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A modified image-based visual servo controller with hybrid camera configuration for robust robotic grasping

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HIGHLIGHTS

- An image-based visual servo controller with hybrid camera configuration is proposed for robotic mobile manipulation.
- A stereo camera is employed to estimate the depth information and update the model online.
- A rule base approach is presented to adjust the gain matrix in the controller adaptively.
- The proposed approaches are validated in a physical vision-based mobile manipulation system.

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ABSTRACT

In order to develop an autonomous mobile manipulation system that works in an unstructured environment, a modified image-based visual servo (IBVS) controller using hybrid camera configuration is proposed in this paper. In particular, an eye-in-hand web camera is employed to visually track the target object while a stereo camera is used to measure the depth information online. A modified image-based controller is developed to utilize the information from the two cameras. In addition, a rule base is integrated into the visual servo controller to adaptively tune its gain based on the image deviation data so as to improve the response speed of the controller. A physical mobile manipulation system is developed and the developed IBVS controller is implemented. The experimental results obtained using the systems validate the developed approach.

1. Introduction

Visually-controlled mobile manipulators have received avid interest from the robotics community because they possess many advantages over the traditional fixed-based (stationary) manipulators [1]. The three main advantages are: first, the mobile base expands the robot's workspace and allows it to traverse through virtually any terrain; second, the visual capability introduces human-like perception to the robot which enhances its ability to execute complex manipulation tasks; third, cooperative manipulation, which uses more than one mobile manipulator, will be beneficial in unstructured environments where human involvement may be inefficient or hazardous. Example situations of application include urban search and rescue, planetary exploration, chemical or nuclear material handling, and explosive disarmament.

Despite the promising capabilities, several issues remain as challenges to the functional development of mobile manipulators [1]. Perception of an unstructured environment can be especially difficult when the position and orientation of a target object are unknown. Furthermore, during manipulation, the redundant degrees-of-freedom provided by the mobile base and the manipulator joints can add to the complexity of the servo motion.

At the Industrial Automation Laboratory (IAL) of the University of British Columbia (UBC), a team of heterogeneous mobile robots is being developed for cooperative applications in unstructured environments (see Fig. 1). In particular, we are in the process of investigating and developing robotic capabilities that will be useful in emergency response situations. The research presented in this paper is a part of this overall research effort within the IAL.

The overall goal of the robotic team includes searching for humans in distress, cooperatively grasping and manipulating objects to help the human, and constructing simple devices by multiple robots in order to transport the affected humans to safety. In order to achieve the overall goal, a significant task in this project is to develop a vision-based autonomous mobile manipulation system that can work in an unknown and unstructured environment. In particular, there are two key technical challenges in the proposed mobile manipulation system. First, the mobile base must be able to navigate in an unknown and unstructured environment autonomously, identify the desired object using computer vision, and approach it using a visual-servo controller. Second, when the mobile robot is close to the desired object, the arm mounted on

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Fig. 1. Heterogeneous multi-robot team in an unstructured environment at IAL.

the mobile base should grasp the object autonomously using vision feedback while the mobile base is moving slowly. Since the first challenge has been met in our prior work [1], the focus of the present paper is the second technical challenge in the mobile manipulation system. Realistically, the scope of the task is to have the mobile manipulator grasp a marked object in an unstructured environment where the object's position and orientation are not known a priori.

2. Related work

Techniques of visual servoing are classified into two categories: position-based visual servoing (PBVS) and image-based visual servoing (IBVS) [2,3]. In PBVS, the control inputs are computed in the three-dimensional Cartesian space, where the positions of features on the target object are derived from a previously known model of the object. The performance of this method is sensitive to camera calibration and accuracy of the object model. The state-of-the-art research on visual servoing has virtually abandoned this method because perfectly calibrated camera systems are not practical and having detailed knowledge about the objects in an unstructured environment is not realistic.

In contrast, IBVS has been the focus of some recent research activities in robotics for its robustness against calibration errors and coarse object models. Control inputs for IBVS are computed in the two-dimensional (2D) image space, and an interaction matrix defines the relationship between the feature point velocities in the image and the camera velocity in 3D space [2,3]. However, IBVS is not free of shortcomings. A key parameter of the translational interaction matrix, which is needed in the approach, is the unknown depth variable for each feature point during each iteration of the control loop. It has a significant influence on the stability of the scheme, the realizable motion of the camera, and the global convergence properties of image errors. For example, instability can cause the manipulator to move to a pose where the image features leave the field of view of the camera, leading to servo failure.

Other techniques have been proposed to achieve a compromise between IBVS and PBVS. Notably, researchers have proposed a novel 2½-D visual servo scheme where translational and rotational degrees of freedom are decoupled in order to allow the translational interaction matrix to be always invertible [4]. Similarly, the partitioned visual servo scheme extends the decoupling effect by defining one image feature for each of the six degrees-of-freedom (DOF) for an object [3]. Since the visual features in the 2½-D scheme are still defined partly by 3D information and the partitioned scheme is not applicable to all objects, neither of the two schemes will be the focus of the present paper.

Besides the theoretical work on visual-servo control as surveyed here, several vision-based mobile manipulator platforms have been developed, which represent the state-of-the-art in prototype robotic systems. The Nomadic Technologies XR4000, developed by the Centre for Autonomous Systems at the Royal Institute of Technology in Stockholm, Sweden, is designed to perform fetch-and-carry tasks. Overcoming the challenge of fixed focal length, two sets of stereo cameras are used to achieve a compromise between the field of view and the resolution [5]. STAIR (STanford Artificial Intelligence Robot), developed by the Artificial Intelligence Laboratory at the Computer Science Department of Stanford University, is intended to serve in domestic scenarios such as unloading a dishwasher and clearing a table [6]. STAIR has a Harmonic Arm as the manipulator and a Segway® Personal Transporter as the mobile base. The STAIR vision system consists of an eye-in-hand webcam and several elevated stereo cameras. In addition, STAIR has a SICK laser scanner for navigation and an on-board power supply. EI-E ("Ellie") is an assistive robot developed by the Health Care Robotics Laboratory at Georgia Institute of Technology. Similar to STAIR, its purpose is to assist in domestic care of patients and/or senior citizens. Unlike STAIR, EI-E behaves through a "clickable interface", where the user defines the target object and destination by using a green laser pointer [7]. There are two visual systems: an omnidirectional camera system which is composed of a hyperbolic mirror with a monochrome camera; and a stereo vision camera mounted on a pan–tilt unit providing 3D colored images of its surroundings.

However, all the mobile manipulation platforms mentioned above do not employ visual-servo control for object grasping. Instead, simple rule-based discrete controllers are used to approach and manipulate objects while observing them visually. Without a feedback controller, however, the grasping behavior of the robot may not be smooth and its stability cannot be guaranteed. In fact, there are few systems that combine visual servoing with a mobile robot manipulation platform. In addition, from the foregoing survey of the mobile manipulator platforms it is evident that a single