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Adaptive autonomous positioning of a robot vision system: Application to quality control on production lines

M.A. Montironi, P. Castellini, L. Stroppa, N. Paone *

Università Politecnica delle Marche, DIISM, Via Brecce Bianche, 60131 Ancona, Italy

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ABSTRACT

This paper presents an adaptive strategy for automatic camera placement in a 3-dimensional space during a robotized vision based quality control. The approach proposed improves the overall efficiency of the system, allowing a correct image acquisition, even in cases where an obstacle along the camera line-of-sight hides the object to be inspected, not making it possible to perform the inspection by template matching. In particular, a strategy for automatically avoiding a possible obstacle is defined.

The paper focuses on a class of obstacles whose position on the scene can be detected by applying a Fast Fourier Transform (FFT) algorithm to the image; these kind of obstacles can rotate randomly. The phase information from the FFT is then used to define the movement necessary to clear the camera line-of-sight and acquire an image of the target object. Such image will result distorted by perspective. However, both the image acquired before and the one acquired after the camera repositioning, together with the knowledge of the relative displacement, are used to partially reconstruct the three-dimensional structure of the object inspected. Corresponding points in the two images are located and perspective distortions resulting from the movement of the camera are corrected. The correction improves the object recognition task since it makes it possible to use a single template on images acquired from very different positions.

The whole method has been tested for on-line quality control of washing machine parts, which represents a typical case of quality control on a production line.

1. Introduction

In recent years, industrial environments have witnessed a stable trend towards intelligent factory automation, with an ever increasing implementation of mechatronic units [1,2], integrated into adaptive and self-optimizing production lines [3,4] and into quality control systems [5,6]. Within this trend, vision systems have played a key role [7], especially in process control [8] and online quality assessment in several fields [9–11]. In fact, vision systems offer a complete representation of the environment [12], which contains a lot of information. Over the years, a wide range of algorithms has been developed to recognize and locate both static and moving parts on an image, as it is usually required in quality control.

State of the art vision based quality control stations is usually made of one or more cameras, fixed in space; the product being assembled on the serial production line passes in front of this constellation of cameras and a set of images is acquired, which are then processed by dedicated software.

The latest production strategies involve frequent changes in the type of product moving along the same assembly line, thus requiring a high level of flexibility and adaptability of the production line and of the vision system. A high level of flexibility can be effectively achieved by robot vision systems; indeed these systems are specifically designed to substitute a constellation of fixed cameras, which is too rigid to allow adaptation to variations in product geometry, position, size, etc. that are often encountered in flexible production systems.

This is why, in flexible production systems, there is a growing trend to apply robot vision, even if this choice has the drawbacks of increasing system complexity and costs and is intrinsically slower, due to the fact that image acquisition is sequential rather than parallel.

The need for self-optimization of robot-vision systems originates from the real problems that can be met in some assembly lines, where production requires a very high flexibility because of the frequent and significant variations of the test items. Such variations may be predictable or unpredictable, therefore the behavior of the robot vision system should be as autonomous as possible and adaptable to the actual scenario occurring. This implies the capacity of the system to recognize the context, understand if there is any problem and, in case the problem exists,

* Corresponding author.
E-mail address: n.paone@univpm.it (N. Paone).

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start a procedure to overcome it by adapting the robot's position in order to correctly acquire the image and perform quality control.

Robot vision systems often implement the most advanced methods for rapidly and autonomously adapting image acquisition parameters, such as illumination of the scene [13], exposure time, or the line of sight of the camera, to the specific working conditions. The flexibility and response speed vision systems acquire through these new techniques have encouraged both the research and industrial communities to move towards a closer integration of these systems with robots. Applications of robot vision range from control of pick and place tasks [14], to autonomous navigation [15,16], to adaptable quality control [17].

In particular, developments in image processing algorithms specific for object recognition, tracking and 3D reconstruction [18,19] have made it possible to achieve a complete, fast and, in some cases, real-time mapping of the environment in which the robot moves.

This paper presents a strategy aimed at further improving the performance of a robot vision system in eye-in-hand configuration used for quality control on a production line. This is achieved by implementing an adaptive strategy for automatic camera placement in the 3-dimensional space so as to extend the applicability of the vision inspection system also to cases where the object under inspection may randomly be hidden by moving parts. The strategy, which exhibits the ability to actively react to the unpredictable presence of an obstacle impairing the correct imaging of the target, is aimed at improving the quality control process which would fail if it were not possible to image the part under inspection due to the presence of an obstacle. This behavior is implemented on the classical eye-in-hand robot vision architecture, based on a 6-DOF robotic arm that moves a camera attached to its end effector in the 3D space.

