PathNav: Computer Vision-Based Navigation Pipeline with Real-Time Perception and Path Planning

Overview

This project presents a robust computer vision pipeline leveraging **YOLOPv2** for autonomous lane-keeping tasks in Unmanned Ground Vehicles (UGVs). The pipeline integrates **real-time perception** with **graph-based path planning algorithms** like A*, ensuring reliable navigation in dynamic and unstructured environments. By combining **deep learning-based vision models** with **classical planning techniques**, this system achieves a **balance of accuracy, efficiency, and adaptability**, making it suitable for real-world applications in autonomous navigation.

Key Features

Perception Module (Powered by YOLOPv2)

1. **Multi-Task Environmental Understanding**
    - **Lane and Drivable Area Detection**: YOLOPv2 accurately detects lane markings and drivable regions in real-time, ensuring robust lane-keeping in diverse road conditions.
    - **Object Detection**: Identifies obstacles, pedestrians, and other dynamic objects critical for collision avoidance.
    - **Semantic Segmentation**: Produces pixel-wise segmentation masks for distinguishing between road surfaces, background, and restricted areas.
2. **Advantages of YOLOPv2**
    - **End-to-End Architecture**: Efficiently integrates multiple perception tasks within a single network, reducing computational overhead.
    - **Real-Time Inference**: Designed for high-speed processing, achieving low-latency predictions suitable for real-time autonomous navigation.
    - **Robustness Across Conditions**: Performs well under varying lighting conditions (e.g., nighttime, glare, fog) and unstructured environments.
    - **Edge Deployment Friendly**: Optimized for embedded hardware acceleration (e.g., NVIDIA Jetson, TensorRT).
3. **Seamless Integration with Path Planning**
    - The perception module generates structured outputs (segmentation maps, bounding boxes) that feed into the planning module, enabling reactive decision-making.

Path Planning Module (Classical Geometric Graph-Based Planning)

1. *A Path Planning Algorithm**
    - Uses **grid-based or graph-based representations** of the environment for efficient pathfinding.

- Employs an **optimal heuristic search** strategy to compute **shortest, obstacle-free paths**.
- Supports **dynamic updates** by integrating real-time object detection from the perception module.

2. **Obstacle-Aware Trajectory Generation**
   - **Collision Avoidance**: Incorporates real-time obstacle maps to adjust paths dynamically.
   - **Smooth Navigation**: Applies **cost functions** to prioritize **smoothness, shortest distance, or energy efficiency** in trajectory generation.
3. **Computational Efficiency**
   - Heuristic-driven search techniques reduce **computational overhead**, enabling fast path replanning in dynamic environments.
   - Supports hierarchical or region-based planning for scalability in large-scale environments.
4. **Scalability & Adaptability**
   - The planning module is adaptable to different terrains and road structures.
   - Compatible with **UGVs, autonomous robots, and smart mobility solutions**.

Future Updates

1. **Enhanced Perception Capabilities**
   - Integration of **multi-sensor fusion** (e.g., LiDAR, radar) to improve robustness in extreme conditions.
   - Support for **panoptic segmentation**, merging instance-level and semantic understanding for richer environmental representation.
2. **Advanced Planning Strategies**
   - Hybrid approaches combining **graph-based algorithms** with **reinforcement learning** for adaptive obstacle avoidance.
   - Implementation of **trajectory optimization** techniques for smoother, kinematically feasible paths.
3. **3D Environment Modeling**
   - Extension to **3D path planning** for multi-level terrains or aerial navigation applications.
4. **Energy-Efficient Navigation**
   - Development of cost models to optimize energy consumption during traversal.
5. **Hardware Acceleration**
   - Deployment support for **edge AI accelerators** (e.g., NVIDIA Jetson, TensorRT) to enhance real-time processing.
6. **Simulation and Testing Suite**

- Release of a modular **simulation environment** for rigorous testing of perception-planning pipelines under diverse scenarios.

This project bridges the gap between **real-time perception** and **actionable path planning**, offering a solid foundation for **next-generation autonomous systems**. Contributions and collaborations are welcome to expand its capabilities and applications!

Note: This project is under active development. Refer to the license for terms of use.