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Optoranger: A 3D pattern matching method for bin picking applications

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ABSTRACT

This paper presents a new method, based on 3D vision, for the recognition of free-form objects in the presence of clutters and occlusions, ideal for robotic bin picking tasks. The method can be considered as a compromise between complexity and effectiveness. A 3D point cloud representing the scene is generated by a triangulation-based scanning system, where a fast camera acquires a blade projected by a laser source. Image segmentation is based on 2D images, and on the estimation of the distances between point pairs, to search for empty areas. Object recognition is performed using commercial software libraries integrated with custom-developed segmentation algorithms, and a database of model clouds created by means of the same scanning system.

Experiments carried out to verify the performance of the method have been designed by randomly placing objects of different types in the Robot work area. The preliminary results demonstrate the excellent ability of the system to perform the bin picking procedure, and the reliability of the method proposed for automatic recognition of identity, position and orientation of the objects.

1. Introduction

To maintain global competitiveness, the manufacturing industry must focus on flexibility and re-configurability, to produce customized work-pieces in a fast an efficient way [1]. Most of the operations are usually performed by Robots in the production line. One of the still unresolved issues is the ability of Robot manipulators to perform well in non-structured environments, where neither shape nor posture of the objects are predictable [2]. Machine vision, both 2D and 3D, is considered to be an essential aid in this context [3].

Fast and effective bin picking from non-organized containers is one of the present challenges for Robots, required to identify objects and to estimate their spatial location and orientation in unstructured bins [4]. Main issues of an effective bin picking are (i) acquisition of the scene through vision, (ii) scene segmentation (i.e., separation of different objects), and (iii) recognition and pose estimation of the segmented objects. These three tasks should be performed in the presence of clutter, shape variability, occlusions, object overlapping. All these aspects make bin picking a still almost unresolved problem.

Presently, scene segmentation and object recognition are based on 2D vision techniques, ideal for elements whose third dimension is negligible, lying on structured bins or on vibrating elements. Blob analysis and learning-based approaches are used, although with some limitations [5].

With complex objects, randomly oriented and partially overlapped, the 3D approach is highly preferable [6], using commercially available 3D scanners based on different principles (time-of-flight, passive and active stereo vision) [7–9]. In 3D vision, scene segmentation is based on depth discontinuities in the point cloud of the scene [10]. Other methods are based on region growing and curvature estimation, in search for planar, convex or concave continuous surfaces [11]. Edge-based approaches are more accurate in detecting border locations, however, the results need further elaboration in order to increase reliability.

Object recognition can be based on the construction of a database of 3D CAD models: every segmented element of the scene is compared with those models, to estimate their orientation [12]. Using 3D CAD models presents the drawbacks of high computational time and resources, as well as the need to create CAD models of the objects and the requirement of a good initial pose estimation to avoid local minima. An alternative model-free approach is based on the extraction of invariant geometric features from the 3D range image [13–15]: these approaches detect simple shapes in work areas with a single topology of objects. More sophisticated techniques, based on super-quadrics [16] spin images [17] and tensors [18,19] allow efficient recognition in semi-clutter scenes: however, their level of complexity might not be compatible with on-line bin picking in industrial plants.

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Methods based on 3D template matching, where the point cloud of a segmented object is compared to the point cloud of a template, present the ability to treat complex shapes that cannot be modelled by local features [20]. Thanks to their robustness, these approaches to object recognition in bin picking applications are being considered with increasing attention.

Our Laboratory is focused on solutions for the industrial world of Robotic manipulation and bin picking using 3D vision [21]. Our approach to satisfy industrial needs in terms of (i) short time-to-market, (ii) high cost effectiveness, and (iii) ease of implementation of the solution, is based on the use of existing hardware and software tools where available and economically sustainable, but trying to adapt some of the hardware or software tools when the commercial ones should be improved in some of their aspects.

We have recently been focused on the implementation of a full 3D solution for bin picking applications, in the presence of semi-cluttered scenes with objects characterized by both simple geometries and free-form shapes. We followed a "building brick" philosophy to simplify the development: we chose a market available laser slit as the acquisition device [22], and the *Match 3D tool* of the commercial 3D Shape Analysis Library (SAL3D) Library (AQSense Inc., Spain) to perform object identification and pose estimation [23]. *Match3D Coarse* follows a template matching approach, based on a best-fit algorithm that quickly aligns and compares 3D point clouds with their respective models (templates).

To complete the chain, a suitable segmentation tool was required, and we focused our efforts to develop a novel tool with superior performances with respect to the state of the art in terms of speed and flexibility. Our segmentation is built on the modules available from the open-source Point Cloud Library (PCL) platform [24]; this library offers an advanced and extensive approach to 3-D manipulation. In particular, we implemented an iterative algorithm based on the Euclidean distance between points in the cloud, that allows to efficiently segment the scene, in the presence of objects of different shapes, dimensions and orientations. The same tool was used to successfully treat occlusions and object overlapping of segmented elements, and this is not present in the state of the art.

