University of Victoria | Graduate Studies

Notice of the Final Oral Examination for the Degree of Master of Applied Science

of

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"Image-Based Visual Servoing of a Quadrotor Using Model Predictive Control"

Department of Mechanical Engineering

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Engineering Office Wing
Room 230

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Dr. Ben Nadler, Department of Mechanical Engineering, UVic (Member)

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Abstract

With numerous distinct advantages, quadrotors have found a wide range of applications, such as structural inspection, traffic control, search and rescue, agricultural surveillance, etc. To better serve applications in cluttered environment, quadrotors are further equipped with vision sensors to enhance their state sensing and environment perception capabilities. In addition to the common sensor suite which includes the global positioning system (GPS) and the inertia measurement unit (IMU), the on-board vision system serves as an important complementary element for the localization and navigation of the quadrotor. Using information extracted from a vision sensor to control the motion of a robot is referred to as visual servoing in the literature. In this thesis, we identify the challenging problems arising in the area of visual servoing of the quadrotor and propose effective control strategies to address these issues.

The control objective considered in this thesis is to regulate the relative pose of the quadrotor to a ground target using a sensor suite consisting of a monocular camera and an IMU. The camera is attached underneath the center of the quadrotor and facing down, and the ground target is a planar object consisting of multiple points. The image features used in the feedback loop are image moments defined in a “virtual image plane” that is always parallel to the flat ground. The deliberate selection of the image features enables the decoupling of the tilt motion of the quadrotor from the image kinematics, so that a dual-loop control structure can be adopted. The dual-loop structure consists of an outer-loop in charge of the vision guidance and an inner-loop in charge of attitude tracking.

During visual servoing, the target object is required to be maintained in the field of view (FOV) of camera, otherwise it would cause failure of control action generation. To ensure that the target object remains in the FOV, a nonlinear model predictive control (NMPC) controller is proposed to explicitly bound the tilt motion of the quadrotor when the quadrotor is maneuvering towards the target object. Furthermore, the bounds on the tilt motion can be automatically adjusted based on the vision feedback to reduce the conservativeness.

Moreover, due to a limited number of sensors on board, the linear velocity information of the quadrotor is not directly measurable, especially in GPS-denied environment, such as indoor or cluttered urban area. This poses challenges in the design of the model predictive controller which typically requires the information of all the system states. Accordingly, a high-gain

observer is designed to estimate the linear velocity of the quadrotor. Since the dual-loop control structure is adopted, the high-gain observer-based NMPC control scheme is employed for the outer-loop control, while the inner-loop control can be tackled by a proportional-derivative (PD) controller.

On the other hand, implementation of the NMPC controller requires solving the proposed optimization problems in real-time, thus inevitably introducing considerable explicit model predictive control (EMPC) controller is designed to improve the real time performance.

Simulation and experimental studies are performed to verify the effectiveness of the proposed control strategies. In addition, image feature extraction algorithms are illustrated to show how the image features are extracted from the captured images.