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Development and characterization of a multi-camera 2D-vision system for enhanced performance of a drink serving robotic cell

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ABSTRACT

A 2D-vision system is integrated into a drink-serving robotic cell, to enhance its flexibility. Two videocameras are used in a hybrid configuration scheme. The former is rigidly mounted on the robot end effector, the latter is fixed to the workplace. The robot cell is based on two Denso robots that interoperate to simulate real human tasks. Blob analysis, template matching and edge detection algorithms cooperate with motion procedures for fast object recognition and flexible adaptation to the environment. The paper details the system workflow, with particular emphasis to the vision procedures. The experimental results show their performance in terms of flexibility and robustness against defocusing, lighting conditions and noise.

1. Introduction

Flexibility plays a key role in robot-based applications, where the ability to perform complex tasks in semi-structured or even unstructured environments is strategic. In production line automation, a very important topic is the design of robotic systems that efficiently recognize and manipulate unorganized objects with little knowledge of the geometry and the pose of the parts [1,2]. The aim is to increase process efficiency and accuracy, and to reduce the time and the cost required to adapt the line to the production of new series. In service and humanoid robot applications, the final goal is to develop techniques for implementing adaptive interaction between the robot, the environment and/or humans. Surgery, nursing, serving disabled people, performing dangerous or remote tasks in place of humans are examples of very demanding applications belonging to this category [3,4].

A robot arm is blind and senseless in nature, and inherently unable to adapt to varying scenarios. It has long been recognized that sensor fusion is fundamental to increase the versatility of robots. Especially in the last decade, vision sensors have become of outmost importance both in research laboratories and in production companies: their integration with the robot cell makes the robot 'see' the environment and adapt its workflow to varying conditions [5].

Vision sensors and image processing techniques have been strongly developed in recent years, for visual inspection and measurement applications. Typical fields are automatic manufacturing, product inspection [6–8], non-destructive testing [9] and welding applications [10]. Their use in combination with robotic cells has been studied since middle eighties by the vision-robotic community. Visual servoing techniques using either 2D and 3D vision sensors, and suitable combinations of them, are widely studied for bin-picking applications and autonomous robotic servicing [11–13].

This paper describes a machine vision system developed to increase the flexibility of a DENSO robot cell for drink serving operations. The cell is called 'Barman'. In its original configuration, two anthropomorphic robots were used to pick-up beer bottles from a conveyor, uncork them and place them on a rotating table. The robots were programmed to perform a very limited set of actions, in a static, highly controlled environment: the bottle shape was predefined, bottles on the conveyor had to be positioned at regular distances one from the other, and the position on the table of each bottle should correspond with the position of suitable bottle racks, rigidly embedded at the border of the table. Due to robots inaccuracies, it could happen that the final position of a bottle did not perfectly match with the position of the corresponding bottle rack, yielding to liquid dispersion.

The DENSO technical staff requested us to upgrade the system toward a 'Smart Barman' version, characterized by improved flexibility with respect to the original system. In particular, the system should be able to (i) serve beer of multiple brands, (ii) serve

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beer in glasses, (iii) detect the presence of bottles (or even non-bottle objects) different from those of allowed brands and (iv) detect mispositioned glasses. The underlying idea was to show the Barman functionalities at exhibitions, to demonstrate to potential costumers the advantages of using vision in combination with robots, especially in terms of flexibility and robustness.

We were requested to develop the vision procedures using the Halcon suite of programs (MVtec GmbH, Germany) [14]. In addition, in order to let DENSO operators to 'tailor' the Barman functionalities, we were requested to implement them on a very flexible, modular software platform, where each single vision function could either be added, removed or modified in its parameters depending on the environment characteristics, such as, for example, lighting conditions and camera typology.

In this paper the vision procedures developed to enhance the barman flexibility are detailed. Their combination to suitable motion procedures within the whole barman workflow is presented. The vision procedures have been validated in terms of their flexibility in the presence of 'costumer-induced' variations of either shape, typology and pose of bottles and of glasses. Particular care has been devoted to characterize their robustness against variations of lighting conditions, image defocusing and noise.

The paper is organized as follows. In Section 2 the Barman robot workcell is described. Section 3 is dedicated to the description of the workflow. Section 4 presents the vision procedures and the motion procedures. Section 5 shows the experimental results.

2. Description of the system

The Barman is composed of three subsystems: the Robot Subsystem (RS), the Vision Subsystem (VS) and the Auxiliary Subsystem (AS). A supervisor PC (SPC) controls them by means of specifically designed software.