In this paper the 3D acquisition procedure, the cloud segmentation and the object identification procedures are presented, together with experimental results performed to test them.

2. Workflow of operation

Fig. 1 shows the workflow of the operations implemented in the method. It is based on three main blocks. The first one performs the acquisition of the 3D scene; this is accomplished by (i) calibrating the acquisition device, (ii) scanning the work area, and (iii) pre-processing the point cloud to simplify subsequent elaboration.

The second block implements the segmentation of the 3D range map. To this aim, the point cloud is filtered to remove data belonging to the transition regions between objects that are partially overlapped or occluded. Clusters are extracted and suitably processed to select those that are represented by 3D sub-clouds corresponding to non-occluded objects. Finally, a restoring operation is carried out on each selected cluster, to maximize the visibility of the 3D features in each sub-cloud.

The last block performs the identification of the objects corresponding to the clusters, and estimates their pose for robot picking. Object identification is performed by matching the available templates to the selected clusters. The templates are 3D clouds of the objects. 3D matching is carried out by means of an alignment algorithm, implemented in the SAL3D Library. The output parameters represent the pose information, that is used as the input to the robot. In the following sections, these blocks are described in detail.

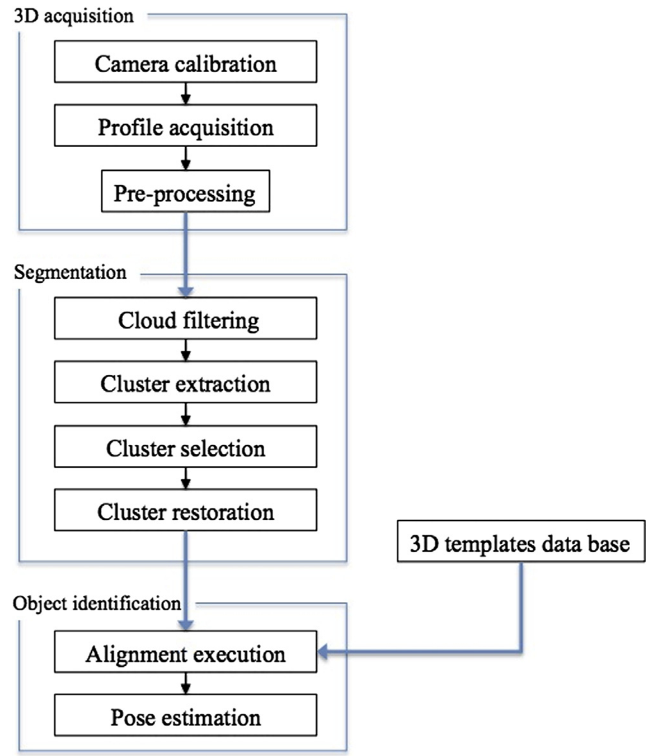

Fig. 1. Flowchart of the procedure.

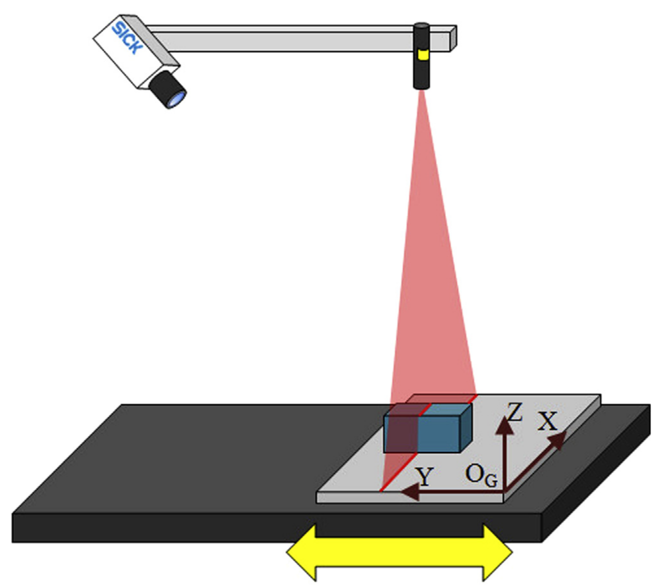

Fig. 2. Layout of the system.

3. 3D acquisition

3D scene acquisition is accomplished by using the high-speed 3D camera *Sick Ranger D50* and a laser diode at 660 nm, equipped with a cylindrical lens, angled by 45° with respect to the camera. As sketched in Fig. 2, it is mounted orthogonally to the working area and produces a very sharp line, in order to have a high contrast between the illuminated pixels and the rest of the image,