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EXPERIMENTAL ANALYSIS OF THE IMPACT OF ADAPTIVE PREPROCESSING ON KEY FEATURE DETECTION AND HUMAN IDENTIFICATION ACCURACY IN COMPUTER VISION SYSTEMS

In the context of the rapid development of digital technologies and computer vision systems, particular attention is given to the tasks of automated analysis of digital images, particularly object detection, segmentation, and identification [1, 2]. These tasks, such as video surveillance, traffic safety, and public order maintenance, are primarily focused on human recognition. As is well known, this often takes place under conditions of limited visibility: fog, low lighting, reduced contrast, insufficient illumination, and so on. As explored in [1], for neural networks to make accurate decisions during classification, the extraction of key features of the object is critical. Under poor visibility conditions, these features are distorted, which leads to the need for improving recognition accuracy and reducing errors. This issue was addressed in the study [2] by implementing adaptive preprocessing, descriptor analysis, and deep learning models. The improvement of the accuracy and robustness of automated segmentation, clustering, and human identification in digital images under reduced visibility conditions is achieved by integrating adaptive preprocessing, feature analysis, and deep learning models to ensure the stable operation of computer vision systems through the enhancement of segmentation quality, detection, clustering, and human identification accuracy [2].

The aim of this study is to analyze the impact of adaptive preprocessing of digital images using classical methods and deep learning models on the quality of key feature extraction (specifically using the Silhouette Score metric) and its influence on the overall accuracy of human identification.

For the experimental study of the comprehensive combination of adaptive image preprocessing, feature descriptor analysis, and deep learning models (such as U-Net, Mask R-CNN, YOLOv8) [2], a sample of 350 digital images was created. This sample includes both proprietary photographs and open datasets, such as COCO and CrowdHuman. These images cover various scenes: individual persons, groups, and crowds, with the presence of external objects. Artificial degradation effects such as fog, noise, dimming, and reduced contrast were simulated. Additionally, normalization, γ -correction, CLAHE, Dehazing, and various filtering techniques (Median, Gaussian, Bilateral) were applied to compensate for distortions.

The experimental analysis of object clustering results after image preprocessing [2] (evaluating the impact of filtering on the Silhouette Score and human identification accuracy in digital images) showed that the application of adaptive preprocessing enhances the accuracy in computer vision systems. A comparison of metrics for each image in the context of clustering and identification is presented in Figure 1.

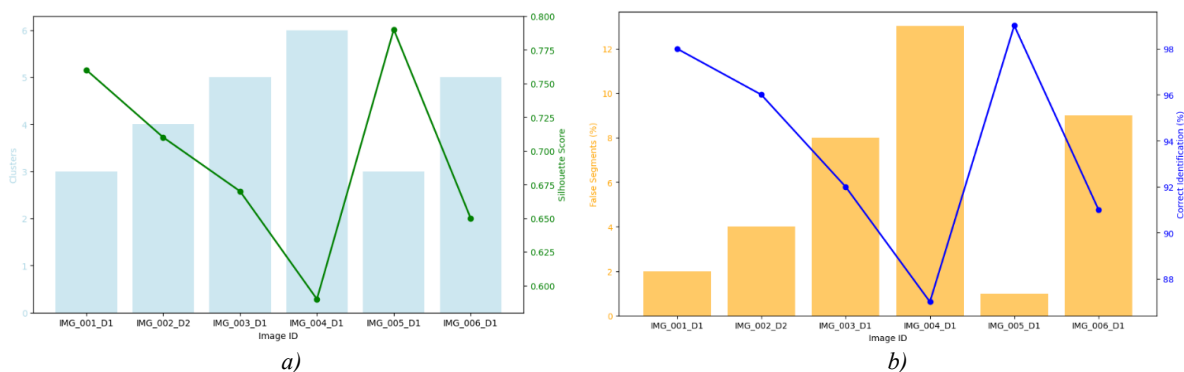


Fig. 1. Comparative analysis of the number of clusters and Silhouette Score values for the test sample of digital images: a) number of clusters and Silhouette Score values for each image; b) percentage of false segments and correct identification.