2.1. The Robot Subsystem

The Robot Subsystem is shown in Fig. 1. It is composed of 2 anthropomorphic 6 DOF robots (DENSO VP-6242G), named Robot_1 and Robot_2. They represent the left and the right arms of the Barman, respectively. The end-effector of Robot_1 is a pneumatic gripper, for bottle picking and glass filling; the end-effector of Robot_2 is a plastic hand equipped with a bottle-opener. The robots are partially embedded into a 'thorax-shaped' case, on which the SPC monitor is placed.

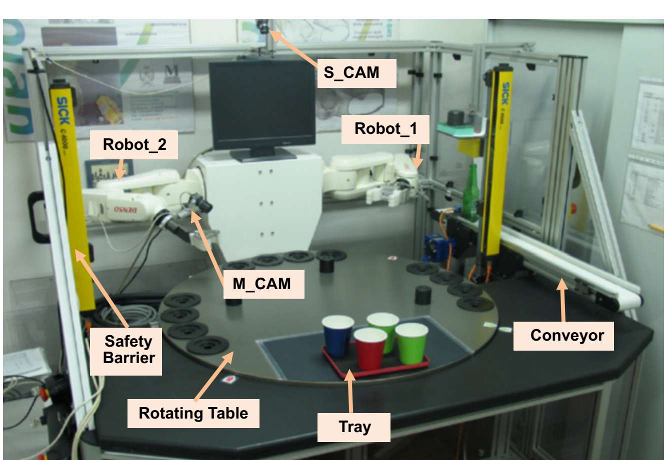

Fig. 1. The Barman system.

Each robot is cabled to its own controller (model RC7M). The supervisor PC controls both robots through TCP/IP ports. The communication between SPC and robot controllers is implemented in the Orin2 platform [15]. The procedures developed to control the whole system are integrated into the VB.NET environment.

2.2. The Vision Subsystem

The Vision Subsystem is composed of 2 CMOS digital USB 2.0 cameras (μEye 1540-M 1280×1024 pixel), both equipped with a 12 mm focal length objective. They are called S_CAM and M_CAM, respectively. As shown in Fig. 1, the former is mounted on the section above the SPC monitor, at about 870 mm from the table. The latter is rigidly mounted at the end-effector of Robot_2. The communication among SPC, S_CAM and M_CAM as well all the vision procedures has been implemented using the Halcon 9.1 vision libraries. The Halcon 9.1 development system is HDevelop, a tool box for building vision applications. It facilitates rapid prototyping of machine vision applications, offering an interactive programming environment, where the Halcon *Operators* are combined to form a procedure. Its 'engine', called HDevEngine, allowed us to directly execute HDevelop procedures by instantiating them within the VB.NET environment. In our work, each vision procedure was developed and tested into the HDevelop environment before integrating it into the whole VB.NET software. This approach allowed us to implement the whole system operations in a modular, reliable application.

2.3. The Auxiliary Subsystem

The Auxiliary Subsystem includes the conveyor and the round table shown in Fig. 1, as well as suitable control and safety sensors. These devices are cabled to the RC7M controllers by means of their I/O communication protocol.

The conveyor delivers bottles to the Barman. A proximity sensor at the end of the conveyor detects the bottle presence. The round table has a diameter of 1m, and can rotate around its center. In Fig. 1, a tray of dimension 220 mm by 180 mm is shown; four glasses are positioned on it. The surface of the tray is black, and the inner surface of the glasses is white, to have high contrast with respect to the tray. Two table positions are allowed. The former, shown in Fig. 1, is the so called Front position; the latter is 180° rotated (Back position). When the table is in Front position, customers are expected to place glasses on the tray. When the table is in Back position, the Barman is expected to fill the glasses. Robot_2 rotates the table. A proximity sensor senses the table position and controls a pneumatic system that locks it.

In Fig. 1, the SICK barriers used to ensure safety are shown. In addition, a SICK laser scanner is mounted beneath the table. Whenever an object is detected inside the safety area of one of these devices, the system stops. Finally, a pressure sensor is used to ensure proper air levels during operation.

3. Description of the workflow

Fig. 2 shows the system workflow. It is based on six tasks, which are implemented by means of a suitable combination of vision and of motion procedures. Vision procedures perform image acquisition and elaboration and give information to the robots about the unknown scene. Motion procedures monitor I/O variables, read data from the sensors and carry out the robot move commands. Vision and motion procedures must share a global reference system (GRS): this is defined using a suitably developed calibration procedure. The tasks are as follows: