Chapter 5
Applications to Industrial Quality Inspection

Industrial quality inspection is an important application domain of three-dimensional computer vision methods. Traditional vision-based industrial quality inspection systems primarily rely on two-dimensional detection and pose estimation algorithms e.g. relying on the detection of point and line features, the extraction of blob features from binarised images, or two-dimensional grey value correlation techniques (Demant, 1999). More advanced vision-based quality inspection systems employ three-dimensional methods in order to detect production faults more reliably and robustly. In this section we regard applications in the automobile industry of the methods for three-dimensional pose estimation of rigid and articulated objects described in Section 1.6.

A typical area of interest is checking for completeness of a set of small parts attached to a large workpiece, such as plugs, cables, screws, and covers mounted on a car engine. A different task is the inspection of the position and orientation of parts, e.g. for checking if they are correctly mounted but also for grasping and transporting them with an industrial robot.

Section 5.1 regards the three-dimensional pose estimation of rigid parts in the context of quality inspection of car engine components. The approach of object detection by pose estimation without a-priori knowledge about the object pose is analysed in Section 5.1.1, while the technique of pose refinement based on an appropriate initial pose is regarded in Section 5.1.2. Here we concentrate on the methods introduced by von Bank et al. (2003) and by Barrois and Wöhler (2007), respectively (cf. Sections 1.6.1 and 4.5.1).

The three-dimensional pose estimation of tubes and cables in the scenario of car engine production is analysed in Section 5.2 based on the method by d’Angelo et al. (2004) outlined in Section 1.6.2. For each scenario we compare our evaluation results to results reported in the literature for systems performing similar inspection tasks. Section 5.3 describes applications of the integrated approaches introduced in Sections 4.1–4.4 (Wöhler and Hafezi, 2005; d’Angelo and Wöhler, 2005a,b,c, 2006, 2008) to the three-dimensional reconstruction of rough metallic surfaces of automotive parts.
Table 5.1 Properties of the three oil cap template hierarchies (ranges of pose angles $\rho$, $\varepsilon$, $\lambda$, and grid sizes in degrees). Hierarchy 1 consists of 4550 templates, hierarchies 2 and 3 of 1331 templates, respectively.

<table>
<thead>
<tr>
<th>Hierarchy</th>
<th>$\rho$ range</th>
<th>$\Delta \rho$</th>
<th>$\varepsilon$ range</th>
<th>$\Delta \varepsilon$</th>
<th>$\lambda$ range</th>
<th>$\Delta \lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$0^\circ$ . . . $180^\circ$</td>
<td>$2^\circ$</td>
<td>$18^\circ$ . . . $72^\circ$</td>
<td>$6^\circ$</td>
<td>$-12^\circ$ . . . $+12^\circ$</td>
<td>$6^\circ$</td>
</tr>
<tr>
<td>2</td>
<td>$0^\circ$ . . . $20^\circ$</td>
<td>$2^\circ$</td>
<td>$30^\circ$ . . . $50^\circ$</td>
<td>$2^\circ$</td>
<td>$-10^\circ$ . . . $+10^\circ$</td>
<td>$2^\circ$</td>
</tr>
<tr>
<td>3</td>
<td>same as 2, but without writing modelled</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.1 Inspection of Rigid Parts

The first typical quality inspection scenario involving the three-dimensional pose estimation of rigid parts is detection by pose estimation (cf. Section 5.1.1), corresponding to a simultaneous detection of the presence and estimation of the pose of an object of known three-dimensional geometry. In the second scenario, pose refinement (cf. Section 5.1.2), a reasonably accurate initial pose of the object is required which is then refined further.

Many applications of pose estimation methods for quality inspection purposes impose severe constraints on the hardware to be used with respect to robustness and easy maintenance. Hence, it is often difficult or even impossible to utilise stereo camera systems since they have to be recalibrated regularly, especially when the sensor unit is mounted on an industrial robot. In this section we therefore describe applications of the monocular pose estimation methods by von Bank et al. (2003) and by Barrois and Wöhler (2007) (cf. Sections 1.6.1 and 4.5.1) in the automobile production environment.

5.1.1 Object Detection by Pose Estimation

The inspection task addressed in this section is to detect the presence and to estimate the three-dimensional pose of the oil cap shown in Fig. 5.1 (von Bank et al., 2003). To generate real-world images with well-defined ground truth poses, we made use of a calibrated robot system. The accuracy of calibration with respect to the world coordinate system is about $0.1^\circ$ with respect to camera orientation and $0.1$ mm with respect to camera position. As the engine itself is not part of the robot system, the relation between world coordinate system and engine coordinate system has to be established separately, which reduces the accuracies stated above by about an order of magnitude.

First, the difference between the measured and the true pose of the correctly assembled oil cap is determined depending on the camera viewpoint and the illumination conditions. The scene is illuminated by a cylindric lamp around the camera lens (confocal illumination) and a halogene spot. The background of the scene may be fairly cluttered. The distance to the object amounts to $200$ mm and is assumed to be known, such that only five degrees of freedom are to be estimated. For this