Vision-based Control for Robotic Systems: Constraint Satisfaction and Related Problems

ABSTRACT

This thesis primarily explores the Image-Based Visual Servoing (IBVS) techniques and their applications in robotic control, emphasizing the need to address significant challenges. IBVS operates by continually assessing the positions of feature points within images, comparing them to their desired locations, and iteratively adjusting control laws until the error state converges to zero, signifying stability. However, this approach is not without its concerns. One such concern stems from the assumption that feature vectors remain perpetually visible in each camera frame, presuming that objects of interest remain within the camera's field of view (FoV). The practical scenario, where features move out of the FoV as robots progress towards their goals, is termed the visibility or FoV problem. Addressing this challenge is pivotal for the effectiveness of vision-based control systems. Furthermore, ensuring that control energy adheres to defined robot saturation limits while accommodating FoV constraints is imperative. This necessitates simultaneous consideration of FoV and input constraints in the design of IBVS control laws. Another important concern centres around the accuracy of depth estimates, which directly impact the image interaction matrix used in the IBVS control law. Inaccurate estimates can severely compromise control performance. Another critical issue is that IBVS predominantly employs kinematic controllers, which disregard dynamic effects from both robot and camera dynamics. These controllers assume instantaneous velocity attainment, but real-world scenarios demand dynamic modeling and control to handle uncertainties effectively.

In situations where dynamic controllers are employed, numerical approximations are often used to estimate velocities from position measurements, introducing a delay into the system. A comprehensive understanding of delay-based analysis is crucial for understanding the behaviour of such controllers. These challenges and considerations underpin the objectives of this thesis, aiming to maximize the potential of IBVS in robotic control applications. Inspired by human capabilities, this research advocates leveraging visual information from cameras to foster cooperative behaviors among robots. An application is presented in the form of leader-follower formation control. Through theoretical exploration and simulations, this research advances our comprehension of IBVS, offering practical solutions to its challenges while opening new avenues for exploiting visual information in real-world robotic control environments.