolution is used to extract features from the input image [13]. It result in a linear transformation of the input data, based on the spatial information present within the image [24].

The sobel operator is a specific type of convolution used for edge detection. It calculates the gradient of the image by applying a kernel, typically of size 3x3 pixels [25]. This operator avoids computing the gradient at interpolation points, and instead, the gradient estimate is centered in the middle of the window, providing an accurate representation of the image's edge information [26].

The pixel formula located around pixel (x,y):

$$\begin{bmatrix} a_0 & a_1 & a_2 \\ a_7 & (x,y) & a_3 \\ a_6 & a_5 & a_4 \end{bmatrix} \quad \text{...} \ (2.1)$$

The gradient magnitude can be calculated with the sobel operator:

$$M = \sqrt{Sx^2 + Sy^2} \quad \text{...} (2.2)$$

Partial derivatives calculated by:

$$S_x = (a_2 + ca_3 + a_4) - (a_0 + ca_7 + a_6) \ \text{.................} (2.3)$$

$$S_y = (a_0 + ca_1 + a_2) - (a_6 + ca_5 + a_4) \text{..................} (2.4)$$

With the constants Sx and Sy expressed as masks in horizontal form:

$$Sx = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \text{..} (2.5)$$

With the constants Sx and Sy expressed as masks in vertical form:

$$Sy = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \text{...} (2.6)$$

E. BSDM

Binary dissimilarity and distance dissimilarity are utilized in pattern analysis issues including classification, grouping, and others [27][28]. Since performance is dependent on the choice of measures, numerous scholars have undertaken intricate efforts to determine the most pertinent binary similarity. Assume that two patterns (i and j) are represented by binary feature vectors, where n is the feature vector's dimension or the number of features (attributes). The training results yield the vector "I", while the test results yield the vector "j" [29].

The Operational Unit Taxonomy (Otus) definitions of binary similarity and distance are displayed in table 1.1. The values of the attributes "a" of several features, i and j, are both (1,1) or presence, which denotes a positive value. The attributes in attribute "b" have "no match" values for i and j, which are between 0 and 1. Attribute "d" comprises attributes where both i and j have values of (0,0) or absence, indicating "negative" total points or "SUM", which is the sum of a+b+c+d. Attribute "c" comprises attributes where the values of i and j are (1,0), indicating a match [30].

The following table from the Operational Taxonomic Unit (OUT) presentation illustrates the link between pattern vectors i and j:

TABLE 1.
UNIT TAXONOMIC OPERATIONAL (OTU)

j \ i	1 (Presence)	0 (Absence)	Sum
1 (Presence)	$a = i \bullet j$	$b = \bar{i} \bullet j$	$a+b$
0 (Absence)	$c = i \bullet \bar{j}$	$d = \bar{i} \bullet \bar{j}$	$c+d$
Sum	$a+c$	$b+d$	$n=a+b+c+d$

III. RESUL AND DISCUSSION

In this study, the data division was carried out as follows: 100 images were used for training, and 7 pages from Surah Al-Baqarah were randomly selected for testing. This division ensures that the model is trained on a larger dataset and tested on unseen data. The 7 randomly selected pages from Surah Al-Baqarah were used to test the model's ability to detect the Ikhfa pattern on varied data.

Although the 80:20 split (80% for training and 20% for testing) is commonly used in larger datasets, in this study, the model was trained using 100 images, while 7 pages from Surah Al-Baqarah were used as test data. This ensures the model is evaluated on data it has not seen before, to assess its generalization capability. Finding the RGB intensity values utilized in image analysis will be the first step in the presentation and discussion of the research findings in this part:

A. Determining RGB Intensity Values

An essential first step is to determine the RGB (Red, Green, Blue) intensity values. A probabilistic correlation software with a unique function to determine intensity values is given the Qur'an letter patterns in this method. After processing the character patterns, this application generates the precise RGB intensity values that will be utilized in subsequent research.

