An Effective Method for the Recognition and Verification of Bangladeshi Vehicle Digital Number Plates

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1 Introduction

The rapid population growth in Bangladesh has posed considerable challenges to traffic management. With nearly 165 million people as of 2020, the country has seen a substantial increase in vehicle numbers. In 2019, the Bangladesh Road Transport Authority (BRTA) reported 40 lakh registered motor vehicles, with unregistered vehicles becoming more common. This surge in vehicles has given rise to various traffic-related issues, such as car theft, traffic violations, and the failure of vehicle owners to renew their tax tokens, leading to significant tax revenue losses for the government. To address these multifaceted challenges and enhance traffic management, an automated system for detecting, recognizing, and verifying Bangladeshi vehicle number plates is imperative. The current manual processes are inefficient and prone to errors, posing significant challenges for traffic police officers. Detecting discrepancies in vehicle registration and tax-token status requires access to the BRTA's offline database, making the procedure cumbersome. Additionally, identifying fraudulent registrations and forged tax-token documents is a complex task.

2 Background

2.1 Existing Work

In the field of automatic number plate recognition, previous studies have primarily focused on detecting and recognizing Bangladeshi number plates. These approaches have included techniques such as edge detection, morphological operations, and template matching. However, none of these existing systems have addressed the critical issue of verifying vehicle registration and tax token status.

1. Mashuk et al. (2010) : Proposed an automatic method for detecting, extracting, and recognizing Bangladeshi analog number plates using Sobel edge detection and Back-Propagation Neural Network (BPNN) for character recognition.
2. Amin et al. (2014): Introduced an automatic technique for recognizing Bangladeshi analog number plates using Sobel edge detection, Hough transformation, and Optical Character Recognition (OCR).
3. Arifuzzaman et al. (2014): Developed a pixel-based algorithm to automatically detect, extract, and recognize English and Bangla number plates using Sobel edge detection and template matching.
4. Roy et al. (2016): Introduced a method for detecting and recognizing Bangladeshi commercial vehicle license plates using boundary-based contour algorithms and template matching.
5. Uddin et al. (2016): Developed an automatic process for Bangladeshi digital number plate detection, segmentation, and character recognition using the Sobel operator and Support Vector Machine (SVM).
6. Abedin et al. (2017): Proposed a contour property-based Bangladeshi license plate recognition system using Python OpenCV, bounding box technique, and Convolutional Neural Network (CNN) for character segmentation and recognition.
7. Chandra et al. (2017): Presented a method with four steps for recognizing Bangladeshi license plates, including detection, extraction, segmentation, and recognition, using Sobel edge detection, bounding box techniques, Radon, Affine transformation, and CNN-based classifiers.

8. Hossain et al. (2018): Introduced a morphological operation and template matching-based technique for Bangladeshi license plate area localization and character recognition using the Sobel operator.

9. Rabbani et al. (2018): Proposed an automatic technique based on morphological operations and CNN for localizing and recognizing Bangla characters on license plates.

10. Islam et al. (2020a): Introduced a method for Bangladeshi license plate localization using morphological operations and histogram analysis, with character segmentation using connected component analysis and bounding box techniques.

11. Hossain et al. (2021): Proposed a machine learning-based Bangladeshi number plate recognition system using connected component analysis, morphological image processing, and a CNN-based model for character recognition.

12. Alam et al. (2021): Developed an automatic system to detect and recognize Bangladeshi number plates using super-resolution techniques, bounding box, and CNN for character recognition.

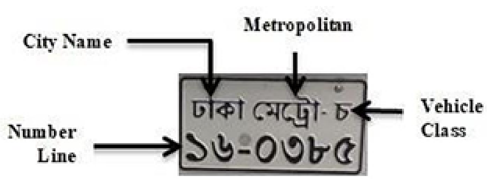
13. Islam et al. (2021): Proposed an automatic system for recognizing Bangladeshi number plates using morphological image processing for plate area extraction and template matching for character recognition.

14. Chang et al. (2004): Introduced a system to detect and identify Arabic license plates using convolution kernel, morphological operations, and BPNN for character recognition.

15. Hung and Hsieh (2010): Presented a system installed in moving vehicles for capturing and recognizing license plates using wavelet transformation, projection methods, and BPNN for character recognition.

