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Accurate plate number recognition based on Sobel edge detection and weighted morphological structuring element

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ABSTRACT

Number plate recognition (NPR) became a very important in our daily life because of the unlimited increase of cars and transportation systems which make it impossible to be fully managed and monitored by humans, examples are like traffic monitoring, tracking stolen cars, managing parking toll, red-light traffic violation enforcement, border, and customs checkpoints. Yet it is a very challenging problem, due to the diversity of plate formats, different scales, rotations, and non-uniform illumination conditions during image acquisition. The proposed system is simple but efficient for recognizing plate numbers. The Sobel edge detection and morphological process are used in the proposed framework with weighted structuring element. This approach simplifies the task by using the bounding box method for character segmentation to segment all the characters on the plate number. Template matching is then applied to recognize the numbers and characters. This approach produces accurate results as shown by the experimental process.

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1. INTRODUCTION

Number plate recognition (NPR) technology was developed in 1976 at the Police Scientific Development Branch in the UK [1]. It is used worldwide for vehicle identification. Vehicles can be identified either manually or automatically through NPR. This image processing technology recognizes vehicles based on their number plate registrations. Vehicle identification plays a crucial role in intelligent infrastructure systems and intelligent transportation systems (ITS). NPR systems find applications in unattended parking lots [2], security control of restricted areas [3], traffic law enforcement [4], congestion pricing [5], and automatic toll collection [6]. Despite the existence of numerous algorithms designed to identify car number plates naturally, challenges persist. Differences in rules, shapes, content, text styles, colors, and formats for number plates across specific countries can cause some algorithms to fail in recognition [7]. Additionally, natural factors like lighting conditions, brightness, and dirt impact the accuracy of NPR results. In Malaysia, number plates may feature two distinct designs: white numbers and letters on a dark background, or vice versa. In 2020, [8] proposed the implementation of a Malaysian automatic number plate detection and identification system that combines AdaBoost and connected component (CC) analysis techniques. The primary objective of this research is to employ the K-nearest neighbor (KNN) classifier approach for detecting unique number plates. The proposed framework involves determining the number plate location through a combination of AdaBoost and character recognition using the KNN technique. During the detection step, the AdaBoost-based vehicle number plate detection algorithm requires offline training to build a robust classifier. This training process involves a substantial dataset of images containing positive and negative number plate samples to enhance the classifier's performance. Subsequently, during the AdaBoost computation for number plate localization (NPL), a sub-image undergoes evaluation by all classifiers to identify it as a potential number plate region. However, Adaboost-based detection results often yield false positives. To address this, the CCA methodology is employed to validate the detected regions and reduce false positives [9]. Given that only specific regions of interest (ROIs) are considered, the CCA approach remains straightforward. It identifies CCs within an ROI after a series of pre-processing steps.

Hendry and Chen [10] proposed an FPGA-based implementation for solving the automatic number plate recognition (ANPR) algorithm, which includes three key methods: NPL, character segmentation (CS), and optical character recognition (OCR). The proposed system is depicted in a block diagram. Initially, the morphological task involves separating the components of the number plate, followed by a noise removal process. Additionally, the author employs connected component analysis (CCA) to label the connected pixels from the previous stage and convert them into binary images. Tang *et al.* [11] further emphasize that CCA scans and assigns values to pixels in a binarized image component based on their connectivity. Subsequently, the CS algorithm operates on pixels and undergoes a three-stage process involving pre-projection, vertical projection, and horizontal projection. Chopade *et al.* [12] proposed a license plate identification system based on conventional edge detection techniques. The research aims to address challenging scenarios related to license plate identification, spanning from image scene capture to plate presentation. Edge detection methods identify pixels with abrupt brightness variations corresponding to object edges in images, as highlighted by [13]. The final step involves noise filtration, which applies condition-based filtering to the detected blobs. Most automobile plate detection systems rely on algorithms that consider blob size, height-to-width ratios, compactness, coordinate values, and white-to-black pixel ratios. Notably, the system's evaluation involved real-time analysis of 522 Malaysian automobile plate images, achieving an overall detection accuracy of 90.6 percent, with 345 images yielding accurate results. Tu and Du [14] introduced feature extraction methods based on the histogram of oriented gradients (HoG). The project's objective is to verify the database of authorized users, granting restricted area access exclusively to authorized vehicles. Pre-processing techniques are then applied to reduce noise, significantly impacting recognition accuracy. The process includes converting shading edges to grayscale outlines and applying a median filter. Additionally, the QT tool and OpenCV image processing are employed for cross-platform application development [15]. OpenCV, a library focused on image processing, plays a crucial role. During feature extraction, the author leverages a histogram of directed gradients (HoG). Notably, HoG remains robust to nearby geometric and photometric variations [16]. The image is divided into cells, and a 1D histogram of angle bearings is computed over each cell's pixels. Differential normalization ensures the descriptor's resilience to lighting variations and shadows. Silva and Jung [17] proposed a methodology for establishing an ideal threshold by minimizing within-class variations between object and background pixels. Kessentini *et al.* [18] specifically chose the Otsu threshold due to its tolerance for brightness variations. To enhance image quality, median filters were applied to mitigate salt-and-paper noise. This step aimed to achieve consistent pixel area for each character on the vehicle's license plate, thereby refining spatial resolution. Evaluating these processed images allowed for precise threshold determination.