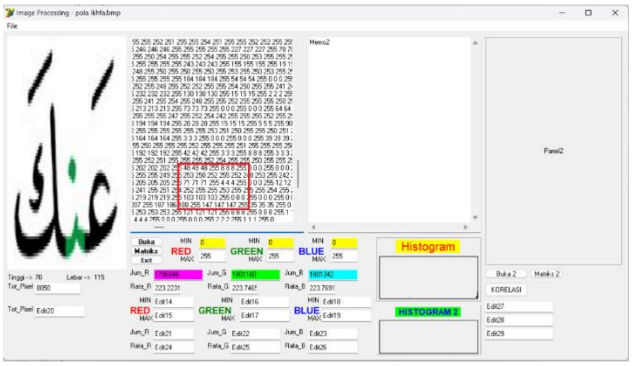


Figure 2. RGB Result of Ikhfa Pattern

B. Conerting Analog Images to Digital Images

The picture pattern is transformed into values that exist in pixels that constitute the image of the Qur'an during the conversion process from analog to digital imagery. A mathematical representation of the digital image is then produced by organizing these values in a table, as seen in the following table.

TABLE 2.
MATHEMATICAL FORM OF IMAGE

f(x,y)	0	1	2	3	4	5
0	48	48	48	255	8	8
1	253	250	252	255	252	248
2	71	71	71	255	4	4
3	252	255	255	253	255	255
4	103	203	103	255	0	0
5	188	255	147	147	147	255

C. Edge Detection Convolution Using Sobel

The sobel operator, which computes the horizontal and vertical directions using a unique kernel, is used for this procedure. This operator computes the gradient of the intensity changes across pixels using the previously acquired grayscale value matrix as a basis. There are two primary components to the sobel kernel itself. Horizontal edges are detected by the first, and vertical edges are detected by the second. As a result, this process makes it possible to highlight the image's key features and aids in gathering pertinent visual data for additional research.

TABLE 3.
SOBEL IMAGE VALUE RESULTS

(x,y)	1	2	3
1	92.02	406.89	108.67
2	92.02	400.98	365.63

3	12.17	373.16	368.05
4	128.14	192.33	462.20

TABLE 4.
NORMALIZATION OF PIXEL VALUES

(x,y)	1	2	3	4
1	0	1	0	0
2	0	1	1	0
3	0	1	1	1
4	0	0	0	1

D. Explanation of the 3W-Jaccard Formula

Gaining a better knowledge of the system's manual calculation procedures is the aim of this formula explanation. By determining how similar the two images are based on a comparison of the corresponding pixel values, this formula makes it easier to assess how accurately the system detects patterns.

$$i = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad j = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The similarity between vectors i and j is determined using the 3W-Jaccrad formula. By initially comparing the items in both vectors, the values of a, b, and c are determined. A stands for the number of elements in common (1,1), b for elements exclusively in vector i (1,0), and c for elements only in vector j (0,1). The result of this computation serves as a benchmark for assessing the degree of similarity between the test pattern image and the pattern stored in the system. The following formula is applied:

$$3W = \frac{3a}{3a + b + c}$$

$$3W = \frac{3(6)}{3(6) + (1) + (3)} = \frac{18}{22} = 0{,}818$$

The value of the 3W-Jaccard is used as a reference to determine how close the pattern that has been stored in the system. Since the value is in the range from 0 to 1, the similarity level increases as it gets closer to the number 1. The result tells the system that the tested image pattern is very similar to the reference pattern.

Besides 3W-Jaccard, the traditional Jaccard formula is also commonly used to measure the similarity between two image patterns. This formula is calculated by comparing the number of common elements (intersection) with the total number of elements present in both image patterns. The Jaccard formula is calculated as follows.

$$S = \frac{a}{a + b + c}$$

$$S = \frac{6}{6 + 1 + 3} = \frac{6}{9} = 0{,}67$$

Where a represents the number of elements that are 1 in both image patterns, b refers to the number of elements that are 1 in the first image pattern only, and c is the number of elements that are 1 in the second image pattern only. The Jaccard formula provides a simpler result without additional weighting on elements that appear in both patterns, making it commonly used in various applications to measure the similarity between sets.