16. Wen et al. (2011): Developed an algorithm for recognizing Japanese car number plates using improved Bernsen algorithm, SVM-based algorithm for shadow removal, and connected component analysis for character segmentation.

17. Singh and Kumar (2019): Developed an automatic Hindi number plate recognition technique using connected component labeling for character segmentation, Histogram of Oriented Gradient (HOG) for character classification, and an Artificial Neural Network (ANN) for classifying Hindi numbers and alphabets.



(a)

Vehicle Category	License Plate Colour	Character Colour	License Plates
Commercial	Green	Black	
Private	White	Black	

(b)

Figure 1: (a) Sample of number plate for Bangladeshi vehicle, (b) Categories of vehicle

2.2 Approach

This study proposes a novel technique that combines morphological image processing and template matching to automate the detection, extraction, recognition, and verification of Bangladeshi vehicle number plates. The proposed method consists of four primary components:

Step - 1: Pre-processing: Input images are resized and converted to gray-scale. Contrast enhancement and tilt correction techniques are applied to improve image quality.

Step - 2: Extraction and Segmentation: This phase focuses on locating the number plate area and segmenting characters. It involves edge detection using the Sobel operator, followed by morphological operations like filling, dilation, and erosion to localize the number plate. The Otsu method is applied for binarization, and character segmentation is accomplished using connected component analysis and bounding box methods.

Step - 3: Recognition: Character recognition is achieved through template matching. Recognized characters are stored in a text file for further processing.

Step - 4: Verification: The system verifies the extracted number plate against a cloud database containing registered vehicle details. If a match is found, the vehicle is marked as registered. Owner details are extracted from the database, and the validity of the car's tax token is checked.

2.3 Authors' Claims

The authors claim the following contributions for this research:

1. The provision of a comprehensive dataset of Bangla templates encompassing numerals, alphabets, and words to assist researchers in the field of automatic Bangladeshi car number plate detection, recognition, and verification.
2. Offering a practical solution for the BRTA to automatically detect unregistered vehicles and expired tax tokens through their cloud database, thereby augmenting registration fee and tax collection.
3. Assisting traffic management authorities in identifying stolen or misused vehicles by comparing the extracted number plates with the BRTA's reported car number plate details.
4. Potential applications in automatic car parking management, toll collection, and law enforcement by the Bangladesh police.
5. Authentication and Verification: The proposed system authenticated and verified all recognized Bangladeshi number plates with a 100% accuracy rate.

2.4 Results

1. **Detection Accuracy:** The proposed method achieved a detection accuracy of 96.8%, successfully detecting 484 out of 500 Bangladeshi number plates in the testing dataset.
2. **Extraction Accuracy:** The system extracted 459 number plates out of the 484 detected plates, with an extraction accuracy of 94.8%.
3. **Segmentation Accuracy:** While segmenting characters within the extracted plates, the system achieved an accuracy of 98.3% for the 459 plates.
4. **Recognition Accuracy:** The system recognized characters within the segmented plates with an accuracy of 97.6%, including words, letters, and digits.
5. **Authentication and Verification:** The proposed system authenticated and verified all recognized Bangladeshi number plates with a 100% accuracy rate.

2.5 Limitations

The limitation of the proposed method is that the system fails to detect and recognize some number plate images which are too noisy or tilted by more than 45°.

2.6 Future Work

To address this limitation, future work on system enhancements could include developing algorithms or techniques that are more tolerant of tilted license plates.

3 Problem Definition

This research addresses the core problem of the need for an automated system to detect, recognize, and verify Bangladeshi vehicle number plates. Manual verification processes conducted by traffic police are labor-intensive and ineffective, posing the following specific challenges:

1. **Manual Verification:** The reliance on manual verification of vehicle number plates by traffic police is labor-intensive and inefficient.
2. **Tax Compliance:** Many vehicle owners fail to renew their tax tokens, resulting in substantial revenue losses for the government.
3. **Stolen Vehicles:** Identifying stolen or misused vehicles is challenging using manual methods.
4. **Traffic Violations:** The increasing number of vehicles has led to rampant traffic violations, making enforcement difficult.
5. **Research Gap:** Limited research has been conducted on Bangladeshi vehicle number plate detection and recognition, necessitating a specialized approach.