Research on adaptive and robust methods useful for autonomous robot positioning shows interesting approaches, in many different application areas, often related to obstacle avoidance. For example [27] describes the case of autonomous repositioning of a robotic manipulator in eye-in-hand configuration that is able to overcome problems related to light changes and to the presence of unexpected obstacles. A survey on active vision in robotic applications is available in [28], which describes methods for sensor planning to determine the pose and settings of vision sensors to undertake a vision-based task. In [29] the autonomous positioning of a robot vision system for the surveillance of dynamic objects with a priori unknown trajectory is described. An analysis of the task of determining a path that passes overall points of an area or volume of interest while avoiding obstacles has been recently presented in [30].

The following sections describe an adaptive strategy that implements algorithms designed to solve the specific problem of obstacle detection and avoidance in order to automatically reposition the camera of a robotized vision system. The system discussed here was specifically developed within a EU funded project [5] to perform quality control on a washing machine assembly line, but the results can be extended to a large variety of production lines that pose similar problems, such as the assembly of appliances in general, of automotive parts. This approach is in line with the increasing interest in flexible manufacturing systems [20], where vision based on-line quality control plays a relevant role.

The autonomous positioning of the camera represents a self-adaptive behavior of the robot vision system that aims at optimizing the quality control process. Section 2 describes the method developed to solve the problem presented above, while Section 3 illustrates the results obtained in an industrial test case where such a problem occurs.

To avoid an obstacle that is in the line of sight of the camera the first step is to detect its presence. This requires image processing algorithms, specific for the type of obstacle and for its possible movements. An interesting type of obstacles that can be met in mechanical systems and that can move are rotating parts; typical examples are pulleys, gears, rotary handles, fastening devices such as clamps, etc. All these parts can assume different angular positions in front of the camera and hide the actual object to be imaged. An example of such a situation is presented in Fig. 1: it is a pulley, whose spoke, if rotated, may mask the electric wire, which is the target object to be imaged. This paper will concentrate on these cases, developing a specific solution for the pulley, which is a rather common component in appliances and represents the general case of rotating parts.

To detect an obstacle such as the pulley spoke, rather than traditional template matching algorithms, we propose to use the information derived from the FFT of the image, which has some specific characteristics that depend on the angular position of the object. Recognizing the angular position of the object without using recognition algorithms allows the system to be more robust than pattern matching and sufficiently flexible to be applied to different kinds of rotating obstacles.

The paper also discusses how the detection of the three-dimensional structure of the environment and of the position of the vision system relative to it, together with the knowledge of camera placement, makes it possible to correct the perspective distortions occurring on images acquired from different positions. This is relevant in order to use the same template when searching for the target, even if the image is distorted by perspective.

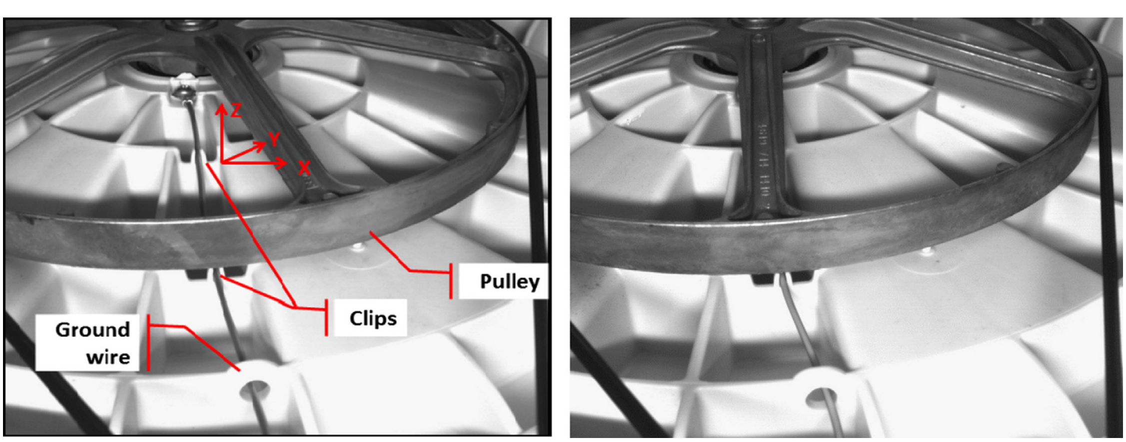

Fig. 1. Image of a tub of a WU, with pulley, ground wire, clip and the reference system used for the camera movement strategy; on the left image the ground wire is visible, where on the right is hidden by the spoke.