The subsequent step involves plate localization, where the system identifies the region containing the car plate within trimmed images. Horizontal and vertical projections play a crucial role in determining spatial resolution [19]. Since the captured photographs come from various camera angles, the third stage focuses on skew detection and rectification. Detecting steepness using polynomial curve fitting on "x-axis" and "y-axis" vectors yields two values for the best-fit line. Curve digression computes the intersection of these lines, aligning them effectively [20]. CS follows, a critical procedure in license plate identification. The bounding box methodology measures linked components based on pixel intensity [21]. The ratio, defined as bounding box width divided by the number of columns divided by the number of rows, guides segmentation. Finally, character recognition ensures accurate results. The database includes alphanumeric characters (0-9, A-Z). Employing the 2-D Pearson correlation processes the relationship rate between input image pixel intensities and character layouts in the database [22]. The chellenges of NPR are different plate sizes and formats which license plates varying in size and format across different countries and regions [23]. Some plates may have special characters or designs that are not recognized by the algorithm, leading to inaccurate results and some license plates have reflective materials that can cause glare or reflections when captured by the camera [24]. This can hinder plate number recognition. Additionally, license plates may use different font styles, sizes, or colors, which can pose additional challenges for the algorithms that are designed to recognize a specific font style. There are some cases which the license plates may be partially or fully obstructed by objects such as dirt, frames, bike racks, or bumper stickers [25]. These obstructions can make it difficult for a system to reliably capture and recognize the plate number.

2. METHOD

In this project, image processing is utilized to analyze images and recognize car number plates. Since standard number plates are typically black and white, working with grayscale images simplifies the process. The next step involves converting the image to binary format for faster processing. Feature extraction is essential for object identification, specifically isolating the plate number from the background. CS techniques are then applied to identify individual characters. Finally, the obtained object is analyzed for accurate license plate recognition. Plate localization, also known as license plate localization or license plate detection, is a specific task in image processing that involves finding and extracting the license plate region from an image or a video frame. It is an important step in various applications such as vehicle recognition, surveillance systems, and ITS. The primary function of this module is to identify potential regions within an image that may contain the plate numbers. To achieve this, Sobel edge detection is employed, which performs a 2-D spatial gradient measurement on the image. This technique emphasizes regions of high spatial frequency that correspond to edges. Specifically, it calculates the horizontal and vertical values of the estimated absolute gradient magnitude at each location in a grayscale picture. Then morphological process is implemented to remove noise and to increase the character detection. Figure 1 shows the process of plate number recognition in this article.