By addressing these issues, the proposed system seeks to improve traffic management, enhance tax collection, and contribute to the broader field of Automatic Number Plate Recognition (ANPR) research.

4 Objectives

The primary objectives of this research are as follows:

1. **Develop an Automated System:** Create an automated system for efficient and accurate detection, recognition, and verification of Bangladeshi vehicle number plates, alleviating the burden on traffic police and enhancing traffic management.
2. **Enhance Accuracy:** Utilize advanced image processing techniques to significantly improve the accuracy of number plate detection, character recognition, and vehicle verification compared to manual methods.
3. **Facilitate Tax Collection:** Enable the Bangladesh Road Transport Authority (BRTA) to collect taxes more effectively by automating the verification of tax-token status, reducing revenue losses due to non-compliance.
4. **Improve Traffic Enforcement:** Aid law enforcement agencies in maintaining road safety and enforcing traffic regulations by identifying unregistered or stolen vehicles.
5. **Support Research:** Contribute to the field of automatic number plate recognition (ANPR) by providing a dataset and methodology specific to Bangladeshi vehicle number plates, fostering further advancements in ANPR technology.

5 Proposed Methodology

The proposed method consists of four steps. At the first step, the input image is pre-processed. The second step has two sub-steps. They are extraction of the license plate area from the input image and then segmentation of the characters from the extracted license plate. The third step is the character recognition stage. Verification of the vehicle is done at the fourth step. These steps are depicted elaborately in Fig. 2 and flow chart in Fig. 3

1. Pre-processing of Input Image
2. Extraction and Segmentation
   (a) Extraction of the license plate area from input image
   (b) Segmentation of characters from the extracted license plate
3. Character Recognition
4. Verification of Vehicle

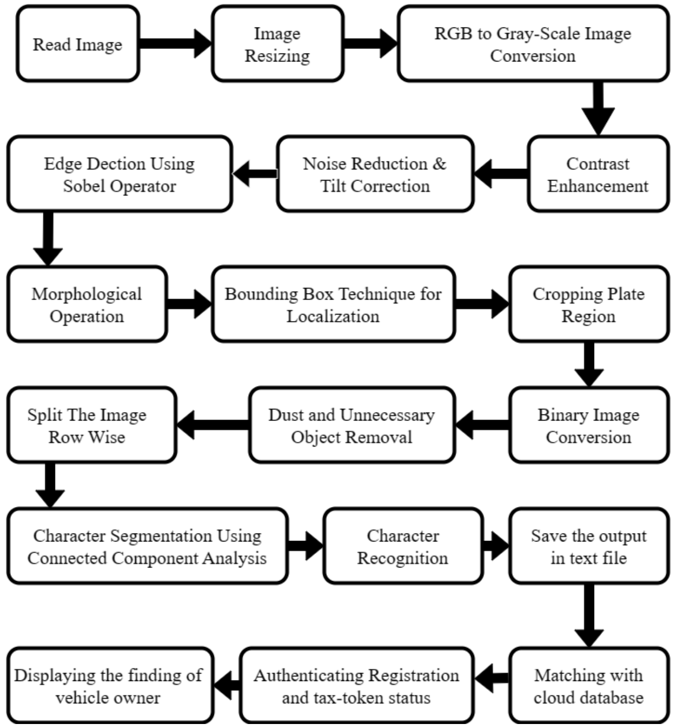


Figure 2: Overview of Proposed Method

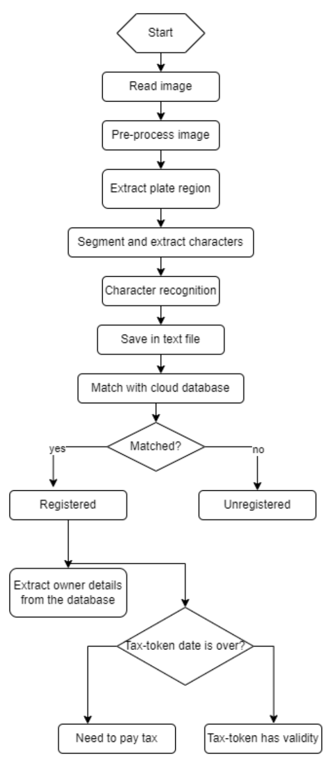


Figure 3: Flow-chart of Proposed Method

5.1 Pre-Processing of the Image Captured

Images captured by a high-resolution camera are fed into the system. The steps of the pre-processing of the image process are given below.

