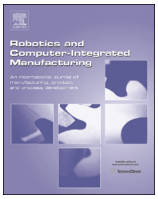
Robotics and Computer-Integrated Manufacturing ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Robotics and Computer-Integrated Manufacturing

journal homepage: www.elsevier.com/locate/rcim



Automatic work objects calibration via a global–local camera system

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ARTICLE INFO

Article history:
Received 14 January 2013
Accepted 13 November 2013

Keywords:
Automatic calibration
Positioning
Visual marker

ABSTRACT

In a human–robot collaborative manufacturing application where a work object can be placed in an arbitrary position, there is a need to calibrate the actual position of the work object. This paper presents an approach for automatic work-object calibration in flexible robotic systems. The approach consists of two modules: a global positioning module based on fixed cameras mounted around robotic workspace, and a local positioning module based on the camera mounted on the robot arm. The aim of the global positioning is to detect the work object in the working area and roughly estimate its position, whereas the local positioning is to define an object frame according to the 3D position and orientation of the work object with higher accuracy. For object detection and localization, coded visual markers are utilized. For each object, several markers are used to increase the robustness and accuracy of the localization and calibration procedure. This approach can be used in robotic welding or assembly applications.

1. Introduction

Most robotic applications require that the location of a work object is known in advance. To fulfill this requirement, expensive fixtures need to be used to fix the work object in a pre-determined position and orientation. When the work object cannot be placed each time in exactly the same place, there is a need to calibrate its actual position.

Shu et al. [1] introduced a multi-camera system for object pose estimation, in particular, the car body in painting shop. Four cameras mounted around robotic workspaces are used to measure the current car body pose in painting shop and guide the robots to adjust their paths. Zhang et al. [2] presented a system for small parts assembly automation positioning with use of an uncalibrated camera. Fixed camera and camera space manipulation were used in 2D assembly applications. Bone et al. [3] used a single wrist-mounted camera and a line laser for modeling and grasping of three-dimensional objects whose shape and location are unknown.

In visually-guided robotics, visual markers are commonly used. Tanaka et al. [4] used a visual marker system to control a flexible manipulator for automatic object handling while Beinhofer et al. [5] focused on optimal placement of markers for mobile robot navigations. Visual markers allow the augmented reality (AR) where a real-world scene is enriched with computer-generated 3D objects. As mentioned in review [6], AR technology is a strong and growing area in manufacturing applications. In review on robot programing methods [7], usage of AR is depicted as a very promising and highly potential approach. One of the implementation of this approach is presented by Ong et al. [8].

The objective of our research is to develop a multi-camera global–local automatic work objects calibration system based on fiducial markers. The rest of the paper is organized as follows. Section 2 gives an overview of the proposed system. Section 3 presents the camera calibration procedures. Section 4 introduces the system implementation. Section 5 discusses the experimental results. Finally, Section 6 summarizes the conclusions and our future work.

2. System concept

The presented system shown in Fig. 1 consists of two modules (subsystems). A global positioning system is based on fixed cameras mounted around the robotic workspace. It is used for presence detection of work object and estimating its position. Information about work object position is used for pose estimation to capture images with a camera mounted on the robot arm. A local positioning system is based on the camera mounted on the robot arm. This camera is closer to the work object and allows more precise localization than the cameras mounted around the robotic workspace.

Work object detection and localization is based on fiducial markers. In our system, markers from ArUco library [9] for augmented reality applications based on OpenCV library [10] are used. The presented markers are similar to ARTag markers [11].

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http://dx.doi.org/10.1016/j.rcim.2013.11.004

Please cite this article as: Schmidt B, Wang L. Automatic work objects calibration via a global–local camera system. Robotics and Computer Integrated Manufacturing (2013), http://dx.doi.org/10.1016/j.rcim.2013.11.004

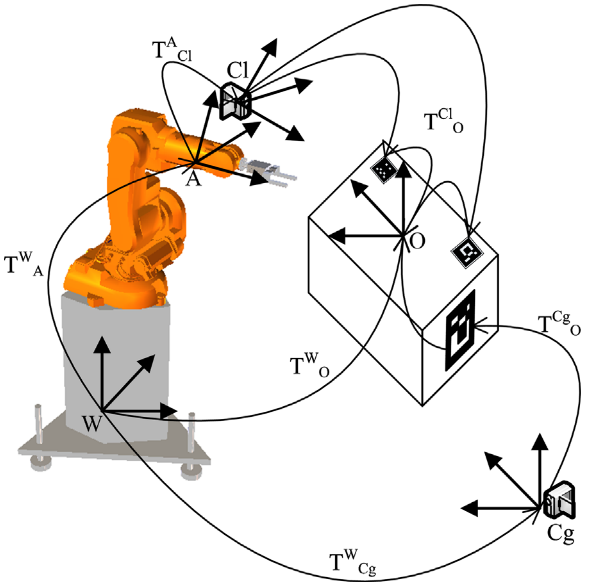

Fig. 1. Concept of a multi-camera automatic work objects calibration system. W – world frame, O – work object frame, A – robot arm frame, Cg – global camera frame, Cl – local camera frame, T – transformation matrix between frames indicated by superscript and subscript.