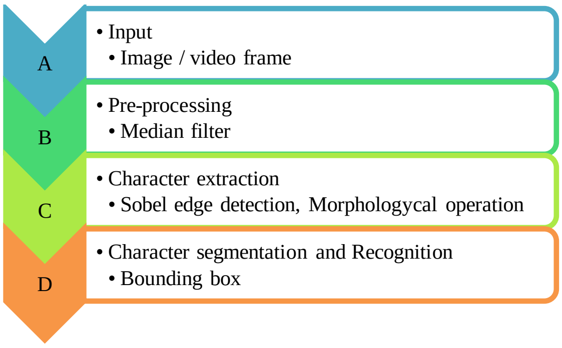

Figure 1. The process of plate number recognition

2.1. Median filtering

A median filter is a type of spatial filter used in image processing. This filter works by replacing each pixel in an image with the median value of its neighboring pixels. This helps in removing outliers or high-frequency noise present in the image while preserving the overall structure and edges. The process of applying a median filter involves moving a small window or kernel over the entire image. In this window, the pixel being processed is replaced with the median value of the pixels within the window. The median value is calculated by sorting all the pixels in the window and selecting the middle value. By replacing each pixel with the median of its surrounding values, the filter effectively reduces the impact of isolated noisy pixels while maintaining the overall structure and details of the image. This makes median filters particularly useful in removing salt and pepper noise, which appears as random white and black pixels in an image. Median filter provides a simple and effective way of removing noise from images while preserving important image features and edges. Figure 2 is the pseudo codes for th e median filter used in this project.

```
Start: outputPixelValue[image_width] [image_height]
Window [window_w × window_h]
edge_x = (window_w / 2)
edge_y = (window_h / 2)
for x from edge_x to image_width – edge_x do
   for y from edge_y to image height – edge_y do; i = 0
      for fx from 0 to window_w do
         for fy from 0 to window_h do
            window[i]: = inputPixelValue [x + fx – edge_x] [y + fy – edge_y]
            i: = i + 1
    sort entries in window []
    outputPixelValue[x][y]: = window [window_w * window_h / 2]; end
```

Figure 2. Pseduo codes for median filter

2.2. Edge detection

Edge detection is a fundamental concept in image processing that involves identifying the edges between different regions in an image. The process of edge detection involves scanning an image and locating areas where there is a significant change in intensity or color. Edges in an image represent significant changes in intensity, so the gradient can help to locate them. Specifically, the gradient is computed by convolving the image with a gradient operator, the Sobel. After calculating the gradient, the next step is to determine which pixels correspond to edges. This is typically done by applying a threshold to the magnitude of the gradient. Pixels with a magnitude above the threshold are considered as edge pixels and marked accordingly, while pixels below the threshold are considered as non-edge pixels. The gradient difference of x-axis and y-axis estimation are given by (1) and (2):

$$\frac{\partial f}{\partial x} = f(x+1, y) - f(x-1, y) \tag{1}$$

$$\frac{\partial f}{\partial y} = f(x, y+1) - f(x, y-1) \tag{2}$$

where the $f(x, y)$ represents the input image and the gradient functions are given at (3) and (4):

$$g_x = h_x * f(x, y) \tag{3}$$

$$g_y = h_y * f(x, y) \tag{4}$$

Sobel filter uses the h_x and h_y with constant matrix values as given by (5):

$$s_x = \begin{pmatrix} 1 & 0 & -1 \\ 2 & 0 & -2 \\ 1 & 0 & -1 \end{pmatrix} * f(x, y) \text{ and } s_y = \begin{pmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{pmatrix} * f(x, y) \tag{5}$$

gradient magnitude for Sobel filter and the gradient direction are given by (6):

$$s = \sqrt{s_x^2 + s_y^2} \text{ and } \theta = \arctan\left(\frac{s_x}{s_y}\right) \tag{6}$$

2.3. Morphological binary dilation and erosion operations

Image dilation and erosion are morphological operations in image processing that is used in this project. The dilation operation expands the boundaries of the objects in an image by adding neighboring pixels to their boundaries. First step is to place the structuring element at each pixel position in the image, which is a small binary matrix or shape, to scan the image. While, the erosion is used to shrink or erode the boundaries of foreground objects in a binary image. Then, compare the structuring element with the corresponding pixels in the image. If any of the pixels in the structuring element and the image are non-zero (i.e., white or foreground), set the corresponding pixel in the output image to be non-zero as well. Finally, repeat this process for every pixel in the image as shown by the (7) and (8) for dilation and erosion respectively.

$$s \oplus \omega E = \bigcup_{b \in E} s_b \tag{7}$$

$$s \ominus \omega E = \bigcap_{b \in E} s_b \tag{8}$$

where s_b is the translation of s by b from region of interest and E represents the element of the dilation and erosion functions. This work proposes weighted structure element ω which will improve the weightage of binary distribution values on the region of interest.