Step - 1: Image Resizing

Step - 2: Gray-scale Conversion

Step - 3: Contrast Enhancement

Step - 4: Tilt Correction (Noise Reduction, Edge Detection, Radon Transform)

Image Resizing: Initially, the input high-resolution RGB image is resized to a standard size of 300 pixels in height and 500 pixels in width. This step ensures that all subsequent processing steps are applied consistently to images of the same dimensions.

Gray-scale Conversion:

The RGB image is then transformed into a gray-scale image using Equation 1.

Equation 1:

$$\text{Grayimage} = 0.299 \cdot R + 0.587 \cdot G + 0.114 \cdot B \quad \text{[ref: Islam et al., 2021]} \tag{1}$$

This equation calculates the luminance of each pixel in the image, giving more weight to the green channel as the human eye is more sensitive to green light.

Contrast Enhancement: The gray-scale image is subjected to contrast enhancement using the MATLAB function imadjust(). Contrast enhancement aims to improve the visibility of details in the image by adjusting the intensity levels. It stretches the pixel values to cover a wider range, enhancing the overall contrast. The result is an image with improved clarity.

Tilt Correction:

a. **Noise Reduction:** The enhanced gray-scale image is filtered using a low-pass filter named 'wiener2' with a 5x5 kernel. This filter helps remove adaptive noise from the image, improving the quality of subsequent processing steps.

b. **Edge Detection:** The Canny edge detector is applied to the filtered image. This step highlights edges or boundaries within the image. The edges are important for identifying the tilt angle.
   - Noise reduction
   - Gradient Calculation
   - Non-Maximum Suppression
   - Double Thresholding and edge tracking by hysteresis

c. **Radon Transform:** The Radon transform is applied to the edge-detected image. The Radon transform is commonly used in image processing to detect lines or angles within an image. In this case, it is used to find the tilt angle of the image. (Chandra et al., 2017)

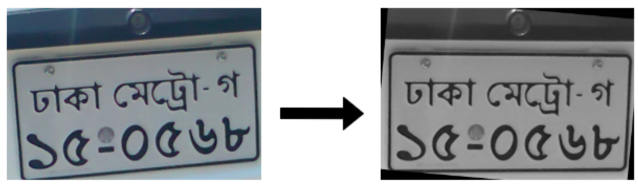
d. **Affine Transformation:** Based on the tilt angle obtained from the Radon transform, an affine transformation is applied to the image. Affine transformations can include translation, rotation, scaling, and shearing. In this case, it is used to correct the tilt angle of the image, ensuring that it is aligned properly. The method can correct up to a 45° tilt angle.

(a) (b)

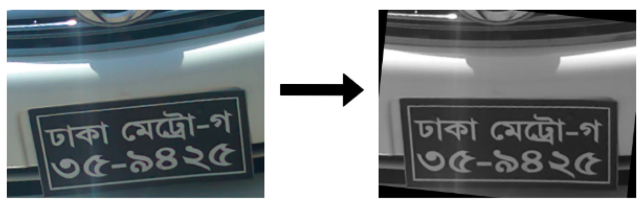
Figure 4: Effect of Gray-Scale Conversion : (a) Before Gray-Scale Conversion and (b) After Gray-Scale Conversion

(a) (b)

Figure 5: Effect of contrast enhancement : (a) Before enhancement and (b) After enhancement



(a) (b)



(a) (b)

Figure 6: Effect of tilt correction : (a) Before tilt correction and (b) After tilt correction

5.2 Extraction and Segmentation of Number Plate

This is one of the important stages of an automatic license plate recognition system. This part of the proposed system performs two major tasks-localization and extraction of the number plate area and segmentation of the number plate characters. The steps of the extraction and segmentation process are given below.

