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SOFTWARE METHOD FOR IMAGE SEGMENTATION UNDER VARIABLE LIGHTING CONDITIONS

Анотація

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Програмний метод сегментації зображень в умовах варіативного освітлення

У даній роботі розглянуто задачу сегментації цифрових зображень в умовах варіативного освітлення. Проведено аналіз існуючих методів нейромережевої сегментації зображень. Запропоновано метод сегментації зображень в умовах варіативного освітлення, що ґрунтується на адаптивному перетворенні зображення відповідно до результатів початкової класифікації та застосуванню нейромережевих моделей U-Net та SegNet. Результат оцінки запропонованого методу продемонстрував понад 0.95 та 0.76 відповідно до метрик Mean Pixel Accuracy та Mean IoU в середньому.

Introduction

Modern computer vision systems increasingly rely on deep learning models to solve various complex image processing tasks, including semantic segmentation. However, the effectiveness and accuracy of these systems depend heavily on the quality and characteristics of the input data. Dark or bright images can cause significant brightness and contrast distortions, resulting in decreased segmentation accuracy and reliability of the resulting masks.

To address this issue, adaptive image pre-processing techniques have become an essential step prior to segmentation. This work focuses on developing and evaluating an image segmentation method that integrates an illumination classification stage, adaptive pre-processing, and a neural network-based segmentation stage. The effectiveness of the proposed method has been assessed using U-Net and SegNet models [1].

Problem statement

To analyze and improve the accuracy of image segmentation under variable lighting conditions based on neural network models.

Terminology

Variable lighting conditions refer to the presence of varying illumination in input images, which can be dark, moderate, or bright, thereby affecting the consistency and accuracy of image segmentation.

The learning rate is a hyperparameter that controls the size of weight updates during neural network training.

A loss function is a mathematical function that measures the difference between the predicted output of a neural network and the ground-truth labels.

Description of the proposed method

To solve the problem of semantic image segmentation under variable illumination conditions, an adaptive preprocessing method based on image luminance classification and targeted enhancement techniques was developed. The purpose of this method is to improve the overall uniformity and contrast of images before they are processed by neural network segmentation models. Consider the sequence of stages of this method:

Luminance classification stage. At the first stage, each input image is analyzed by the hybrid luminance classifier, which determines its illumination category as *Dark*, *Moderate*, or *Bright*. The classification process is based on several statistical metrics of relative luminance, computed using the weighted RGB formula [2]:

$$RL = \frac{0.2126R + 0.7152G + 0.0722B}{255} \quad (1)$$

To improve robustness, the classifier ignores background regions that are either too dark or too bright, as they often contain no informative content. Key metrics include the median and percentile luminance values (p20, p80), standard deviation, contrast, and histogram skewness. Based on these statistics, the image is dynamically assigned to one of three classes using adaptive thresholding rules.

Adaptive preprocessing stage. Depending on the classification result, one of three image enhancement pipelines is applied.

Dark images are enhanced using a combination of Contrast-Limited Adaptive Histogram Equalization (CLAHE) on the L-channel of the LAB color space, followed by adaptive gamma correction [3]. The gamma value is computed based on the mean luminance, allowing for a stronger correction in darker scenes. Optional denoising is also applied to reduce artifacts.

Bright images undergo a tone-mapping procedure based on the Reinhard algorithm, which compresses the high dynamic range while preserving details in bright regions. Denoising is optionally performed to smooth color transitions.

Moderate images are refined using unsharp masking to improve edge clarity and local contrast without introducing excessive noise.

The robust adaptive pipeline ensures that each image is enhanced optimally according to its illumination characteristics. As a result, the processed dataset exhibits higher contrast consistency and improved spatial feature distinguishability, which significantly facilitates downstream segmentation by neural networks.

Image segmentation stage. At the final stage, the enhanced images are processed by a convolutional neural network that performs semantic image segmentation. In the proposed method, two convolutional architectures – U-Net and SegNet – are employed and compared to evaluate the effectiveness of the proposed adaptive preprocessing approach [3].

Results

For the training process, a Car Segmentation Dataset was used. It contains images of vehicles along with corresponding segmentation masks that label car components – wheels, body, windows, headlights, and the background. To emulate varying lighting conditions, noise and brightness reduction were applied. All input images were resized to 512×512 pixels to ensure consistent input dimensions across the dataset. During training, the Cross-Entropy loss function and Adam optimizer with a learning rate of 0.0005 were used to optimize segmentation accuracy. To ensure convergence and stability of the results on the relatively small dataset, the training process was conducted over 200 epochs with a batch size of 16.

An example of image preprocessing and segmentation result is shown in Fig. 1.

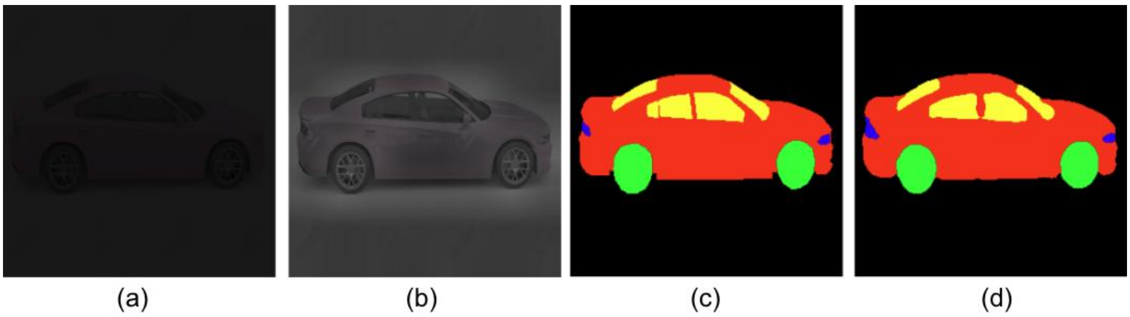

Fig. 1. Example of image preprocessing and segmentation result: (a) dark original image, (b) adaptively-enhanced image, (c) ground-truth mask, (d) predicted mask.

The performance of the models was assessed using pixel accuracy and mean intersection over union (mIoU) on both the training and validation datasets. These metrics provide a comprehensive evaluation of segmentation precision and consistency. The evaluation of quantitative performance metrics is presented in Table 1.

Table 1

Quantitative performance metrics evaluation

Model	Train			Test	
	Loss	Mean Pixel Accuracy	Mean IoU	Mean Pixel Accuracy	Mean IoU
without adaptive image preprocessing					
SegNet	0,1056	0,9586	0,7563	0,9398	0,7049
U-Net	0,0650	0,9743	0,8330	0,9555	0,7636
with adaptive image preprocessing					
SegNet	0,0890	0,9644	0,7736	0,9536	0,7398
U-Net	0,0521	0,9794	0,8619	0,9562	0,7763

Conclusions

The work addressed the issue of semantic image segmentation under variable lighting conditions. A segmentation method based on image classification, enhancement, and the application of U-Net and SegNet neural networks was proposed. The evaluation results of the proposed method showed a Mean Pixel Accuracy of over 0.95 and a Mean IoU of 0.76 on average.

Further areas of research may include refining the enhancement methods, modifying the image segmentation module, and exploring post-processing techniques. Specific solutions include applying modified filtering algorithms in pre-processing to smooth color transitions while preserving sharp boundaries, and integrating Conditional Random Fields (CRFs) post-processing to sharpen object contours and correct pixel errors in the final masks.

References

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