**Project Title:**

**A Zero-Reference Low-Light Image-Enhancement Approach Based on Noise Estimation**

**Abstract**  
Computer vision is primarily concerned with improving images in low-light settings, as poor lighting can cause significant noise and color distortions, which has implications for applications like autonomous driving, medical imaging, and surveillance. In practical use, traditional enhancement methods are limited to training data that is either paired or unpaired, making them less relevant in real-world scenarios where such a matched dataset may not be available.

This project introduces a new approach, called the **Zero-Reference Low-Light Image-Enhancement (ZLEN)** approach, to improve image quality by estimating noise and using high-order curve expressions without reference images. This approach employs a convolutional neural network (CNN) that is lightweight and can predict curve parameters, resulting in improved noise reduction and increased contrast while keeping computational overhead low. Moreover, the incorporation of semantic-aware attention modules in image processing enhances visual clarity.

The performance of ZLEN is boosted by rigorous experimentation on benchmark datasets, which consistently yields superior results to current zero-reference methods. In addition, its practical use in real-world applications such as underground mining and nighttime surveillance highlights the effectiveness of ZLEN. According to the results, ZLEN provides a feasible, efficient, and effective way to enhance low-light images in real-time that doesn't require any pre-existing datasets. Further refinement could be aimed at including more contextual information in future enhancements.

**Project Objectives**  
The main focus of this project is to devise a new **zero-reference low-light image-enhancement** technique that minimizes noise interference while still maintaining a **lightweight network architecture**. **Zero Limit Energy (ZLEN)** is a proposed approach that enhances low-light images without the need for training data, making it suitable for real-life applications where such data is not available.

Its approach emphasizes the improvement of the **high-order curve expression** that governs how low-light images are compared to their enhanced equivalents, while also dealing with noise using a **noise-estimation module** and subsequently applying the **n+1NP (zero-reference noise loss function)**. This project aspires to achieve pioneering results in **improving low-light images**, especially in areas like **coal mines and nighttime surveillance**.

**Methodology**  
The process comprises several fundamental steps:

1. **Enhancing the Noise Map Features:** A low-light image input is fused with the original image and transformed into a **noise estimation map** using confocal planes.
2. **Higher-Order Curve Expression:** A high-order curve expression is proposed, incorporating a noise term to minimize noise in the enhanced image.
3. **CNN-Based Parameter Estimation:** A **lightweight convolutional neural network (CNN)** estimates the high-order curve parameters, linking the low-light image to its enhanced version.
4. **Reference-Free Loss Functions:** Two loss functions are used—one for **noise estimation** and another for **color consistency** while reducing noise.
5. **Semantic-Aware Attention Module:** This module extracts **semantic-aware features** from the noise map, improving input features for the curve estimation network.
6. **Depth-Curve Estimation Network:** A network ensures **accurate image enhancement** by dynamically adjusting curve parameters.

**Key Findings**  
By using the **ZLEN method**, SOTA (state-of-the-art) performance is surpassed compared to other **zero-reference and unpaired-reference image-enhancement methods**. This approach exhibits **greater improvement** in **noise reduction and color accuracy** than current techniques while maintaining **computational efficiency**.

This method has proved successful in **improving low-light images in harsh environments like coal mines**. The **robustness and usefulness** of ZLEN are demonstrated through **rigorous qualitative and quantitative analyses on benchmark datasets**. **Real-time applications** benefit from **faster processing speeds** compared to other non-full-reference methods.

**Step-wise Solution Approach**

**Step 1: Noise Estimation**

* Estimate noise and apply it to the low-light image.
* Calculate the color representation of the provided image.
* Use gradient analysis to generate a **noise map** using the color map.
* Integrate the original image into the noise map for better accuracy.

**Step 2: Higher-Order Curve Expression**

* Define a **high-order curve expression** that considers noise.
* Use this curve to **enhance the image while minimizing noise**.

**Step 3: Lightweight CNN and Zero-Reference Loss Functions**

* Estimate **high-order curve parameters** using a **compact CNN**.
* Apply **noise-estimation loss** and other **reference-free loss functions** for noise and color correction.
* Optimize the curve parameters through **gradual adjustments**.

**Step 4: Semantic-Aware Attention Module**

* Use a **semantic-aware attention module** to extract noise-related features.
* Generate **feature representations** from the **RGB values** of the image.
* Utilize the attention map to **enhance image details**.

**Step 5: Depth-Curve Estimation Network**

* Incorporate **dropout layers** to minimize noise in the **depth-curve-estimation network**.
* Optimize the **curve parameters for RGB channels** to enhance contrast.
* Ensure **network convergence** using reference-free loss functions.

**Step 6: Real-Life Implementation**

* Apply **ZLEN** in challenging environments like **coal mines and indoor areas**.
* Assess enhanced images for **noise reduction, color accuracy, and aesthetic appeal**.

**Step 7: Performance Evaluation**

* Conduct **qualitative and quantitative analyses** on benchmark datasets.
* Compare **ZLEN’s performance** with modern **zero-reference and full-reference methods**.
* Validate its effectiveness via **user trials and perceptual quality assessments**.

**Reference:**

[1] Cao, P.; Niu, Q.; Zhu, Y.; Li, T. A Zero-Reference Low-Light Image-Enhancement Approach Based on Noise Estimation. *Appl. Sci.* 2024, 14, 2846. <https://doi.org/10.3390/app14072846>

**Team:**

Amrita Singh Rajput

E22cseu0365