Step - 1: Detect Edges using the Sobel Operator

Step - 2: Apply Morphological Operations (Filling, Dilation, Filling Again, and Erosion) to Detected Image

Step - 3: Apply the 'Bounding Box' Technique for Localization

Step - 4: Extract the Plate Using 'imcrop'

Step - 5: Convert to Binary Image using the Otsu Method

Step - 6: Resize the License Plate

Step - 7: Removal of Dust and Unnecessary Objects

Step - 8: Split the License Plate Row-Wise into Two Portions

Step - 9: Sequentially Locate Characters using Connected Component Analysis

Step - 10: Apply the 'Bounding Box' Technique for Character Segmentation

Step - 11: Extract and Resize Segmented Characters

5.3 Localization and Extraction of the Number Plate Area

Step - 1: Detect Edges using the Sobel Operator: In this step, the input is a tilt-corrected gray-scale image.

$$G(x) = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 2 & -2 \\ +1 & 0 & -1 \end{bmatrix} \text{ --- Eq - 2}$$

The horizontal components of the gradients are calculated using the second kernel:

$$G(y) = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \text{ --- Eq - 3}$$

Step - 2: Apply Morphological Operations(Filling, Dilation, Filling Again, and Erosion: After detecting edges, the resulting edge-detected image undergoes a series of morphological operations. The operations include filling, dilation, filling again, and erosion, and they are performed seven times in total.

- **Filling:** Filling fills in white pixels with black pixels within the edges.
- **Dilation:** Dilation expands the edges, making them thicker.
- After dilation, **filling** is performed again.
- **Erosion:** Erosion then removes small white pixel areas from the edge boundaries.(Albashir et al., 2020)

These morphological operations help refine the edges and roughly localize the license plate area.

Step - 3: Apply the 'Bounding Box' Technique for Localization To precisely localize the license plate area, the 'bounding box' technique is applied to the eroded image. This technique identifies areas with sudden changes in pixel values from low to high. The smallest possible rectangles (bounding boxes) are created around these areas. These bounding boxes define the boundaries of the license plate area.(Hossain et al 2018)

Step - 4: Extract the Plate Using 'imcrop' Once the license plate area is localized using the bounding boxes, the actual license plate is extracted. This extraction is done using the 'crop' method, which takes the gray scale image and the bounding box coordinates as input. The result is the extracted license plate area.

Step - 5: Convert to Binary Image using the Otsu Method The extracted gray-scale license plate image is converted into a binary image. This conversion is achieved using the Otsu method, which computes a threshold value based on the image's histogram to separate foreground (characters) from the background. Pixels above the threshold are set to white, and those below are set to black, effectively binarizing the image.

Step - 6: Resize the License Plate After binarization, the license plate image is resized to a standardized size of 240 pixels in height, while maintaining the original width. This resizing ensures consistency in character size for further processing.

Step - 7: Removal of Dust and Unnecessary Objects Dust and unnecessary objects are removed from the resized license plate image. This is accomplished using functions like 'strel' and 'bwareaopen' in MATLAB, which are commonly used for noise reduction and object removal. (Hossain et al 2018)

