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Reflective workpiece detection and localization for flexible robotic cells

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ABSTRACT

A smart vision system for industrial robotic cells is presented. It can recognize and localize a reflective workpiece, and allows for automatic adjustments of the robot program. The purpose of the study is to improve industrial robots awareness of the environment and to increase adaptability of the manufacturing processes where full control over environment is not achievable. This approach is particularly relevant to small batch robotic production, often suffering from only partial control of the process parameters, such as the order of jobs, workpiece position, or illumination conditions.

A distinguishing aspect of the study is detection of workpieces made of diverse materials, including shiny metals. Reflective surfaces are common in the industrial manufacturing, but are rarely considered in the research on object recognition because they hinder many of the object recognition algorithms. The proposed solution has been qualified and tested on a selected benchmark in a realistic workshop environment with artificial light conditions. The training of the object recognition software is an automatic process and can be executed by non-expert industrial users to allow for recognition of different types of objects.

1. Introduction

Flexibility in manufacturing is a multifaceted concept. Its definition varies according to the context. In [1] twelve different definitions are reported. Chryssolouris [2] proposes several quantitative definitions of the flexibility. This work is mostly concerned with product flexibility, which is the ability of a manufacturing system to make a variety of part types with the same equipment [3]. It is referred to as reconfigurability of a manufacturing system on cell and work-piece levels, or its ability to switch with minimal effort to a particular family of workpieces.

This kind of flexibility is particularly relevant in collaborative human-robot scenarios for small and medium enterprises, where some operations, usually handling, are executed by the human operator, while the others, usually assembling or processing, are performed by the robot [4]. Introduction of the human factor brings the advantage of more dexterity in the execution of tasks but introduces a source of variability within the workplace. The cell may not be considered a structured environment anymore, so this scenario hinders offline robot programming [5]. Therefore an adaptive robotic system should be aware of the environment, analyze it, and change its behavior dynamically [6,7].

In a hypothetical scenario, where workpieces are handled and positioned by a human worker, and robot is supposed to do some other operations on them, the variable aspects are workpiece readiness, type, state and location.

2. State of the art

In this section some methods to solve the above mentioned problems of object detection, recognition and localization are presented with a focus on industrial applications.

Detection of unknown objects is a frequent task in video processing and surveillance. Background subtraction is a very popular approach to detect unknown objects [8]. More elaborate methods may rely on image segmentation [9,10] or saliency detectors [11].

Background subtraction allows to highlight the areas of the image which are significantly different from the previous (background) images. In the industrial settings with a fixed camera, this allows to see what areas of the work space are different with respect to some reference state, or, in other words, to see where new objects have appeared or the work area was modified.

Object detection and the wider problem of *object recognition and localization* do not necessarily imply that vision-based techniques should be used. Autonomous vehicles often use laser scanners to detect unknown objects [12,13]. Some industrial applications opt for non-visual methods to recognize and localize objects too. RFID is a common means to carry object type and identity [14]. Three-dimensional range imaging and scanners like Kinect are becoming increasingly popular too [15–18]. For a full review of 3D data acquisition techniques see [19]. But machine

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vision still remains one of the most popular methods for parts identification [20].

Reflective objects are rarely considered in visual recognition research. Sometimes the object is only slightly reflective and the traditional methods are still applicable [21], but this is rarely the case for textureless objects. Many authors employ workarounds like relying on contours [22] or using 3D scanners [23,24]. However, 3D scanners often fail to obtain reliable 3D depth images from non-Lambertian surfaces, and few point-to-point correspondences can be found in a stereo pairs [24]. Impressive results based on matching the contours were achieved in [25,26]. Unfortunately, the method relies on a custom multi-flash camera [27]. To the extent of our knowledge at the time of writing, no commercial implementation of such hardware exists, and the image processing code is not widely available, neither in Open Source nor commercially.

Many industrial applications rely on relatively simple marker-based [28–30] and convolution-based methods [22,31]. Recognition and localization problems can be completely bypassed when fiducial markers used. Their practical applications are limited by the necessity to attach and detach markers, operations which complicate the production process. Convolution-based method is a case of an example-driven search. They are especially sensitive to variability of the object, and usually are not scale- and rotation-invariant [32,33]. Thus both approaches are poorly suited for localization of manually positioned reflective objects in industrial environment.