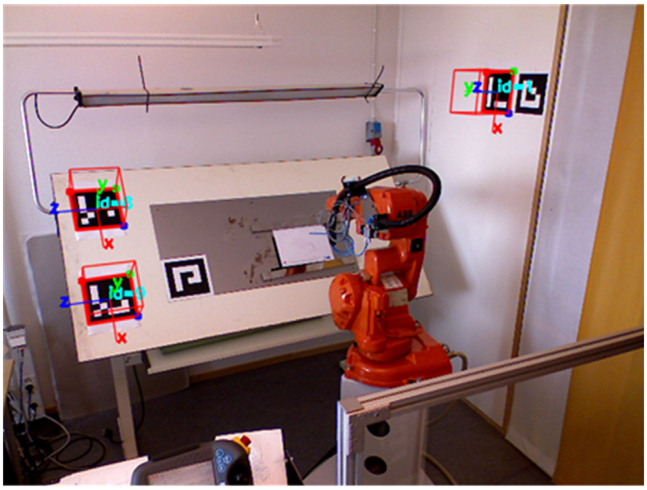

Fig. 2. View from Kinect RGB camera. Detected fiducial markers are marked by cubes (the two un-marked markers are of different type, not configured to be detected).

They are in form of a square black border and 5 by 5 interior grid of cells representing logic value “0” or “1” used to code identification value of the marker. Such a coding scheme allows defining up to 1024 different markers. Fig. 2 depicts the detected markers with added cubes and frames.

For each work object, we assign at least one marker. Properties of the marker consist of marker ID coded into this marker, real dimension and the transformation matrix T which describes spatial marker position with respect to the work object frame. Dependency between work object frame and markers frame are illustrated in Fig. 3. To recognize and localize the work object, at least one marker that was assigned to the object needs to be detected. If more markers are detected in the view, more data points are available for object position and orientation calculation. More data points mean better accuracy in positioning. Additionally, it is possible to create a 3-dimensional pattern by composing the set of markers with different orientations.

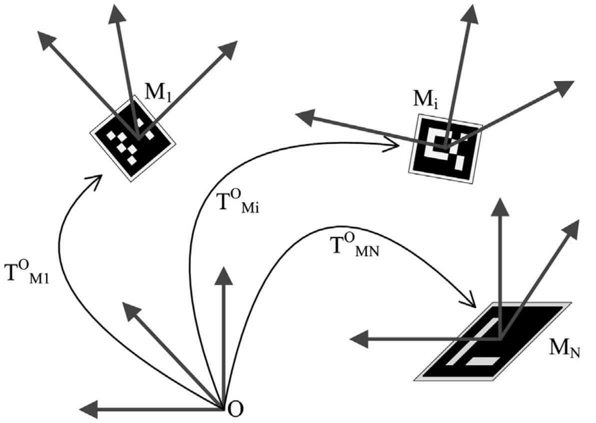

Fig. 3. Homogenous transformation between object frame and markers frames. O – work object frame, M – marker frame with instance indicated by subscript, T – transformation matrix between frames indicated by superscript and subscript.

The idea of data processing and flow is presented in Fig. 4. First, the cameras calibration needs to be performed as described in Section 3. Images captured by the cameras are acquired by the Image Acquisition module. The Marker Detection module uses a Camera ID to retrieve camera parameters to compensate distortion error. Next, markers present in images are detected. In the Object detection and localization module, extracted IDs from the markers are compared with the IDs of those configured markers. When a matching is found, the parameters of the marker are used for its position estimation and the work object position calculation. Additionally, with the assumption that the work object is not moving, the averaging of data collected from several snapshots can be performed.

3. Camera calibration

Camera calibrations procedures are performed to obtain the intrinsic and extrinsic camera parameters. The intrinsic parameters are used for obtaining the relative position of the object according to the frame fixed with camera. This procedure needs to be performed only once. The extrinsic parameters are to locate the camera coordinate frame with respect to external coordinate frame. This procedure needs to be repeated each time the position of the camera is changed with respect to the reference frame. To perform the calibration procedures, methods based on [12] from OpenCV 2.3 library are used. For cameras position calibration, method presented by Motai and Kosaka [13] has been adopted and implemented.

3.1. Camera intrinsic parameter calibration

For camera parameters calibration, the pinhole model is used with radial and tangential distortion model defined in Eqs. (1)–(5), where R and t are the extrinsic camera parameters rotation matrix and translation vector, respectively, which define the transformation between world coordinates (X, Y, Z) and camera coordinates (x, y, z). The intrinsic camera parameters consist of focal lengths f_x and f_y, principal point (c_x, c_y), and distortion coefficients k_1–k_6 for radial distortion and p_1, p_2 for tangential distortion.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = R \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + t \tag{1}$$

$$\begin{aligned} x'' &= x/z \\ y'' &= y/z \end{aligned} \tag{2}$$

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