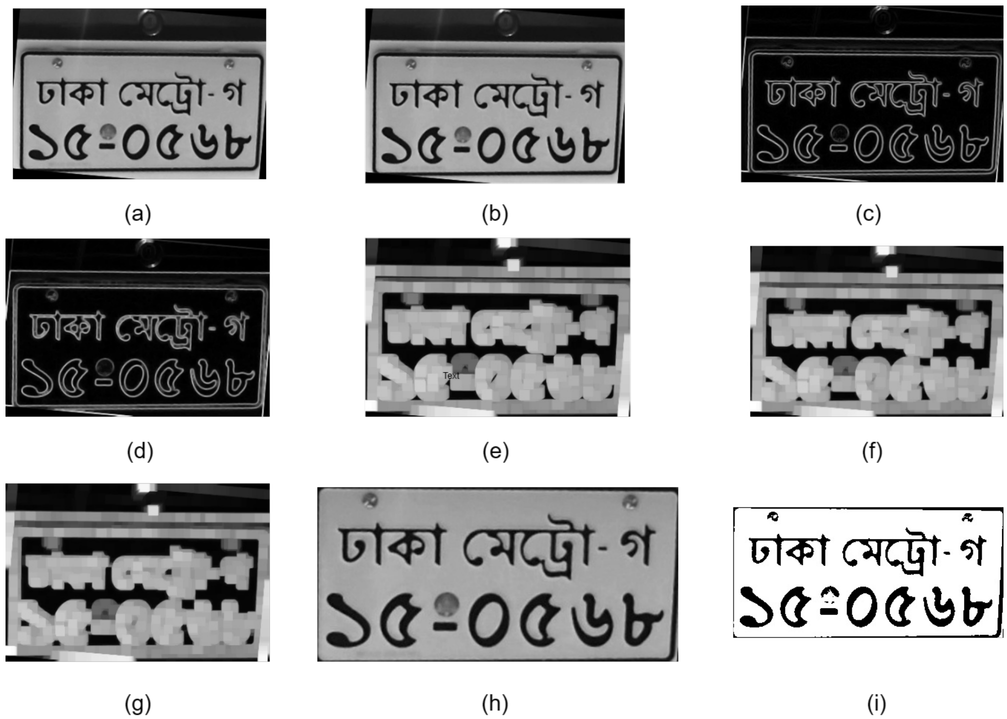


Figure 7: Extraction Process : (a) Pre-Processed Image, (b) Grey-Scale Image, (c) Sobel Image, (d) Filled Image-1, (e) Dilated Image, (f) Filled Image-2, (g) Final Eroded Image, (h) Extracted Plate Image and (i) Binarized Image

5.4 Segmentation of the Number Plate Character

Step - 8: Split the License Plate Row-Wise into Two Portions After the extraction of the number plate, the proposed method begins the character segmentation process. The double-line Bangladeshi number plate is divided equally row-wise into two portions: the upper portion, which typically contains words and letters, and the lower portion, which contains digits.

Step - 9: Sequentially Locate Characters using Connected Component Analysis To segment the characters from both the upper and lower portions, the 'connected component analysis' technique is used. This technique sequentially finds the location of the words, letters, and digits from left to right in both the upper and lower portions of the license plate.

Step - 10: Apply the 'Bounding Box' Technique for Character Segmentation For the actual segmentation of characters within the license plate portions, the 'bounding box' technique is employed. This technique marks the segments with yellow-colored rectangles, effectively defining the boundaries of each character within the license plate.

Step - 11: Extract and Resize Segmented Characters After marking the character segments with bounding boxes, the segmented characters are extracted from the license plate portions. These segmented characters are then resized to a standardized size of 42 pixels in height and 24 pixels in width, ensuring uniformity in character dimensions.

The segmentation process follows the algorithm provided in Algorithm 1, which is designed to segment characters from the input image.

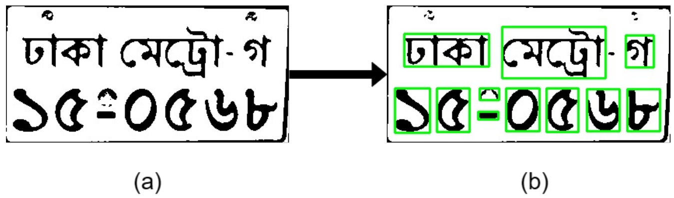


Figure 8: Character Segmentation Visualization : (a) Binarized Image and (b) Bounding Box Marking Character Image

