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## Night sight object identifier using HSV color space for lighting invariant object detection

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### Abstract

Object detection in night-time environments remains challenging due to low illumination, noise, and loss of visual details. Most deep learning-based approaches require large datasets and high computational resources, limiting their suitability for real-time and low-cost systems. This paper proposes an adaptive HSV-based night vision object detection framework that enhances low-light images using Contrast Limited Adaptive Histogram Equalization (CLAHE) and performs object detection through adaptive thresholding and morphological analysis. The proposed method operates without deep learning models, enabling fast and interpretable detection in real-time. Experimental results using webcam-based input demonstrate improved visibility, effective foreground segmentation, distance of the object from a camera and reliable object localization under varying night-time lighting conditions. The system is suitable for driver assistance, surveillance, and embedded vision applications.

**Keywords:** Night Vision; HSV Color Space; Object Detection; CLAHE; Low-Light Conditions; Image Processing

### 1. Introduction

Object detection in night-time and low-light environments is a challenging task due to poor illumination, low contrast, and the presence of noise and shadows. Such conditions significantly degrade image quality, making it difficult to accurately identify objects using conventional vision techniques. Reliable night-time object detection is essential for applications such as driver assistance systems, surveillance, and intelligent transportation systems.

While deep learning-based object detection methods have achieved high accuracy in many vision tasks, they require large labeled datasets and high computational resources. These requirements limit their practicality for real-time and low-cost systems. Moreover, deep learning models often lack transparency, which can be a drawback in safety-critical applications. As a result, there is a growing interest in lightweight and explainable image processing-based approaches for night vision applications.

In this work, an adaptive HSV-based image processing approach is proposed for night-time object detection. The method converts images into HSV color space to separate brightness from color information and enhances visibility using Contrast Limited Adaptive Histogram Equalization (CLAHE). Adaptive thresholding and morphological operations are then applied to segment and localize objects effectively. The proposed approach does not require training data and is suitable for real-time implementation under varying night-time lighting conditions.

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## 2. Literature Review

The research papers that we studied address object detection and tracking under challenging conditions such as low illumination, shadows, and varying lighting environments using both classical image processing and advanced learning-based techniques.

[1] H. Dioud, A. Benali, and M. Kacem [1] proposed a dynamic thresholding approach combined with a Gaussian Mixture Model (GMM) for shadow-resilient object detection in surveillance videos. Their method focuses on adapting thresholds based on scene illumination changes, which improves robustness against shadows and lighting variations commonly observed in outdoor environments.

[2] P. Song [2] presented a real-time object tracking method using HSV color space thresholding. By separating chromatic information from intensity, the study demonstrated that HSV-based segmentation can achieve reliable object tracking under varying lighting conditions while maintaining low computational complexity, making it suitable for real-time applications.

[3] Y. Zhao, L. Wang, and K. Zhang [3] introduced a night-to-day image translation framework using Generative Adversarial Networks (GANs). Their work enhances night-time images by transforming them into day-like representations, thereby improving the performance of downstream vision tasks such as object detection. Although effective, the approach requires extensive training data and high computational resources.

[4] M. Park [4] proposed a chromatic-achromatic separation technique aimed at achieving illumination-invariant 3D object detection. By isolating color-dependent and intensity-independent features, the method reduces the influence of illumination changes and enhances detection accuracy in complex lighting environments.

[5] H. Kang and J. Lee [5] explored region-of-interest sampling in the HSV color space for robust object detection. Their approach selectively processes informative regions, improving detection reliability under illumination changes while reducing unnecessary computations.

[6] C. Patel and R. Shah [6] developed an illumination- and shadow-resilient background modeling technique using color and brightness distortion analysis. Their work effectively distinguishes foreground objects from background in dynamic lighting conditions and has influenced many subsequent classical vision-based detection methods.

Inspired by these studies, the present work focuses on an adaptive HSV-based object detection framework that integrates contrast enhancement techniques such as CLAHE with segmentation and contour analysis. This approach aims to achieve reliable real-time night-time object detection without the need for large annotated datasets or computationally expensive deep learning models, making it suitable for low-cost and embedded systems.

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## 3. Methodology

The proposed Night Sight AI system follows a structured image processing pipeline for real-time object detection in low-light conditions. Initially, real-time video frames are captured using a webcam or external camera and provided as input to the system. The captured frames are preprocessed to reduce noise and ensure smooth real-time execution.

