Assignment 4

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1 Exercise 2: Cone Detection

1.1 Objective

The objective of this exercise was to design a robust, end-to-end pipeline to detect and localize traffic cones in diverse environments. The system needed to handle challenges such as multiple cones, varying backgrounds (grass, road), lighting variations (shadows, highlights), and partial occlusions.

1.2 Pipeline Architecture

Our approach evolved through two iterations. The initial attempt utilized edge detection and Hough transforms, but the final robust pipeline focused on color segmentation in the LAB space combined with a custom contour grouping algorithm.

The final pipeline consists of the following stages:

1. **Preprocessing:** The input image is smoothed using a Gaussian Blur (5×5 kernel) to suppress high-frequency noise before color conversion.
2. **Color Space Conversion (LAB):** The image is converted from BGR to the LAB color space. Unlike RGB, LAB separates lightness (L) from color components (a and b), making the detection more robust to lighting changes/shadows compared to standard RGB thresholding.
3. **Color Segmentation:** We apply thresholding on the A channel. The specific range allows us to isolate the orange hue of the cones effectively while ignoring the background.
4. **Morphological Refinement:** To clean the binary mask, we apply:
   - **Opening:** Removes small noise speckles (false positives).
   - **Closing:** Fills small holes within the detected cone regions.
5. **Contour Grouping & Convex Hull:** A key challenge was that a single cone often appeared as multiple fragmented contours ("strip" problem). To solve this, we implemented a custom clustering algorithm:
   - Centroids of all valid contours are calculated.
   - Contours whose centroids are within a distance of 100 pixels are grouped together.
   - A single Convex Hull is computed for each group, creating a unified bounding box for the cone.

1.3 Justification of Choices

1.3.1 Why LAB Color Space?

In our first version, we experimented with Gamma correction and CLAHE. However, we found that converting to LAB space provided better separability. The 'A' channel (for Orange and Red cones) and in some cases 'B' channel (for Yellow cones) are particularly effective for isolating the cones from background regardless of the lighting intensity (L-channel).

1.3.2 Edge vs. Region-Based Detection

Our initial implementation (v1) attempted to use Canny edge detection and Probabilistic Hough Lines to find the structural sides of the cones. While conceptually sound, this approach was prone to false positives from background clutter (e.g., fences, pavement cracks). The region-based approach (Color Segmentation) proved significantly more robust for this specific dataset.

1.4 Observations and Failure Analysis

- **Strip failure:** The grouping algorithm handled many cases where the cone's strips caused the mask to break into top and bottom halves. By clustering centroids, these halves were correctly identified as a single object in many cases, but it stills fails in few cases.
- **Lighting Variations:** The LAB thresholding remained consistent across both indoor and outdoor shadows, as the color channels (a, b) remain relatively stable even when lightness (L) varies.
- **Color:** The current pipeline relies heavily on the specific orange color of the cones. It may fail if:
  - There are other orange objects in the scene (e.g., orange clothing).
  - The lighting is extremely tinted (e.g., strong sunset), significantly shifting the a, b values.
- **Multiple cones:** It is not