The comparison between 3W-Jaccard, which yields a value of 0,818, and Jaccard, which yields a value of 0,67, shows the difference in how the two formulas measure similarity between two image patterns. 3W-Jaccard gives three times the weight to elements present in both image patterns, resulting in a higher similarity value of 0.818, indicating a stronger level of similarity. In contrast, Jaccard calculates similarity in a simpler manner, without additional weighting for common elements in both patterns, resulting in a lower value of 0.67. This difference reflects that 3W-Jaccard is more sensitive to elements that appear in both patterns, while Jaccard provides a more balanced and straightforward measure of similarity.

E. System Performance Measurement

The goal of this step is to ascertain how well the algorithm can identify letter patterns in the Qur'anic image. This image shows the interface of the application used to find the Ikhfa pattern in the Qur'an. In the middle of the display, the Qur'an text that has undergone a preprocessing process is shown with a color that represents a particular tajwid pattern. On the right, the green, yellow and red marks indicate the results of tajwid pattern detection, including Ikhfa, and the red box ndicates the area of the text that is being analyzed in more detail. At the bottom, the table shows information about the label and tajwid detection, including the category and level of detection accuracy.

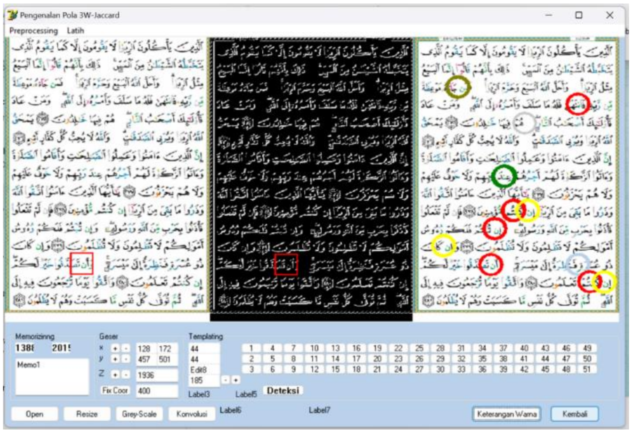
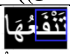
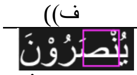
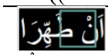
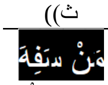
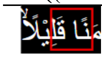
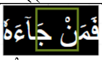
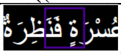


Figure 3. Ikhfa Pattern Detected

Evaluation was performed using a confusion matrix to measure the model's performance, which involves calculating True Positives (TP), False Positives (FP), True Negatives

(TN), and False Negatives (FN) for each detected Ikhfa pattern. To provide a more comprehensive view of the model's performance, additional metrics such as precision, recall, and F1-score were also calculated.

TABLE 5.
SYSTEM PERFORMANCE

Tajweed Pattern Image	TP	TN	FN	FP	Sensitify (TPR) $\frac{TP}{TP+FN}$	False Positive R (FPR) $\frac{FP}{FP+TN}$	Akurasi $\frac{(TP+TN)}{(TP+TN+FP+FN)}$ x10
 (نْ) Meet ((ت	16	0	3	0	0,84	0	84,21
 (نْ) Meet ((ك	6	0	2	2	75	1	60
 (ـٍ) Meet ((ش	1	0	0	1	1	1	100
 (نْ) Meet ((ف	3	0	3	0	0,5	0	50
 (نْ) Meet ((ص	1	0	0	0	1	0	100
 (نْ) Meet ((ذ	2	0	0	0	2	0	100
 (نْ) Meet ((ط	3	0	0	0	3	0	100
 (ـً) Meet ((ث	1	0	0	0	1	0	100
 (نْ) Meet ((س	1	0	0	2	1	1	33,3
 (ـٌ) Meet ((ق	2	0	0	0	2	0	100
 (نْ) Meet ((ش	1	0	0	2	1	1	33,3
 (ـً) Meet ((ف	1	0	0	0	1	0	100
 (نْ) Meet ((ز	3	0	1	0	0,75	0	75
 (نْ) Meet ((ظ	1	0	0	0	1	0	100
 (ـٌ) Meet ((ف	5	0	0	0	5	0	100
 (ـً) Meet ((ق	1	0	1	0	1	0	50
 (ـٌ) Meet ((ض	1	0	0	0	1	0	100
 (نْ) Meet ((ج	1	0	0	0	1	0	100
 (نْ) Meet ((د	1	0	0	0	1	0	100
 (ـٍ) Meet ((ف	3	0	1	0	0,75	0	75
 (نْ) Meet ((ث	2	0	0	0	2	0	100
Rata – Rata							83,84%

