A First Step towards Hybrid Visual Servoing Control Based on Image Moments

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Abstract. The paper is concerned with a specific class of visual servoing problem, in which camera motion (including both translation and rotation) are constraint to be in the Z-axis direction. Such a constraint condition makes it possible to find appropriate image moments reflecting object depth and orientation. Image moments, as a kind of global image features, can be benefit to the performance of visual servoing system, such as insensitivity to image noise, nonsingularity in image Jacobian, and etc. In the paper, the mathematic relationships between image moments and object-depth-and-orientation are firstly introduced. Then appropriate image moments are selected, on the basis of which a hybrid visual servoing system is build. In our system, visual servoing controller consists of two parts: one is called translation controller which is in charge of object depth control, the other is called rotation controller which controls object orientation. The simulation results show that our hybrid visual servoing system performances well with a high accuracy.

Keywords: visual servoing; image moment.

1 Introduction

In a visual servoing system, vision is employed as a feedback signal to control the actuator to track a static or moving part. Applications for visual servoing control include seam tracking, conveyor tracking, part placement precision, robotics, and etc. Generally speaking, the visual servoing control methods are divided into two classes [1]: position-based visual servo (PBVS) method and Image-based visual servo (IBVS) method. The former methods need to estimate the target position. The accuracy of this kind of methods relies on the accuracy of target model and camera calibration. While the latter methods treat the control problem as the one of controlling image features [2], hence can avoid the above disadvantage of PBVS methods. But IBVS methods have their own problems: local minima, coupled features that lead to unadequate robot trajectories [3], complexity control of a non-linear system, and etc.

To overcome the problems of IBVS and PBVS, some authors [4]-[5] have been recently studying the hybrid method of visual servoing. In most hybrid methods,

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translation motion v and rotation motion ω of a point in 3D workspace are separately controlled. The image Jacobian relationship is given by:

$$\dot{f} = J_v(u, v, Z)v + J_w(u, v)\omega$$

where $\dot{f}$ is the velocity of the corresponding point in the image, J_v (u, v, Z) is a function of both image coordinates of the point and its depth, J_w(u, v) has no relation to depth and is a function of only the image coordinates of the point.

It should be pointed out that the performances of visual servoing control largely depend on the selection of image features. Most hybrid visual servoing systems use local image feature, for example points (typically corners or centroids). The problems of local image feature are that they are sensitive to image noise, possibly result in singularities or poor conditioning in image Jacobian. One solution to such problems is using global image feature, since global image feature provide a generic representation of any object and is robust to image noise. Image moments [5], as a kind of global image feature, have been used for a long time in image analysis, and now can be calculated in real time. Studies indicate that object position and orientation in 3D space can be estimated from image moments [8].

In traditional IBVS control, motion in the Z-axis direction often play a key role, because depth information is essential to image Jacobian, and large rotation motion about Z-axis often leads to control problem. So, the study of our hybrid visual servoing control based on image moments is started from Z-axis control. That is, our study is concerned with a specific class of visual servoing problem, in which motion (involving translation and rotation) are constrained to be in the Z-axis direction. Therefore our control task can be described as how to design a hybrid controller under the above restrictions, in the control of which a camera is driven to its ideal position where the object depth and orientation are equal to the given expectation.

In the paper, firstly we try to find out proper image moments reflecting object depth and orientation. Then, based on the selected image moments we design a translation controller and a rotation controller, which lead to satisfying dynamics of a hybrid visual servoing system.

2 Mathematical Preliminaries

In this section, we analyze the mathematical relationship between image moments and object pose in the assumption of that:

1) the object be rigid and planar, which is always perpendicular to the optical axis of the camera (also called Z-axis or depth-axis) ;
2) in the process of visual servoing, only the Z-axis motion of the camera be permitted, which includes both translation component and rotation component.

As depicted in Fig.1, two reference frames are set: One is the camera frame {C} whose original point O is set at the center of camera lens, another is the image frame {I} whose original point o is set at the image center.