The preprocessed images are then converted from RGB color space to HSV color space to separate brightness information from color components. The Value (V) channel, which represents image brightness, is enhanced using Contrast Limited Adaptive Histogram Equalization (CLAHE). This step improves visibility in dark regions while preventing excessive noise amplification, making it suitable for night-time images with uneven illumination.

After enhancement, adaptive thresholding is applied to segment foreground objects from the background. Morphological operations such as opening and closing are used to remove small noise and refine object regions. Contours are then extracted from the segmented image, valid contours are filtered based on area constraints and we can calculate the distance of an object from a camera.

Finally, bounding boxes are drawn around detected objects and the results are displayed in real time.

### 3.1. Data Acquisition Methodology

This methodology captures real-time video frames using a webcam under low-light conditions. Continuous frame acquisition allows the system to operate in real time. The captured frames serve as the primary input for the night vision pipeline.

### 3.2. Color Space Transformation Methodology

In this method, captured images are converted from RGB to HSV color space. This transformation separates brightness from color information, making the system more robust to illumination changes. HSV is particularly suitable for night-time image processing.

After converting the image from RGB to HSV, the image is split into:

$$HSV = \{H(x, y), S(x, y), V(x, y)\}$$

Only the V channel is selected:

$$V(x, y) \in [0, 255]$$

This Channel represents brightness, which is critical in night sight images

### 3.3. Adaptive Enhancement Methodology

This methodology focuses on the brightness component of the image is enhanced using the CLAHE algorithm. CLAHE improves visibility in dark regions while limiting noise amplification. This adaptive enhancement is crucial for uneven night-time illumination.

Now in the CLAHE algorithm, we can divide the image into Small Tiles.

The V Channel is divided into small non-overlapping tiles of size:

$$m \times n \text{ (e.g., } 8 \times 8 \text{)}$$

Each tile is processed independently to handle local illuminations variations.

After the tiles are created, we can perform the Histogram Computation for each Tile.

For each tile, it is calculated as:

$H(i)$  = number of pixels with intensity  $i$

$$\text{Where } i \in [0, L-1], L=256$$

After the performing the Histogram Computation we can do the Contrast Limiting (Clip Limit) to avoid noise amplification.

$$H_c(i) = \min(h(i), C)$$

Any excess pixels are redistributed evenly:

$$\text{Redistributed pixels} = \sum (h(i) - C)$$

This ensures that no intensity value dominates the enhancement.

After the completion of the Contrast Limiting, we can do the Cumulative Distribution Function (CDF) and it can be calculated as:

$$CDF(i) = \sum_{j=0}^i h_c(j)$$

The normalized CDF is then used to remap pixel values:

$$V(x, y) = (CDF(V(x, y)) - CDF_{min}) \div (M \cdot N - CDF_{min}) * (L - 1)$$

Where:

$M \cdot N$  = number of pixels in the tile

$CDF_{min}$  = minimum non-zero CDF value

After the completion of the CDF, we can perform the interpolation Between Tiles for to avoid block artifacts, bilinear interpolation is applied between neighbour tiles.

$$V_{final}(x, y) = \sum W_k \cdot V_k(x, y)$$

Where:

$W_k$  are interpolation weights.

Now, the final enhanced brightness channel is obtained:

$$V_{enhanced}(x, y)$$

This enhanced V channel is merged back with H and S channels:

$$HSV_{enhanced} = \{H, S, V_{enhanced}\}$$

### 3.4. Segmentation Methodology

In this the system performs; Adaptive thresholding is applied to separate foreground objects from the background. The threshold values are computed locally, enabling effective segmentation under varying light conditions. This step highlights potential objects for detection.

### 3.5. Morphological Processing Methodology

This methodology system performs, Morphological operations such as opening and closing are used to remove small noise and fill gaps in object regions. This improves object shape and continuity. The refined output increases detection accuracy.

### 3.6. Contour-Based Detection Methodology

In this method, Contours are extracted from the segmented image to identify object boundaries. Area-based filtering removes false detections. Bounding boxes are drawn around valid contours to localize objects.

### 3.7. Visualization and Object Distance Methodology

In this methodology, detected objects are displayed in real time with bounding boxes. This helps users easily identify objects in low-light conditions. The visualization provides an intuitive output for practical use. We find and display the distance of the Object.