The results of the experimental analysis showed that the highest classification result does not depend on the maximum number of clusters but on their optimal selection combined with quality preprocessing. The best results (correct human identification) were observed for image IMG_005_D1, where the optimal number of clusters is 3, and the percentage of correct identification reaches 99%. At the same time, images with a higher number of clusters, such as IMG_003_D1 (5 clusters), achieved 92% correct identifications. This pattern is confirmed by the mathematical quality assessment: the highest Silhouette Score is achieved for image IMG_005_D1, which also confirms the best clustering quality, particularly regarding identification accuracy. A low Silhouette Score indicates a deterioration in clustering

quality, reducing the correctness of identification. The smallest number of false segments was observed for images IMG_005_D1 and IMG_001_D1, which indicates the high effectiveness of image preprocessing for these scenes. Images with high degradation levels show low Silhouette Scores and a high number of false segments, confirming the challenges in clustering under significant image distortion.

It is worth noting that the quality restoration of key features in the image through adaptive filtering has allowed for the effective application of not only clustering methods but also deep learning models. Specifically, experiments demonstrated consistently high segmentation performance using the U-Net and Mask R-CNN architectures (IoU metric up to 0.95) and detection with the YOLOv8 model (mAP up to 0.95) [2]. This confirms the synergistic effect of integrating classical preprocessing and neural network approaches.

The advantages of the proposed approach lie in this synergistic integration, combining classical computer vision algorithms with deep learning models. Classical methods provide interpretability, high speed, and low computational cost, while neural networks offer a high ability to generalize and detect complex patterns. Additionally, the approach's adaptability to types of degradation is a key strength: rather than applying universal processing for each type of distortion (fog, dimming, impulse noise), a specialized combination of methods is used. This targeted approach allowed for a significant increase in the integral image quality index under the most challenging conditions. High accuracy and robustness are also achieved thanks to the comprehensive data preparation and the use of powerful architectures such as U-Net, Mask R-CNN, and YOLOv8.

However, the proposed approach has its limitations. One of the key challenges is the difficulty of compensating for smoke. The most challenging scenes for segmentation and detection remain those with smoke or combined effects. For scenes with smoke, the least improvement effect was observed due to the physical complexity of fully compensating for the semi-transparent layer in the image. The method is also sensitive to domain changes: for night-time detection, where the human silhouette is weakly expressed, it is often necessary to use background context and attention mechanisms. However, such solutions are sensitive to changes in cameras and scenarios, and thus require complex domain validation, rather than being tested on a single training dataset. Another unresolved issue is the transfer of features to other sensors, as training light-invariant features has certain limitations, making them difficult to transfer across different sensor types. Moreover, strict evaluation protocols are required to avoid the loss of the system's ability to distinguish objects.

The results obtained indicate that adaptive preprocessing and the correct selection of the number of clusters improve clustering efficiency and human identification accuracy, particularly in challenging conditions of digital image degradation. The integration of adaptive filtering methods during preprocessing helps mitigate the impact of complex visual environments, ensuring high reliability of feature description and subsequent object identification. Thus, the quality of digital images improves, segmentation and detection accuracy increases, and clustering efficiency is enhanced. As a result, human recognition and identification accuracy in digital images has increased to 99%, even under difficult visual conditions. The computer vision system has gained high robustness (resilience) to various types of image degradation and can be successfully and reliably applied in real-world video monitoring systems, ensuring traffic safety, public order, and more.

The prospects for further research should be directed towards addressing unresolved challenges in human identification under limited visibility conditions. In particular, there is a need to improve algorithms for handling the most complex types of image degradation, such as scenes with smoke (where full compensation of the semi-transparent layer remains difficult), and combined effects. Furthermore, an important step will be the thorough validation of the proposed solutions "across domains" to ensure their robustness to camera changes and various scenarios. Tasks related to uncertainty modelling, transferring recognition results beyond conventional (e.g., road) domains, and improving instance segmentation in scenes with dense crowds also remain relevant. Additionally, attention should be given to adapting the developed methods for use with various sensor types and establishing strict evaluation protocols to avoid the loss of discriminability during model training.

References

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