Arjit Sasan, 2026, 14:3
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology
An Open Access Journal

Comparative Analysis of Low-Light Image Enhancement Techniques and Their Impact on YOLOv8 Object Detection

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Abstract- Low-light conditions present significant obstacles in the design of computer vision solutions, considering that dark images have poor visibility, reduced contrast, unseen details, and higher noise levels, which result in reduced object detection system performance. This research proposes Lumnia, a low-light image enhancement and object detection solution that utilizes multiple image enhancement algorithms and YOLOv8 object detection. The system employs four enhancement modes, which include CLAHE (Contrast Limited Adaptive Histogram Equalization), Gamma Correction, simplified Zero-DCE inspired image enhancement technique, and Auto Enhancement mode. The enhanced image is then sent for further processing using YOLOv8 to detect objects. In addition, the solution uses several image quality metrics, such as MSE (Mean Squared Error), PSNR (Peak Signalto-Noise Ratio), and SSIM (Structural Similarity Index) to evaluate the image enhancement process and assess the differences between the original and enhanced images. The project was written using Python programming language, and it makes use of Flask web framework, OpenCV library, NumPy package, scikit-image, and Ultralytics YOLOv8. Experiments reveal that various image enhancement methods result in varied image visibility and object detection results.

Keywords— Low-Light Enhancement, YOLOv8, CLAHE, Gamma Correction, Computer Vision, Image Processing, Object Detection, Zero-DCE Inspired Enhancement

I. INTRODUCTION

The performance of computer vision algorithms depends very much on the quality of images. Under low-light conditions, pictures taken by cameras tend to have low brightness, lack of contrast, hiding important details, and high noise levels. The consequence of this phenomenon is the reduction of the efficiency of object detection due to difficulties in recognizing visual details.

Low-light enhancement techniques aim to restore the hidden image information from darker areas and make the images more visible. Traditional enhancement techniques, like histogram equalization or gamma correction, are popular due to their high computational speed and straightforward implementation. Recently, new techniques that use adaptive enhancements similar to the concept of deep learning, called Zero-DCE, have emerged.

In the current project, we will develop and compare various low-light enhancement algorithms along with analysis of their effect on the results of YOLOv8 object detection. The system will enable users to upload a low-light picture, perform enhancement using various methods, measure the quality of images, and observe detection results via web interface.

Comparison between original low-light image and enhanced image is illustrated below:

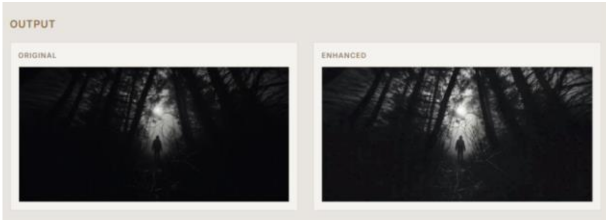

Figure 1: Comparison between original low-light image and enhanced output.

The major goals of this project are:

- Implementation of various low-light enhancement algorithms.
- Comparison of enhancement algorithms based on measurements of image quality.
- Application of enhancement algorithms for object detection in YOLOv8 framework.
- Creation of an interactive web interface for image processing and visualization.
- Analysis of the influence of image enhancement on object detection visibility.

II. LITERATURE REVIEW

1. Enhancement Techniques for Low Light Images
Enhancement techniques are useful in enhancing images captured under low-light conditions.

The techniques include:

- Histogram Equalization
- Adaptive Histogram Equalization
- CLAHE
- Gamma Correction

The techniques are computationally efficient and real-time.

2. CLAHE
Contrast Limited Adaptive Histogram Equalization (CLAHE) enhances local contrast while limiting noise amplification. The difference between CLAHE and histogram equalization is CLAHE involves processing smaller image blocks and merging their enhancement results.

CLAHE can be applied in:

- medical imaging
- surveillance systems
- low-light photography
- night vision systems

3. Gamma Correction
Gamma correction refers to nonlinear intensity transformations to brighten the darker parts of an image.