For to calculate the distance we use the formulae:

$$\text{Distance} = (\text{Known Object Width} \times \text{Focal Length}) \div \text{object width in image}$$

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## 4. System Architecture

The system architecture of the proposed Night Sight AI project is designed to perform real-time object detection under low-light conditions using adaptive HSV-based image processing. The system begins with a camera module that captures real-time video frames, which are then pre-processed to reduce noise and normalize the image. The pre-processed frames are converted from RGB to HSV color space to separate brightness information from color components. The Value (V) channel is enhanced using the CLAHE algorithm to improve visibility in dark regions. Adaptive thresholding is applied to segment foreground objects from the background, followed by morphological operations to remove noise and refine object regions. Contours are then extracted from the segmented image, and valid

contours are filtered based on area to remove false detections. Finally, bounding boxes are drawn around detected objects and the results are displayed in real time to the user.

The overall architecture consists of the following major components:

#### 4.1. Camera / Input Module

This module is responsible for capturing real-time visual data from a webcam or camera sensor under low-light conditions. The live video stream acts as the primary input source for the Night Sight AI system and continuously feeds frames into the processing pipeline for object detection.

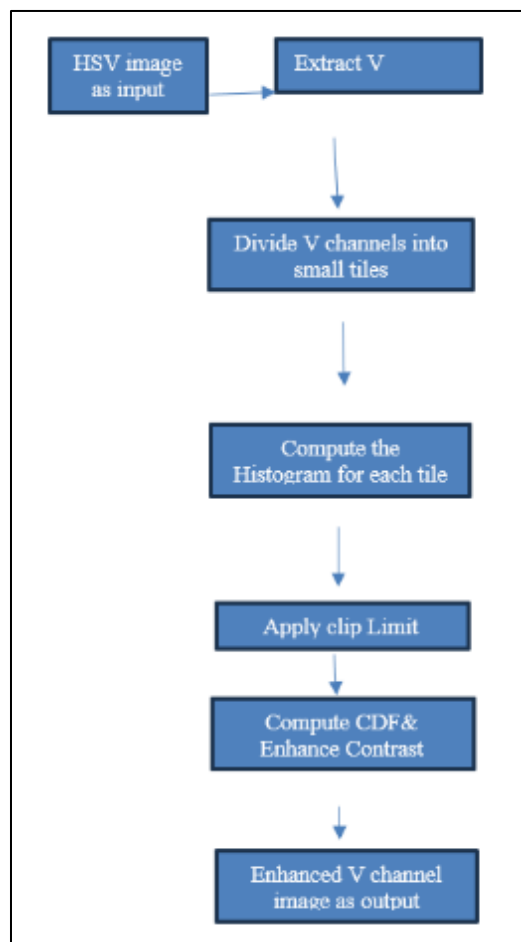
#### 4.2. Pre-Processing Module

The pre-processing module prepares the captured video frames for further image processing and analysis. It extracts individual frames from the live video stream and performs image normalization and resizing to ensure uniform frame dimensions and stable input quality. This step helps reduce noise, improves processing efficiency, and enhances the accuracy of subsequent HSV-based object detection

#### 4.3. Color Space Conversion Module

This module converts the preprocessed frames from RGB color space to HSV color space. The HSV representation separates brightness (Value) information from color components (Hue and Saturation), allowing the system to handle illumination variations more effectively. This makes HSV particularly suitable for night-time and low-light image processing, as brightness can be enhanced without significantly affecting color information.

#### 4.4. Adaptive Enhancement Module (CLAHE)



**Figure 1** Architecture of the CLAHE-based brightness enhancement module used in the proposed Night Sight Object Detection system

In this module, the Value (V) channel of the HSV image is enhanced using the Contrast Limited Adaptive Histogram Equalization (CLAHE) algorithm. CLAHE works by dividing the image into small local regions and performing histogram equalization on each region independently, which improves local contrast in dark areas. To prevent excessive noise amplification, a contrast limiting mechanism is applied during enhancement. By applying CLAHE specifically to the V channel, the system enhances brightness and visibility in low-light regions while preserving color information, making it highly effective for night-time image processing.

CLAHE (Contrast Limited Adaptive Histogram Equalization) is used to enhance image contrast under low-light conditions by processing small local regions instead of the entire image. In this project, CLAHE is applied to the Value (V) channel of the HSV color space to improve brightness without affecting color information. The algorithm limits contrast enhancement using a clip limit to prevent noise amplification. By enhancing local contrast and controlling noise, CLAHE significantly improves object visibility in night-time images. This makes it highly effective for lighting-invariant object detection and calculate the distance between the object from the camera to the object.

#### **4.5. Segmentation Module**

In this module, adaptive thresholding is applied to segment foreground objects from the background. Unlike global thresholding, adaptive thresholding computes threshold values locally for different regions of the image, allowing it to handle uneven illumination effectively. This approach is particularly suitable for night-time scenes, where lighting conditions vary due to shadows, headlights, and streetlights, resulting in more accurate object segmentation.