2.4. Character segmentation and recognition

Segmentation plays a decisive role in NPR, as subsequent phases heavily rely on it. The bounding box method is the optimal solution for segmenting individual characters and numbers on the license plate. Each letter and number is isolated within its bounding box, facilitating further processing. CS goal is to divide each character into its own bounding box. If the license plate spans multiple lines, the process reads characters line by line. This step prepares the characters for subsequent analysis. In the final phase, character recognition ensures accurate identification. The input image is compared with a template file containing 36 characters (from ‘0’ to ‘9’ and letters from ‘A’ to ‘Z’). Template matching extracts and resizes the characters to a consistent size (24x42 pixels) and converts them into text form. The binary image templates of the numbers and characters used in the experimental analysis are provided by Figure 3.

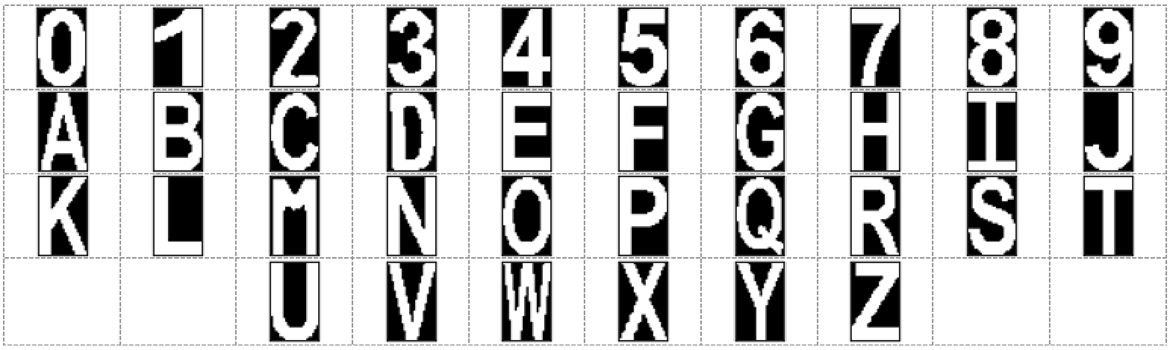

Figure 3. The number and character templates in binary image format

3. RESULTS AND DISCUSSION

For optimal results, the following steps must be met during CS. Uniform size on each segmented character should match the dimensions of the template character. Specifically, the height and breadth of each character block should be 24x42 pixels. Precise positioning during segmentation is to ensure that each character is positioned accurately with the ideal orientation is 180 degrees (straight position). The deviations from this alignment may impact the accuracy of the recognition phase. By adhering to these steps, the result can achieve more accurate character recognition. Figures 4-6 display sample photos of the results, which serve as the basis for assessing the algorithm’s performance and observing the system accuracy. Accuracy is evaluated across the entire testing image, ensuring successful completion of all stages and successful conversion into text form recognition. First of all, Figure 4 shows the effectiveness of morphological operation with weighted structure element ω at 0.7. It removes unwanted white dotted on the bounding box of ‘image 7’. The morphologycal process by erosion makes thinning layer of number “7”. Hence, the white dotted will be vanished due to this erosion process with proper selection of structured element size. With the same structured element size, the dilation process takes place to increase the edges or making the white region fatty. All input images will be implemented this process until it matches one of the bounding box templates. Figure 5 shows the simulation result with yellow background and black foreground which indicates accurate detection of the plate number of “50NNY”. Then, additional sample input images are used as shown by Figure 6 with different colour formats of background and foreground. There is also raw images and output results based on the MATLAB simulation. These raw images contain different characteristics such as varying contour of background and foreground, with spaces or not, dash and number of characters. The results demonstrate accurate recognition of each character as presented in this figure. The first output of black background and white foreground conversion show the recognition process is capable to be used for Malaysia plate number system. Eventually, the proposed work is successfully recognise each character as shown by the results in Figure 6.