More elaborate methods rely on feature-based matching. The features may be derived from CAD models [34] or chosen manually in an ad-hoc manner [35]. Unfortunately, the choice of good invariant features is not straight-forward and requires human expertise.

General object recognition methods are very helpful if the system is supposed to deal with highly variable object appearances. Many such methods are able to learn or select good features automatically, given a good training set [36–38]. These methods have been successfully used for face or pedestrian detection and general object recognition.

In this paper a system for detection, recognition and localization of a workpiece made of reflective metal is proposed. It does not rely on fiducial markers and can cope with high variability of the illumination conditions and object appearance.

The proposed solution is build upon a simple background subtraction to detect unknown objects, and a Viola-Jones classifier to recognize the workpiece. 3D scanners were avoided because their performance is known to degrade when working with the reflective surfaces. Automatic feature selection based on actual workpiece appearance was preferred over the manual feature selection or features design from the object design. The output of the system is used to adjust and run the robot program, and the performance of the method is validated experimentally.

3. Case study

To demonstrate our implementation of the adaptive robotic cell, a case study was planned which consisted of 1) manually positioning of an aluminum CNC machined workpiece on the bench, 2) detection, recognition and localization of the workpiece using a vision system, 3) adjustment of the robot program according to the type and the location of the workpiece, or sending a signal to delay or prevent program execution, if the workpiece is not present or it is a wrong one (Fig. 1). This section describes various aspects of the experiment, such as workpiece design and material selection,

Workpiece. The workpiece used in the experiment has geometrical features typical of most mechanical components, such as, cylindrical holes and pins, prismatic ribs Fig. 2.

Material. The choice of the workpiece material is the fundamental decision in the design of the experiment. Image interpretation and object recognition depend on many properties, such as texture, color, visible edges which may vary according to the material [39].

Metals and polymers are both frequently present in manufacturing, but metals represent a challenge for many vision methods. On a reflective material we may see false specular edges or edges highlighted according to particular orientation between light source, object surface and observer [39]. Specular reflections are often overexposed, thus texture and color information may be easily lost. Surface roughness is another factor to consider. Rough surfaces may appear to have more diffuse reflection. Smooth surfaces tend to produce more specular reflections. Polished reflective

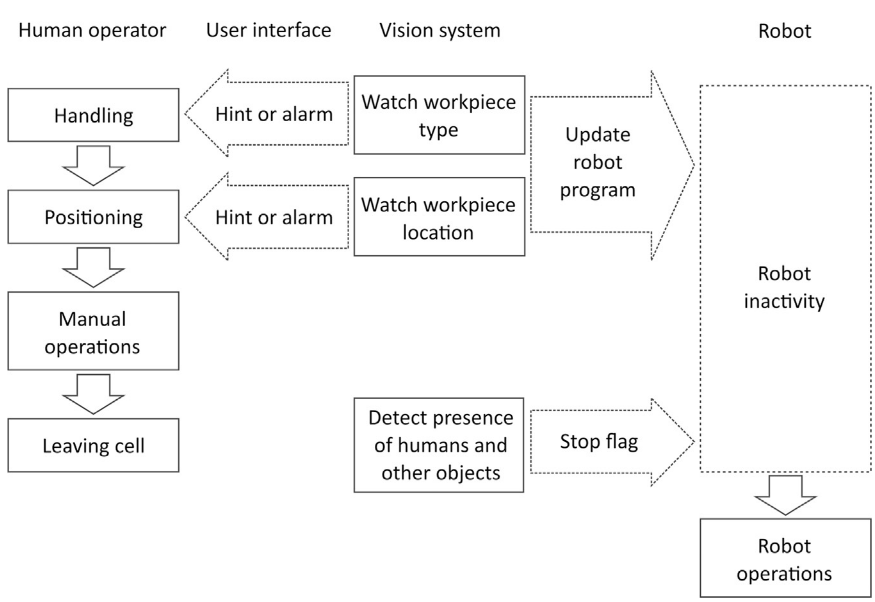

Fig. 1. A potential role of a vision system in an adaptive robotic cell, where some operations like handling and positioning are carried out by a human operator. The vision system may communicate to the human (by suggesting what to do or warning about irregularities) and with the robot (by adjusting the robot program and vetoing execution until the environment is ready).