Gamma correction uses the following formula:

$$I_{out} = I_{in}^{\gamma}$$

Gamma correction is computationally simple and efficient for real-time image processing systems.

4. Zero-DCE
Zero-DCE stands for Zero-Reference Deep Curve Estimation. It is an image enhancement technique for images captured under low light condition. Zero-DCE estimates adaptive enhancement curves using deep learning methods.

However, the project doesn't use the pretrained Zero-DCE neural network. Instead, it uses an improvised Zero-DCE image enhancement technique using concepts of adaptive illumination and enhancement curves.

5. YOLOv8 Object Detection
YOLO is an object detection technique based on convolutional neural networks. YOLOv8 is one of the recent versions offered by Ultralytics. It supports accurate and fast object detections.

In the project, the YOLOv8n pretrained model will be used for object detection.

III. PROPOSED METHODOLOGY

The methodology involves image enhancement and object detection together in one process.

1. System Workflow
The workflow of the proposed methodology is presented below:

- User uploads a low-light image.
- Enhancement method is selected by user.
- Image enhancement is done.
- Image quality metrics are calculated.

- Object detection through YOLOv8.
- Detection Results shown on screen.

System Flow:
Input Image → Enhancement → Metrics Calculation → YOLOv8 Detection → Output Result

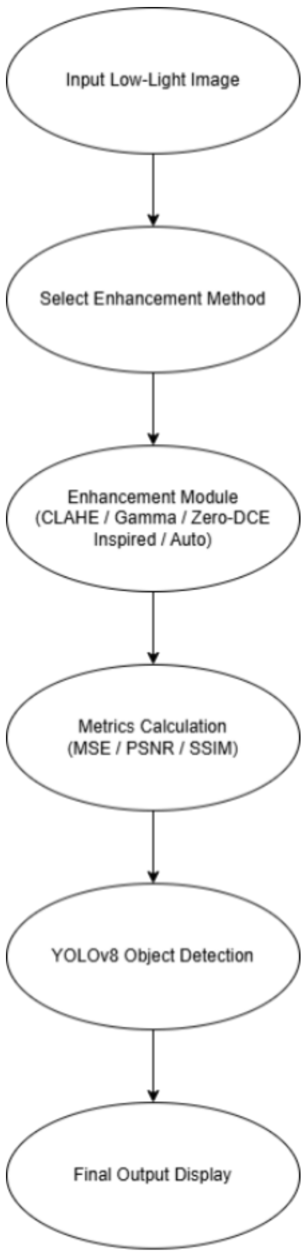

Figure 2: Overall workflow of the proposed low-light enhancement and object detection system.

IV. SYSTEM IMPLEMENTATION

The following technologies are used to implement the project:

Component	Technology
Programming Language	Python
Backend Framework	Flask
Image Processing	OpenCV
Object Detection	YOLOv8
Frontend	HTML, CSS
Scientific Computing	NumPy
Metrics	scikit-image

The project is structured as follows:

File	Purpose
app.py	Flask backend and routing
enhance.py	Enhancement methods and metrics
detect.py	YOLOv8 detection logic
index.html	User interface

V. ENHANCEMENT TECHNIQUES

1. CLAHE Enhancement
CLAHE enhances local contrast without too much amplification.

CLAHE enhancement process is done by converting the image into LAB space and then applying enhancement on the L-channel only.

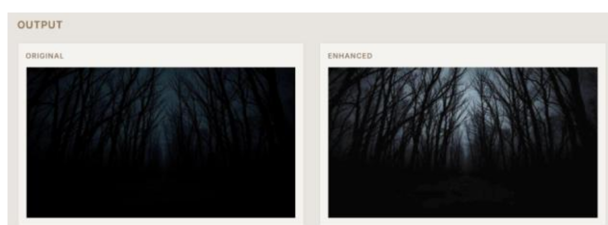

Figure 3: Enhancement result obtained through the use of CLAHE method.

Advantages

- Better local contrast
- Vivid details in shadow areas
- No change to color balance

2. Gamma Correction
Gamma correction enhances the image through nonlinear intensity modification.

Gamma correction implemented in the project uses lookup tables.