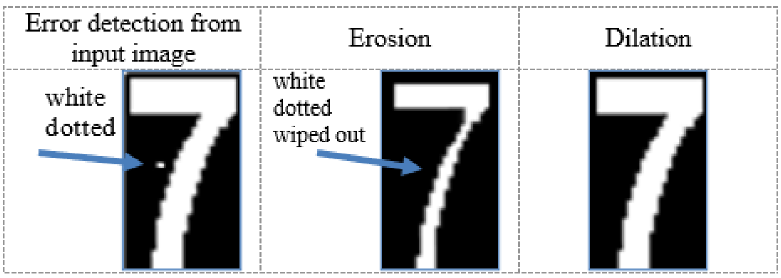

Figure 4. Morphological operation removes unwanted white dotted

Figure 5. The simulation result is based on the yellow background and black foreground using MATLAB

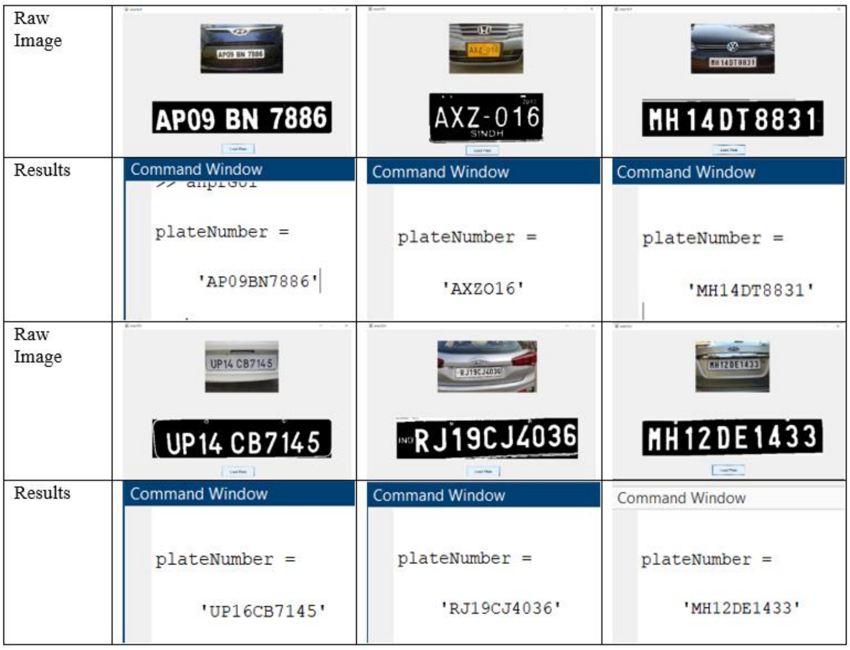

Figure 6. Accurately recognize the plate numbers through the proposed system

4. CONCLUSION

In conclusion, plate number recognition technology has proven to be a highly effective and efficient tool for automating the process of identifying and tracking vehicles. Thru the proposed work, Sobel edge detection and weighted morphological structuring element operation is capable to be implemented in real live and improved accurate rates. It has numerous applications, including law enforcement, parking management, toll collection, and traffic management. It eliminates the need for manual entry or visual inspection of license plates, reducing human error and improving efficiency. In parking facilities, it enables automated entry and exit of vehicles, streamlining the parking process and reducing waiting times. The data generated by plate number recognition systems can be analyzed to gain valuable insights for monitoring traffic patterns, identifying vehicle ownership trends, and making informed decisions for infrastructure planning and policy formulation. Overall, automatic plate number recognition in this work offers increased efficiency, security, convenience, and data-driven insights, making it a valuable tool in various domains.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Ahmad Fauzan Kadmin		✓	✓			✓					✓	✓		
Khairul Azha A Aziz				✓			✓				✓			
Mohd Saad Hamid			✓			✓			✓					
Lim Then Sean		✓			✓		✓							

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [Rostam Affendi Hamzah], upon reasonable request.

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