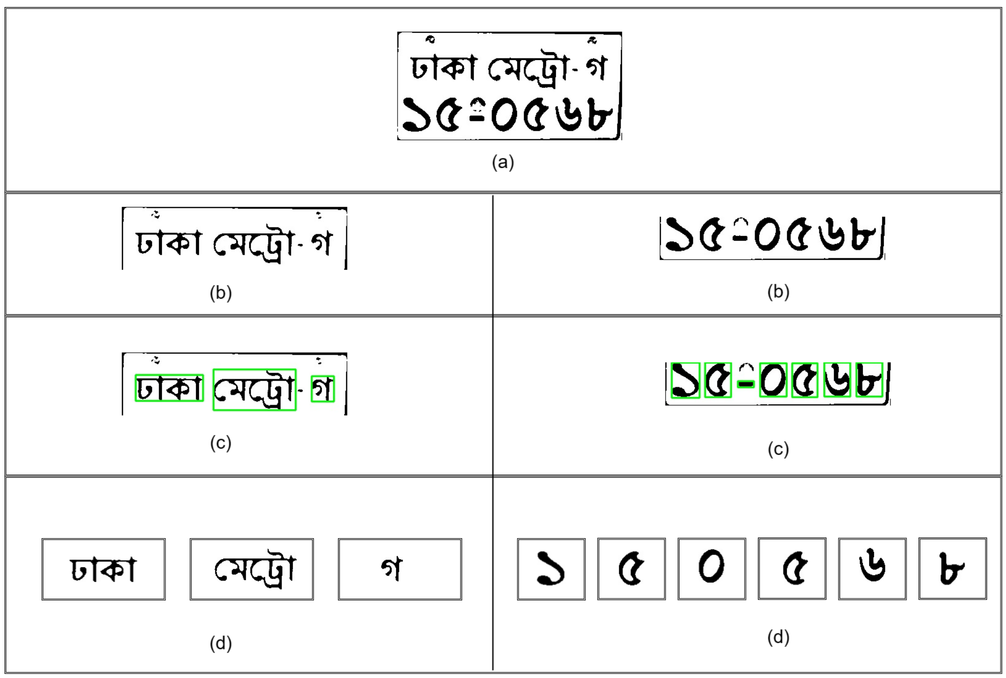


Figure 9: Character Segmentation Process : (a) Binarized Image, (b) Equally Divided Upper and Lower Portion, (c) Bounding Boxing Characters-Words and (d) Segmented Characters

5.5 Recognition of Characters

Character recognition is a crucial component in the development of an automatic number plate recognition system. This process involves identifying individual characters from segmented portions of license plates.

In this particular research, 20 vehicle classes from three cities in Bangladesh, namely 'DHAKA' (ঢাকা), 'SYLHET' (সিলেট), and 'CHATTOGRAM' (চট্টগ্রাম), were selected for a case study. The Bengali characters for these vehicle classes were associated with their English equivalents, and recognition was performed for these characters as well as numerical characters used on Bangladeshi license plates.

The recognition method employed in this research is template matching. Six templates were created for each of the Bengali characters [উ (U), ক (KA), খ (KHA), গ (GA), ঘ (GHA), চ (CA), ছ (CHA), ট (TA), দ (DA), ধ (DHA), থ (THO), ড (DO), ঢ (DHO), ন (NA), ব (BA), ম (MA), র (RA), ল (LA), স (SA), and হ (HA)].

The character recognition process involves the following steps:

Step 1: Correlation of Upper Portion: Each extracted character from the upper portion of the segmented license plate is correlated with all the templates in the template data-set.

Step 2: Template Validation: If the correlation coefficient for a particular template exceeds a predefined threshold value (0.45), the system recognizes that template as a valid probable character.

Step 3: Maximum Correlation Coefficient: The template with the maximum correlation coefficient value is selected and saved as text in a string. To Find Maximum Correlation Coefficient among Templates

$$mc = \arg\max(c) = \arg\max\left(\frac{\sum_m \sum_n (r_{mn} - \bar{r})(s_{mn} - \bar{s})}{\left(\sum_m \sum_n (r_{mn} - \bar{r})^2\right)\left(\sum_m \sum_n (s_{mn} - \bar{s})^2\right)}\right)$$

Here , mc = Maximum Correlation Coefficient c = Correlation Coefficient between a segmented character and template $r_m n$ = $s_m n$ = Image matrices r = s = the average of $r_m n$ and $s_m n$ Respectively [Ref : Islam et al., 2021]

Step 4: Correlation of Lower Portion: The same process as in Step 1-3 is repeated for the lower portion of the segmented license plate characters.

Step 5: Concatenation: The recognized characters from the upper and lower portions are combined and saved in the same string.