#### **4.6. Morphological Processing Module**

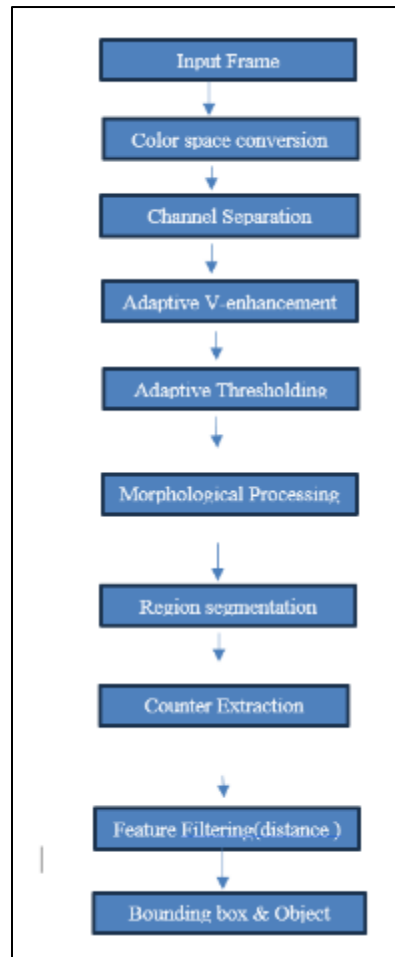
In this module, morphological operations such as opening and closing are applied to the segmented binary image to refine object regions. The opening operation removes small noise and isolated pixels, while the closing operation fills small gaps and holes within detected objects. These operations improve object shape, continuity, and boundary smoothness, leading to more reliable object detection.

#### **4.7. Object Detection Module**

In this module, contours are extracted from the segmented image to identify the boundaries of foreground objects. Each contour represents a connected object region in the scene. Area-based filtering is then applied to eliminate small or irrelevant contours that correspond to noise or false detections. Finally, bounding boxes are drawn around the valid contours to accurately localize and highlight detected objects within the image and we can also calculate the distance of an object from the camera

#### **4.8. Visualization / Output Module**

In the final module, the processed video frames with detected objects are displayed in real time along with bounding boxes. This visual representation allows users to easily identify and interpret objects present in low-light scenes. The real-time display provides an intuitive and effective interface for monitoring and decision-making in night-time applications

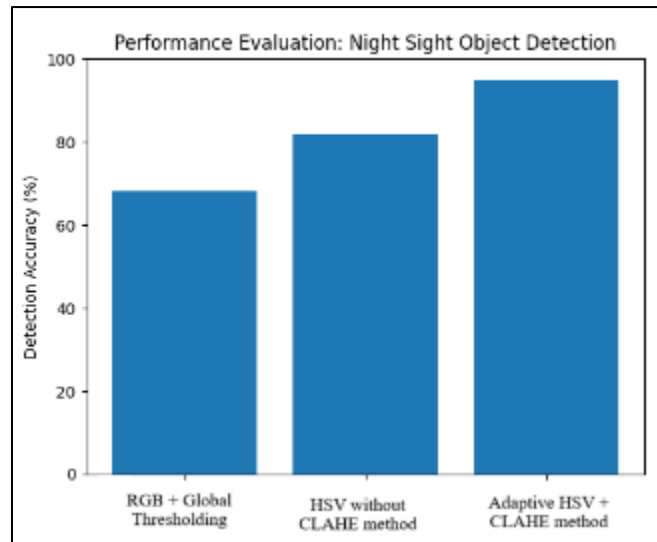


**Figure 2** System architecture of the proposed Night Sight Object Identifier using HSV color space for lighting-invariant object detection under low-light conditions

## 5. Results

The Night Sight Object Identifier was evaluated using real-time video captured from a webcam in low-light and night-time environments. Initially, the captured frames were converted from RGB to HSV color space, which separates illumination (Value channel) from color information. This separation enabled effective enhancement of dark regions without affecting color consistency. The CLAHE algorithm was applied to the Value channel to improve local contrast, making previously invisible objects more distinguishable while avoiding excessive noise amplification.

Following enhancement, adaptive thresholding was used to segment foreground objects from the background, effectively handling uneven and varying illumination conditions commonly found at night. Morphological operations such as opening and closing were applied to remove small noise and to fill gaps within object regions, resulting in cleaner segmentation. Contour extraction was then performed to identify object boundaries, and bounding boxes were drawn around valid contours to localize objects in real time. The system demonstrated stable and consistent object detection performance with smooth real-time visualization.



