Virtual Reality Calibration for Telerobotic Servicing

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Abstract

A virtual reality calibration technique of matching a virtual environment of simulated graphics models in 3-D geometry and perspective with actual camera views of the remote site task environment has been developed to enable high-fidelity preview/predictive displays with calibrated graphics overlay on live video. Reliable and accurate calibration is achieved by operator-interactive camera calibration and object localization. Both rely on nonlinear least-squares algorithms combined with linear ones. Since the object pose becomes known through object localization, the computer-generated trajectory mode can be effectively used in our new approach. This newly developed calibration technique has been successfully utilized in a recent JPL/GSFC (Jet Propulsion Laboratory/Goddard Space Flight Center) telerobotic servicing demonstration. The positioning alignment accuracy achieved by this technique from four camera views was 0.51 cm on the average for a tool insertion in the servicing task.

1 Introduction

Graphics simulation has been widely used in telerobotic servicing during the off-line task analysis and planning and also during the introductory operator training [6], [7]. However, the use of graphics simulation during the on-line telerobotic operation, for example, as a tool for on-line preview visualization, has been limited due to the lack of accurate matching between simulated environment and the actual remote site task environment. We have recently developed a virtual reality calibration technique that enables reliable, accurate matching of a graphically simulated virtual environment to the actual task environment through operator-interactive camera calibration and object localization. Although there exist many camera calibration [2], [5], [16], [17] and object localization [1], [4], [5], [13], [14] methods, none of them specifically address the calibrated graphics overlay on live video for use in preview/predictive displays. In this paper, we first present key new features of our camera calibration and object localization procedures. Then, we report experimental results of calibration errors of these procedures. Thereafter, we briefly describe a successful use of the virtual reality calibration technique in the ORU (Orbital Replacement Unit) changeout remote servicing demonstration task performed in May, 1993, between JPL and NASA GSFC.

2 Camera Calibration for Graphics overlay

Our camera calibration method which is designed for calibrated graphics overlay has three key new features: 1) A robot arm itself is used as the calibration fixture, 2) An operator-interactive data entry is adopted to obtain reliable correspondence data. 3) A nonlinear least-squares algorithm combined with a linear least-squares algorithm is employed to obtain accurate camera parameters.

In general, camera calibration requires a calibration fixture to determine the camera effective focal length and the camera position and orientation relative to the calibration fixture. In preview/predictive display applications, one must also determine the robot arm position and orientation relative to the calibration fixture in order to superimpose the robot arm graphics model on the actual video image of the arm. However, a precise measurement of the robot arm location relative to the calibration fixture is difficult and error-prone. Placing a calibration fixture in the actual remote work site is also often not easy. Thus, in our new approach of camera calibration, the robot arm itself is used as the calibration fixture, eliminating cumbersome procedures of using an external calibration fixture.

An operator-interactive methodology is adopted to provide the correspondence information between 3-D object model points of the robot arm and 2-D camera image points, since it is still difficult for a computer vision system to find correspondence points reliably. Fig. 1 shows the graphical operator interface used during the operator-interactive camera calibration. The solid-shaded 3-D graphics is displayed on the upper left window, and the live (or stored) video picture received from the remote site appears on the lower left window. As the operator clicks 3-D object model points or 2-D image points, their coordinate values appear on the scrolled list widget of the upper right camera, calibration GUI. When all desired object points and their corresponding image points at different arm poses are entered, the operator can request the system to compute the camera calibration parameters.

There is a standard linear least-squares method that determine the camera parameters (camera position, orientation, and effective focal length) for given 6 or more 3-D object points and their corresponding images in 2-D screen coordinates [2], [16], by assuming that the image formation of the camera can be modeled by a perspective projection of the 3-D world onto