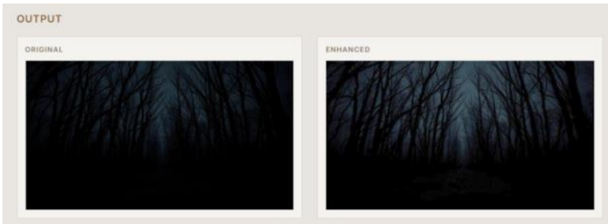

Figure 4: Enhancement result obtained through the use of Gamma Correction method.

Advantages

- Faster execution time
- Simpler implementation
- Real-time results

Disadvantages

- Does only global enhancement
- Too much brightness in certain areas

3. Zero-DCE Inspired Enhancement

The Zero-DCE Inspired Enhancement algorithm implemented in the project:

- Illumination estimation
- Adaptive Enhancement Factor Generation
- Gamma-based exposure control

The Adaptive Enhancement process can be represented as:

$$I_{enhanced} = I^{\alpha}$$

Where α is generated according to illumination estimation from the image.

In order to estimate the illumination value, the maximum channel intensity is taken into account. Adaptive enhancement curves are applied for different regions of an image.

This method is based on Zero-DCE enhancement techniques but does not use any pre-trained Neural Network provided by Zero-DCE.

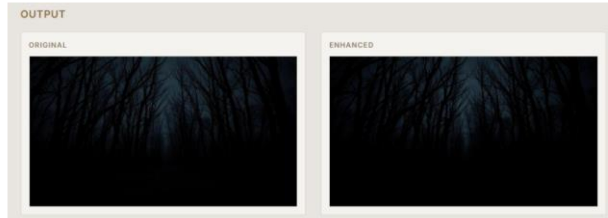

Figure 5: Enhancement result obtained using the Zero-DCE Inspired Enhancement technique.

4. Auto Enhancement Mode

Auto enhancement technique works by comparing CLAHE and Gamma Correction enhancement outputs and choosing the enhancement result that has better image properties.

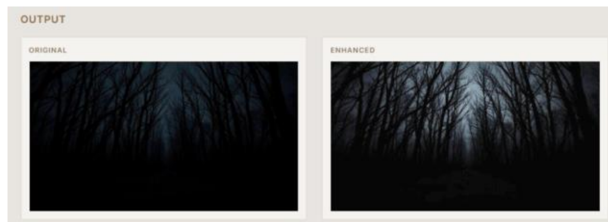

Figure 6: Enhancement result obtained using the auto enhancement mode.

VI. IMAGE QUALITY METRICS

The application uses different image quality metrics between the original and enhanced images.

1. MSE (Mean Squared Error)

The application calculates Mean Squared Error between original and enhanced images.

$$MSE = \frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n}\big(I(i,j) - K(i,j)\big)^2$$

Smaller MSE value means smaller error between images.

2. PSNR (Peak Signal-to-Noise Ratio)

PSNR uses MSE to measure the degree of image quality similarity.

$$PSNR = 10\log_{10}\left(\frac{MAX^2}{MSE}\right)$$

Bigger improvement quality is marked with bigger PSNR values.

3. SSIM (Structural Similarity Index)
SSIM calculates the structural similarity between original and enhanced images.

The SSIM index ranges from 0 to 1:
- Similarity is close to 1.
- Different from 1 represents structural distortion.

Object Detection Using Yolov8
In the current project, YOLOv8 is applied for object detection after image enhancement process.
Pretrained YOLOv8n model is used within the Ultralytics framework.

YOLOv8 detects objects and provides:
- bounding boxes
- classification labels
- confidences

User has the option to set confidence threshold.
Smaller confidence thresholds mean:
- More objects will be detected.
- May cause false detection.

Bigger confidence thresholds mean:
- Most confident objects will be detected.
- Weakly identified objects in dark parts of images will be ignored.