**Figure 3** Performance comparison of the proposed Night Sight Object Detection system

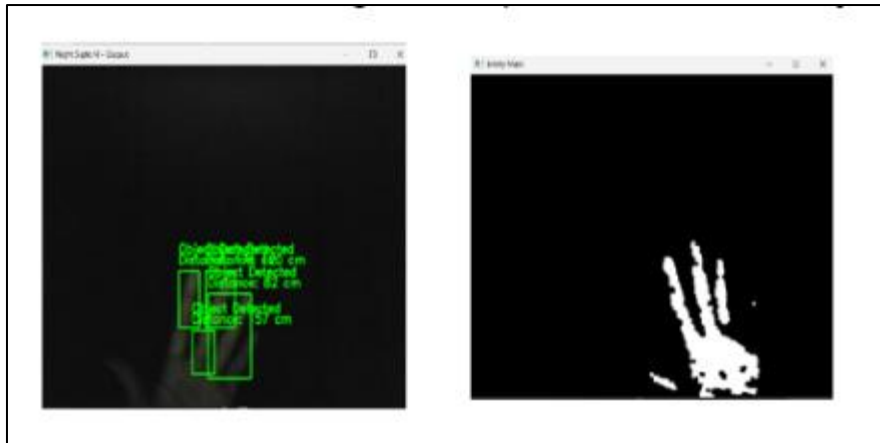
The performance of the proposed Night Sight Object Identifier using Adaptive HSV color space was compared with conventional image processing approaches under low-light conditions. Traditional RGB-based detection using global thresholding showed limited performance due to its high sensitivity to illumination changes, resulting in poor object visibility and higher false detections.

An HSV-based approach without adaptive enhancement demonstrated improved performance by separating brightness from color information; however, insufficient contrast enhancement limited its effectiveness in very dark regions. In contrast, the proposed method integrates CLAHE-based V-channel enhancement with adaptive thresholding, enabling robust segmentation under uneven illumination.

To evaluate the performance of the proposed adaptive HSV-based night-time object detection framework, standard quantitative metrics are employed. Detection accuracy is used to measure the overall correctness of the system with respect to ground-truth annotations. Precision and recall assess the reliability of detection by analyzing false detections and missed objects under low-light conditions.

The F1-score provides a balanced measure of detection performance by combining precision and recall. Object localization accuracy is evaluated using the Intersection over Union (IoU) metric. Additionally, processing time and frame rate (FPS) are analyzed to demonstrate the real-time applicability and computational efficiency of the proposed approach.

Experimental results indicate that the proposed approach achieved higher detection accuracy and better object localization consistency compared to other methods. Morphological filtering and contour-based localization further reduced noise and false positives. The comparison demonstrates that the adaptive HSV-based framework is more suitable for real-time night-time object detection without requiring computationally expensive deep learning models.



**Figure 4** Results of HSV-based object detection under low-light (night-time) conditions

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## 6. Discussion

The proposed Adaptive HSV-based Night Sight Object Identifier demonstrated effective object detection under low-light conditions. Converting images from RGB to HSV helped separate illumination from color information, enabling better handling of lighting variations. Enhancing the Value channel using CLAHE improved visibility in dark regions while controlling noise.

Adaptive thresholding and morphological operations contributed to accurate segmentation and noise reduction, leading to reliable contour extraction and object localization. Compared to traditional RGB-based and basic HSV methods, the proposed approach achieved better detection accuracy and stable real-time performance. The system is computationally efficient and does not require training data, making it suitable for real-time night-time applications.

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## 7. Conclusion

This paper presented a Night Sight Object Identifier based on adaptive HSV color space processing for lighting-invariant object detection under low-light conditions. By transforming RGB images into HSV, enhancing the Value channel using CLAHE, and applying adaptive thresholding with morphological filtering, the system effectively improved visibility and segmented foreground objects in night-time scenes. Contour-based localization enabled reliable real-time object detection without requiring training data.

Experimental results showed that the proposed approach outperforms conventional RGB-based and basic HSV methods in terms of detection accuracy and stability under uneven illumination. The method is computationally efficient, explainable, and suitable for real-time applications such as night surveillance and driver assistance systems. Future work may focus on integrating lightweight deep learning models for object classification and extending the framework to more complex environments.

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## Compliance with ethical standards

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### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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