$$\text{Overall Percentage} = \frac{Total\ Percentage\ of\ Tested\ Patterns}{Number\ of\ Patterns}$$

$$= \frac{84{,}21 + 60 + 100 + 50 + 100 + 100 + 100 + 100 + 33{,}3 + 100 + 33{,}3 + 100 + 75 + 100 + 100 + 50 + 100 + 100 + 100 + 75 + 100}{21}$$

$$= 83{,}84\%$$

As a manual baseline, a tajwid expert was asked to annotate Ikhfa patterns across seven test pages of Surah Al-Baqarah and identified a total of 67 Ikhfa patterns. When compared to the system output, 56 patterns were correctly detected (true positives), while 11 patterns were missed by the system (false negatives), resulting in an overall accuracy of 83.84%. Based on the confusion matrix, the system achieved a precision of 0.889, recall of 0.835, and an F1-score of 0.861. These values were calculated using the following formulas:

$$\boldsymbol{Precision} = \frac{TP}{TP+FP} = \frac{56}{56+7} = \frac{56}{63} = 0{,}889$$

$$\boldsymbol{Recall} = \frac{TP}{TP+FN} = \frac{56}{56+11} = \frac{56}{67} = 0{,}835$$

$$\boldsymbol{F1-score} = 2\,x\,\frac{Precision\ x\ Recall}{Precision+Recall} = 2\,x\,\frac{0{,}889\ x\ 0{,}835}{0{,}889+0{,}835}$$

$$= 0{,}861$$

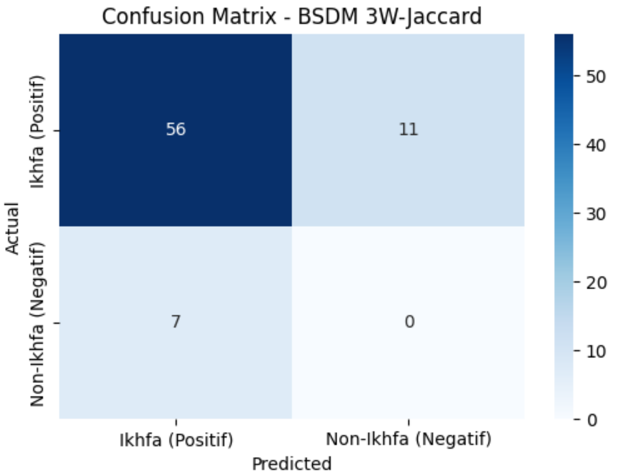


Figure 4. Confusion Matrix

The high precision value indicates that most of the detected Ikhfa patterns were correct, while the relatively high recall demonstrates the system's ability to successfully detect the majority of existing Ikhfa patterns. With an F1-score of 0.861, which represents the harmonic mean of precision and recall, the system demonstrates a balanced and effective performance in identifying Ikhfa patterns.

Compared to CNN-based models that have achieved higher accuracy levels, such as 99% in tajwid classification tasks [31], the proposed method using BSDM with the 3W-Jaccard formula shows competitive performance despite using a smaller dataset and requiring significantly lower computational resources. Moreover, the method offers greater interpretability and does not require GPU-based training, making it more suitable for lightweight and pattern-specific applications such as Ikhfa detection.

IV. Conclusion

This study concludes that the Binary Similarity and Distance Measures (BSDM) method is effective for detecting Ikhfa patterns in digital images of the Qur'an, particularly in Surah Al-Baqarah. The system, supported by preprocessing steps such as grayscale conversion, resizing, and Sobel edge detection, achieved a detection accuracy of 83.84% based on expert validation. Among the 21 combinations of Ikhfa patterns, the most frequently detected was the Ikhfa Ta' (ت) with 16 instances, while several other letters appeared only once. For additional evaluation purposes, the Jaccard and 3W-Jaccard formulas were used to measure pattern similarity, yielding scores of 0.67 and 0.818 respectively. These similarity measures helped support the validity of the BSDM method, which proved to be computationally efficient, interpretable, and suitable for rule-based detection of tajwid patterns in Qur'anic texts.

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