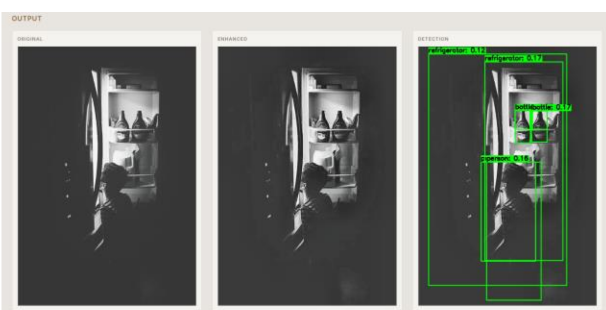

Figure 7: Result of YOLOv8 detection.

VII. RESULTS AND OBSERVATIONS

Different low-light images were used for testing including:
- Indoor scenes
- Dark object pictures

1. Enhancement Results and Observations
- CLAHE techniques produced great local contrast enhancement.
- Gamma correction technique provided fast brightness enhancement.
- The Zero-DCE inspired technique provided smooth enhancement in extremely dark regions.
- The Auto mode technique dynamically selected image enhancement technique depending on image quality.

2. Detection Observations
Different image enhancement techniques provided different object visibility and detection results when processed using YOLOv8.
- Low confidence thresholds:
- Will detect more objects.
- High confidence thresholds:
- Will detect more confident objects.
- Small or partially visible objects received low confidence values.
- Extremely dark images sometimes produced wrong detection results.

3. Image Quality Metrics Analysis
In this project, the following image quality metrics are calculated:
- MSE
- PSNR
- SSIM

These metrics can be used for comparing image quality between the original and enhanced images.

Table 1: Comparison of image quality metrics measured using different techniques.

Enhancement Technique	MSE	PSNR	SSIM
CLAHE	744.71	19.41	0.3057
Gamma Correction	235.92	24.4	0.7082
Zero-DCE Inspired	8.21	38.99	0.9277

The actual values of these metrics depend on the chosen image and image enhancement techniques.
The analysis shows that different enhancement techniques affect image quality metrics differently.

CLAHE produced strong local contrast enhancement and improved structural visibility. Gamma correction increased overall brightness rapidly but occasionally affected structural consistency. The Zero-DCE inspired enhancement method produced smoother illumination enhancement and balanced image quality across darker regions.

The variation in MSE, PSNR, and SSIM values indicates that enhancement techniques influence image quality differently depending on brightness and contrast conditions.

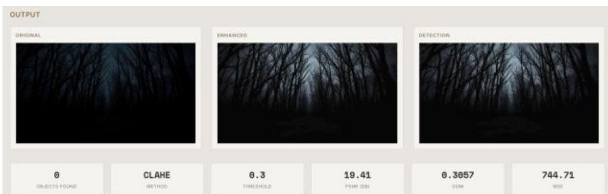

Figure 8: Result of image enhancement using CLAHE technique and its quality metrics.

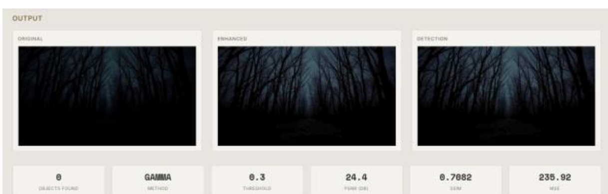

Figure 9: Result of image enhancement using gamma correction technique and its quality metrics.

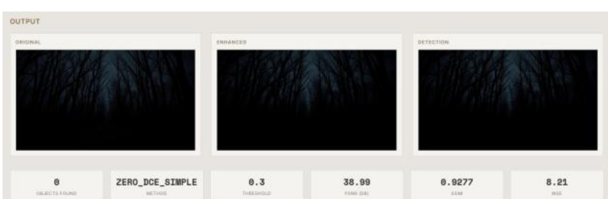

Figure 10: Result of image enhancement using Zero-DCE inspired technique and its quality metrics.

4. Effect of Different Enhancement Techniques on YOLOv8 Detection

Table 2: Objects detected with different enhancement techniques.

Enhancement technique	Objects detected
CLAHE	8
Gamma Correction	7
Zero-DCE inspired	8

The effect of different enhancement techniques on YOLOv8 object detection was tested by applying each of the techniques to the same low-light image having multiple objects.