Algorithm 1 License Plate Character Segmentation

Require: Input image I (Unnecessary object removed image)
Ensure: Output image P (Resized segmented characters)

Compute Image Size
Calculate the size of input image I and assign rows to m and columns to n.
Split Image into Two Portions
Divide I into two equal row-wise portions: $Image1$ (upper portion) and $Image2$ (lower portion).
Connected Component Analysis for Upper Portion
Apply connected component analysis to $Image1$ using `bwlabel`, resulting in labeled components in Q and the count in N.
Calculate Bounding Boxes for Upper Portion
Use `regionprops` to calculate bounding boxes for labeled components in $Image1$, storing results in D.
Loop Over Connected Components in Upper Portion
for n in 1 to N **do**
  Step 6: Draw Bounding Box for Upper Portion
  Draw a yellow rectangle around connected component n using bounding box coordinates from D.
end for
End Loop for Upper Portion
Step 9: Loop Over Connected Components in Upper Portion (Again)
for n in 1 to N **do**
  Find Pixels Belonging to Current Component
  Find row and column indices of pixels belonging to component n in binary image Q.
  Extract Region of Interest (ROI) for Upper Portion
  Extract ROI corresponding to component n from $Image1$ and assign to P.
  Resize Character Image
  Resize P to a standardized size of 42 pixels in height and 24 pixels in width.
end for
Repeat the Process for Lower Portion
Repeat Steps 3 to 11 for $Image2$ (lower portion) to segment and resize characters.
return Resized segmented characters P.

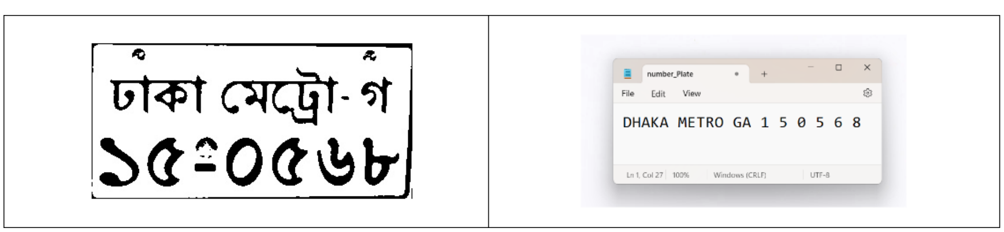


Figure 10: Character Recognition

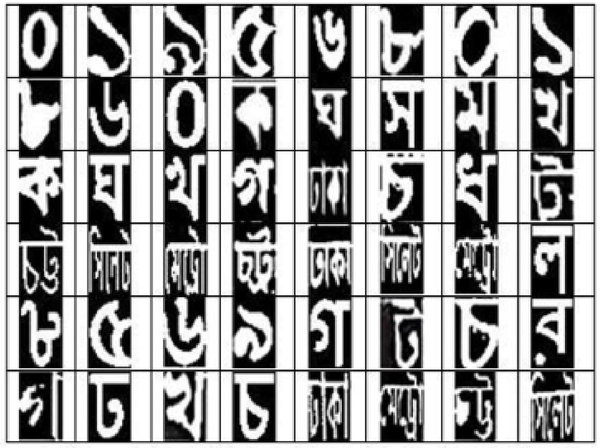


Figure 11: Sample of Templates

5.6 Verification of the Vehicle

Step - 1: Connect with the Cloud Database: The verification process begins by establishing a connection with a cloud database, which stores information about registered vehicles, including license plate numbers, owner details, and tax-token expiration dates.

Step - 2: Match the Text File: The system retrieves a text file generated during the recognition stage, which contains the recognized license plate number. It then compares this recognized number with the data in the first column of the cloud database, which contains registered license plate numbers.

Step - 3: If Not Matched: AIf there is no match between the recognized license plate number and the database, a message box is generated, indicating that the vehicle is unregistered. This suggests that the vehicle may not be authorized to operate in the smart city.

Step - 4: If Matched: If a match is found between the recognized number and the database, the system proceeds to fetch additional information about the vehicle, such as the owner's name and address.

Step - 5: Compare Tax-Token Expiry Date: The system retrieves the present date and time and then compares it with the tax-token expiry date associated with the matched vehicle in the database.

Step - 6: Tax-Token Validity Check: If the tax-token expiry date is greater than the present date, a message box is generated, indicating that the vehicle is registered and that its tax-token is still valid. The message includes the additional information fetched in step 4.

Step - 7: Tax-Token Renewal Reminder: If the tax-token expiry date is earlier than the present date, a message box is generated. It acknowledges that the vehicle is registered but reminds the owner that they need to renew the tax-token for the vehicle. Again, this message includes the additional information fetched in step 4.

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