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Low-altitude road following using strap-down cameras on miniature air vehicles

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ABSTRACT

This paper addresses the problem of autonomously maneuvering a miniature air vehicle (MAV) to follow a road using computer vision as the primary guidance sensor. We focus on low-altitude flight with the objective of maximizing the pixel density of the road in the image. The airframe is assumed to be a bank-to-turn fixed-wing MAV with a downward-looking strap-down camera. The road is identified in the image using HSV classification, flood-fill operations, and connected-component analysis. The main contribution of the paper is the derivation of explicit roll-angle and altitude-above-ground-level (AGL) constraints that guarantee that the road will remain in the footprint of the camera, assuming a flat earth. The effectiveness of our approach is demonstrated through high fidelity simulation and through flight results.

1. Introduction

This paper addresses the problem of tracking a visually distinct connected structure on the ground using a miniature air vehicle equipped with a strap-down camera. Potential structures include roads, pipelines, and perimeters of forest fires. To be specific, we will focus our attention in this paper on road following.

A potential road-following application of interest to the military is convoy support where the objective is to detect roadside bombs and ambushes along the anticipated route of the convoy. Surveillance and reconnaissance of these routes can be accomplished using low-altitude miniature air vehicles (MAVs) which relay video data to human operators associated with the convoy. Passive sensing devices like video cameras are covert and are therefore essential for this type of military operation. The GPS position of a road may not be available, and even if it is, the MAV's GPS receiver may be jammed by an adversary. Vision-based control using automated road tracking can meet the reconnaissance needs for convoy support while accommodating for potential GPS jamming without revealing the MAV's presence and position.

There are many applications where borders are not well defined or adequately mapped. Fire fighters confront situations where the extent of a fire may be unknown and changing in time. High-altitude aircraft and satellites are often requested for overhead imagery but these resources are not always available. Surveillance of fire perimeters using manned helicopters and aerial vehicles are limited because updrafts resulting from the fire create dangerous flying conditions. For safety reasons, manned aircraft are not used at night to survey forest fires. MAVs are an attractive alternative because they are relatively inexpensive to manufacture and replace, and because they can be used to obtain high-resolution imagery of the fire and its perimeter.

Studies that specifically address border and road following using cameras onboard unmanned ground vehicles (UGVs) have appeared in the literature for more than a decade [1–3]. Each of these studies presents a method to effectively extract the road from the video stream, project the estimated road position onto the inertial frame, and maneuver the vehicle to follow the road. A vanishing point in the image is used to simplify computer-vision algorithms and provide improved road-directional bearings. A vanishing point is the point in the image where the road merges with the horizon. In [1], an edge-detection algorithm is used to extract the road edges. By analyzing a smaller image window, the algorithm processes more complex calculations in real-time including estimating the road location. In [2], the road is registered onto a virtual map. Using this virtual map, sophisticated path corrections and intersection analysis improve the UGVs estimated path as it travels. The ability for a UGV to adjust to non-ideal road conditions is demonstrated in [3], where two assumptions are used to ensure that the road is effectively classified by processing the onboard video. The first assumption is that the vehicle begins operation on the road and generally remains there while the guidance algorithm is active. Secondly, ground-vehicle movement and general road structure are estimated using the vanishing point of the road. These assumptions significantly ease computation and decision complexity in the guidance loop.

Overhead views obtained by MAVs provide an alternate perspective to strategically important areas that cannot be obtained by ground vehicles. Researchers have only recently begun to

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