Method Overview: Monocular Distance Estimation Using Ground Plane Geometry

1. Problem Definition

The goal of this method is to estimate the distance to an obstacle using **only a single RGB camera**, without relying on depth sensors, stereo vision, or LiDAR. The system is designed for **short-range obstacle detection** (approximately 3–4 meters) in front of the user.

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2. Key Assumptions

The method relies on the following assumptions:

- The camera is mounted at a known height **h** above the ground.
- The camera is tilted downward with a known pitch angle **θ**.
- The obstacle is in contact with the ground (ground-plane assumption).
- The camera's vertical field of view **α** and image height **H** are known.
- The vertical pixel coordinate **y** of the obstacle's ground-contact point can be detected from the image.

These assumptions are reasonable for pedestrian environments such as sidewalks, roads, and indoor floors.

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3. Principle of the Method

This approach is based on **triangle similarity under the pinhole camera model**.

Parameters:

h => Camera height above ground

θ => The angle of inclination the camera makes with the ground plane (Pitch Angle)

α => Camera's vertical field of view (vertical FOV)

H => The total vertical resolution of the image

y => The vertical pixel position of the object in the image (0 is the top pixel, H is the bottom pixel)

From the captured image, the **ground-contact point** of the obstacle is identified. Its vertical pixel position **y** is used to compute the angular deviation **φ** from the camera's optical axis:

$$\phi = \left(\frac{y - H/2}{H}\right) \cdot \alpha$$

The total angle between the camera ray and the ground plane is then:

$$\theta + \phi$$

Using basic trigonometry, the horizontal distance **d** to the obstacle is computed as:

$$d = \frac{h}{\tan(\theta + \phi)}$$

This calculation corresponds to finding the intersection of a camera ray with the ground plane.

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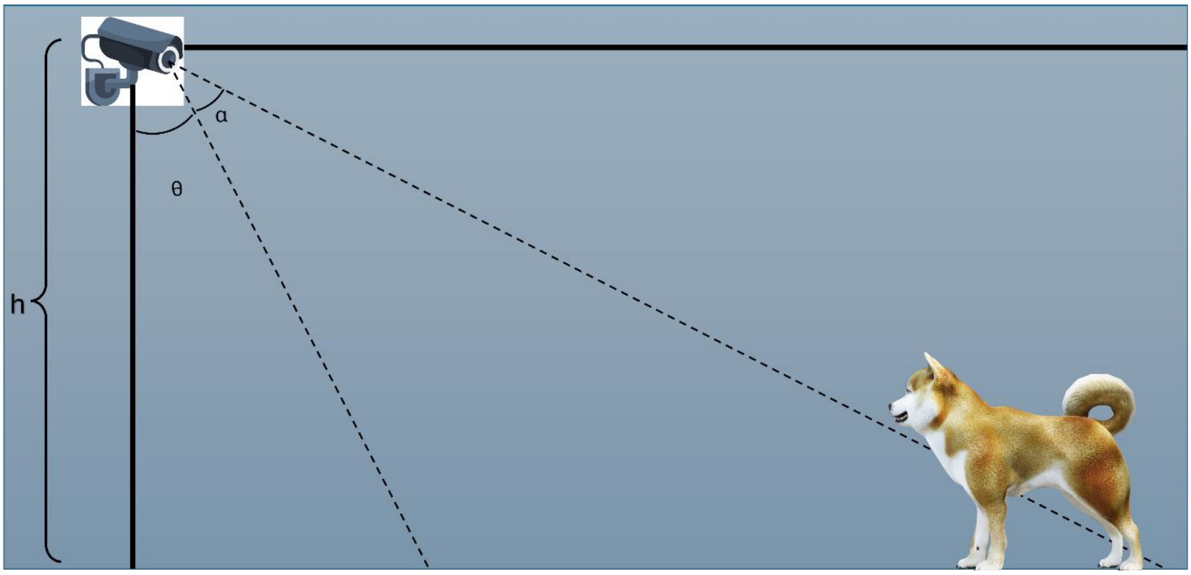
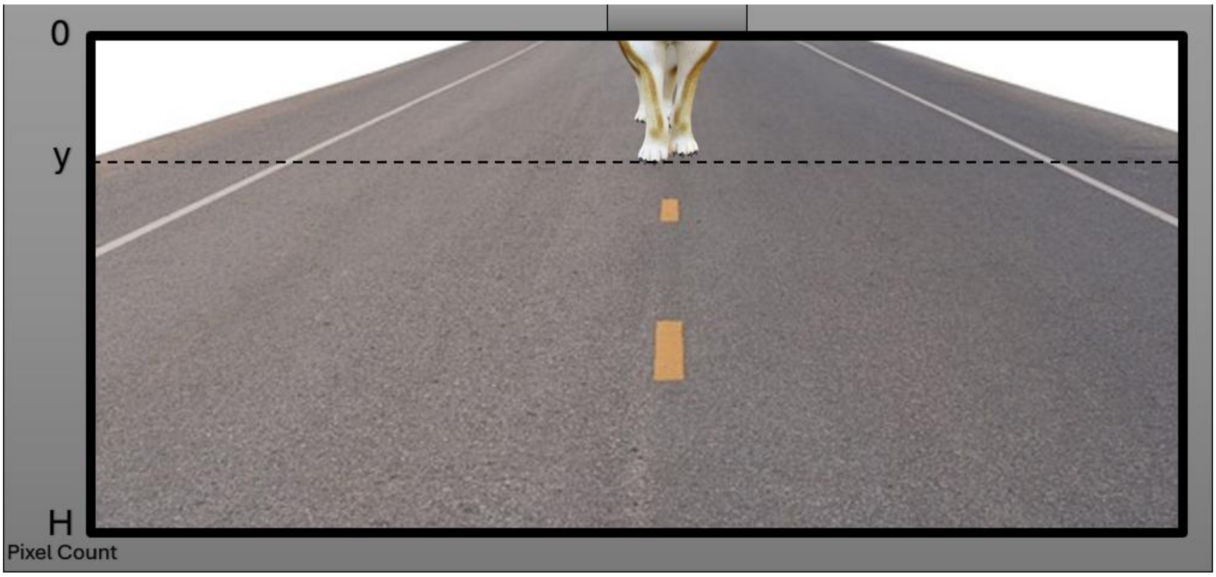
4. Improvements

IMU-Based Dynamic Pitch Compensation
Since the camera mounted on a wearable device cannot remain perfectly stable, an Inertial Measurement Unit (IMU) is used to continuously estimate and update the camera's pitch angle in real time. By compensating for head and body movements, the IMU enables more robust ground-plane intersection calculations and reduces distance estimation errors caused by natural user motion.

Discrete Distance Zone Classification
Rather than relying on precise metric distance values, estimated distances are categorized into discrete proximity zones to improve robustness and user safety. The detected obstacles are classified into distance ranges such as **Near**, **Medium-Near**, **Medium**, **Medium-Far**, and **Far**. This discretization mitigates the impact of pixel-level noise and geometric uncertainty while providing reliable and intuitive feedback for obstacle avoidance.

Stability-Oriented Obstacle Awareness
By combining IMU-based pitch correction with distance zone classification, the system prioritizes consistent obstacle awareness over exact numerical accuracy. This approach is particularly suitable for short-range obstacle detection in wearable assistive systems, where stable and conservative feedback is more critical than centimeter-level precision.


α
θ
h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