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Design and stability analysis of visual servoing on cable-driven parallel robots for accuracy improvement

Abstract

Cable-driven parallel robots (CDPRs) are a kind of parallel robots with cables instead of rigid links. They are characterized by high payload capacity, large workspace while having low inertia and reconfigurability, including the possibility to easily change its moving-platform. However, existing CDPR slack accuracy, which prevents them from being more widely used. Several applications could benefit from CDPRs centimetric or millimetric positioning indoors: (i) handling small objects in large spaces; (ii) precise handling and assembly of large heavy parts in large spaces; (iii) 3D printing of large parts. For example, the CAROCA prototype produced at IRT JV currently has repeatability of around 1 mm in position, but its accuracy is only around 10 cm.

In order to improve the accuracy of CDPRs, we can use exteroceptive sensors such as cameras to control the CDPRs in its Cartesian space. Few studies exist in the literature on this approach, while it is a relevant and promising approach. With an onboard camera mounted on the moving-platform and used in visual servoing control of CDPRs, it is possible to have high accuracy with respect to a target object. Indeed, as the object is perceived, the control is only stopped when the desired accuracy is achieved. However, the moving-platform is not observed and its pose must be estimated.

The objective of this thesis is to design visual servoing approaches for CDPRs that would lead to improved robot behavior and to evaluate the robustness of the robotic system by the Lyapunov stability analysis. This doctoral thesis is composed of five chapters. The first one introduces the state of the art and the relevant fundamental concepts to be used later.

The second chapter deals with the estimation of the moving-platform pose. Altogether seven methods are proposed and experimentally evaluated on two CDPRs during different tasks. It is determined that pose estimation by control integration is the most adapted for our requirements.

The third chapter deals with stability analysis of different visual servoing approaches. After a detailed analysis of Pose-Based Visual Servoing (PBVS) on a planar and a spatial CDPRs, it is concluded that a link between system stability and moving-platform pose exists. Thus, a novel workspace named Control Stability Workspace (CSW) is defined and computed for all combinations of CDPR geometries and visual servoing approaches used in this thesis. This allowed us to evaluate the effect of different perturbations on CSW volume and system stability. Extensive validation in simulation and on two spatial CDPRs is performed.

In the fourth chapter the use of trajectory planning and tracking is proposed to deal with undesired trajectory deviations in presence of perturbation. An improvement of CDPR accuracy during trajectory is shown.

The fifth chapter deals with tension management for visual servoing. A Tension Correction Algorithm (TCA) is proposed to deal with cable slackness that can occur during task execution. It is shown that with TCA a CDPR can be controlled by visual servoing even over extended time periods without deterioration of robot behavior.

Finally, conclusions are drawn and perspectives for future work are proposed.

Keywords : Cable robots, accuracy, visual servoing, stability analysis, workspace, control