It was observed that the effect of different enhancement techniques on YOLOv8 detection outputs was dependent on image lighting conditions, namely, brightness, contrast, and visibility.

Upon application of CLAHE enhancement technique, local contrast and object boundaries became clearer and more evident; therefore, it resulted in enhanced object detection outputs.

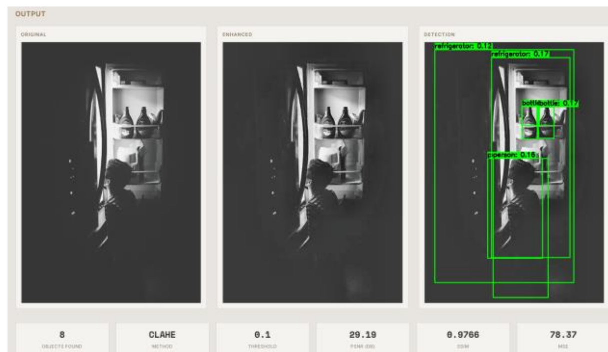

Figure 11: YOLOv8 detection results after CLAHE enhancement.

Gamma correction improved the visibility of objects in moderately dark images due to increased brightness and better visibility. Sometimes, increased brightness caused blurred object detection outputs.

Figure 12: YOLOv8 detection results after applying Gamma Correction enhancement.

Zero-DCE inspired enhancement technique helped to improve visibility of darker areas while providing smooth illumination; hence, it improved YOLOv8 detection outputs.

Figure 13: YOLOv8 detection results after applying Zero-DCE inspired enhancement.

These comparative results showed that different enhancement techniques had an impact on YOLOv8 detection outputs depending on brightness, contrast, and visibility of the image. Also, variation in object detection counts in comparison to other enhancement techniques demonstrated that enhancement quality affected YOLOv8 detection outputs.

Limitations

The present limitations of the project are as follows:

- The project does not incorporate the official pretrained Zero-DCE neural network.
- Noisiness can increase in very dark photos.
- Image lighting affects detection.
- Supports image-only enhancement process.
- The pretrained YOLOv8n is used instead of customized training on low light.

Future Scope

Future work on the project might include:

- Utilization of pretrained Zero-DCE models officially.
- Supporting video enhancements.
- Negative noise reduction algorithms.
- YOLOv8 customization through training.
- Mobile version.
- GPU support.

VIII. CONCLUSION

This research work illustrated Lumnia as a comparative low-light image enhancement and object detection tool.

The project incorporated the following components:

- CLAHE
- Gamma Correction
- Zero-DCE inspired enhancement
- YOLOv8 object detection

Thus, it can be concluded that various low-light image enhancement techniques have different effects on image visibility and the outputs of YOLOv8 object detector.

Various image enhancement techniques resulted in different outputs; therefore, comparative analysis would help select appropriate image enhancement techniques.

Future scope for improvement can allow incorporating more sophisticated image enhancement techniques and object detection models in the project's architecture.

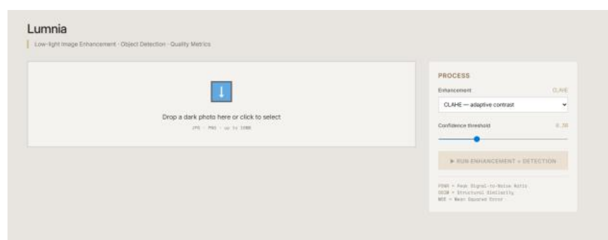

Figure 14(a): User Interface for image uploading and configuring parameters.

Figure 14(b): Output image after enhancement along with YOLOv8 detection.

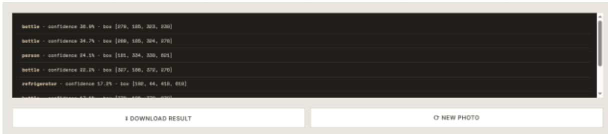

Figure 14(c): Detection log interface displaying detected objects, confidence scores, and result management controls.

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