Paper Review
Visual Servo Control Part 1: Basic Approaches

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1 Paper Summary

This tutorial paper introduces two classical visual servo control methods in great detail: image-based visual servo (IBVS) and position-based visual servo (PBVS). It first introduces the problem of visual servoing as a minimization of error based on some image features and camera parameters. Based on such overall problem formulation, this paper then derives from scratch the velocity controller that ideally makes the tracking error decay exponentially. To achieve such controller, the pseudoinverse of the interaction matrix (which relates camera velocity and rate of error changes) is required. Different approaches for estimating this pseudoinverse are compared in terms of tracking behavior both in image space and in camera motion. In addition to tracking feature points in image space (IBVS), this paper also shows the derivation for a visual servo controller that directly track camera position(PBVS). Stability analysis is carried out for both IBVS and PBVS, and results are two-sided. Even though local convergence is usually guaranteed, IBVS does not guarantee any global asymptotic convergence due to having multiple local minima. On the other hand, while PBVS shows favorable convergence property in theory, it is very sensitive to estimation error, which will affect the stability in practice.

2 What I Learned

1. There is a trade off between the performances of camera motion tracking and image space feature tracking. A straight line trajectory is usually desirable in both domain, but not achievable at the same time.
2. Using a combination of L_e^+ and $L_{e^*}^+$ in IBVS can achieve more balanced and smooth tracking on both camera domain and image domain.

3 Opinions

3.1 Up Votes

- I like how this tutorial structures the content in a very organized way, starting from problem formulation to goals to achieve. It first gives a comprehensive review on camera projection and 3D geometries, and derives the visual servo control law from scratch. It makes the math fairly straight for readers to follow.
- I also really like the graphics in this paper. It really aids understanding the different type of controllers and performances. The figure that shows a geometrical interpretation of IBVS also makes understanding the benefit of using a hybrid controller clearer.

3.2 Down Votes

Among all the nice derivations this tutorial presents, there is one short coming in my opinion, which is the limited number of examples. Most if not all examples used in this paper are tracking of four coplanar points. This does not come nearly as close to any objects in reality. I think some examples should at least consider using polygonal 3D shaped objects.

4 Evaluations

The goal of this paper is to provide a tutorial on the emerging visual servoing problem as well as comparing different classical methods that attempt to solve the problem. This is a valid objective as it provides a quick background introduction of visual servoing without requiring extensive computer vision and control background for the readers. It neatly derives the basic approaches to achieve visual servoing while at the same time sets off a solid background for more advanced methods presented in part 2 of this tutorial series.

I believe the quality of this paper is exceptional. It comprehensively covers multiple approaches that make different level of assumptions. For example, if depth information is available, we can use IBVS with the exact pseudoinverse of the interaction matrix. If not, this paper also shows that there is another way of estimating the pseudoinverse by fixing it with the optimal-state interaction matrix, which is really to implement in practice. The graphics shown in this paper is also exceptional for understanding the performances of different controllers in both camera motion tracking and image space tracking. Finally, it also carried out theoretical stability analysis for both IBVS and PBVS, which leads to a conclusion and discussion on the challenging open problems in visual servoing.

5 Questions

1. I am quite curious why does estimating L_e^+ with $L_{e^*}^+$ still work when the error is large (e.g. Figure 2)?

2. In the stability analysis, why is Equation 19 satisfied when the approximations involved in $\widehat{L_e^+}$ are not too coarse? What does it even mean to have approximations not too coarse?