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Integration of Multi-Camera Vision System for Automatic Robotic Assembly

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Abstract

An automated assembly cell does not come with the luxury of intelligence. A non-adaptive robot manipulator must have more accurate parts and assembly fixtures to a greater accuracy than their assembly tolerances. Accurate parts presentation and the fixturing of assemblies can be a complex and costly portion of an automated cell. Machine vision can be integrated with the assembly process to effectively and efficiently guide the assembly process. This paper presents a framework for an automatic assembly system that consists of an industrial robot and a three-camera vision system, where the tasks involve object detection, pose estimation during pick and place operations, and assembly verification. Given a pocket calculator as an application, the proposed framework can successfully perform autonomous assembly of a pocket calculator. The experiment results verified the efficacy of the proposed method.

Keywords: eye-in-hand; machine vision; robotic assembly.

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1. Introduction

Machine vision systems are widely used in automated assembly and quality assurance tasks. Machine vision is typically sought after due to the higher flexibility of the assembly systems, as well as better quality of the final

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products. Flexibility of the assembly system can be very valuable to the manufacturing company. Pallets and other placing devices may tie up a large amount of capital, which could be invested elsewhere if machine vision systems are included into assembly cells.

Integration of a variety of machine vision systems can be challenging. It is also a demanding job to select the best fitting machine vision system. From a hardware perspective, one could come up with categories like PC-based systems [1], [2], [3], [4], intelligent cameras [5], and DSP-systems [6]. It is possible to divide systems based on their function, such as surveillance, failure detection, assembly verification, and dimension measurement. One can even divide the systems by how they are programmed or the type of cameras that are used. In this paper we introduce a machine vision system with three subsystems for automatic assembly, i.e., object detection and pose estimation system, placing correction system, and assembly verification system. Fig. 1 illustrates the overall system layout.

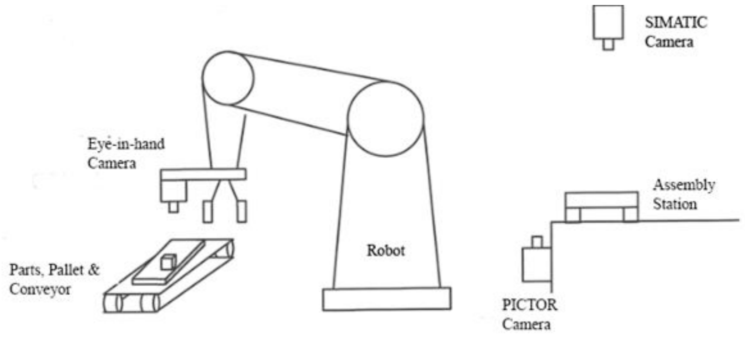


Fig. 1. System layout.

2. System Architecture

2.1. System Architecture

The three-camera vision systems in our assembly cell were installed at different places for performing their tasks. The eye-in-hand camera SONY XC55 is a PC-based system for object detection and pose estimation; it provides data to the assembly robot for grasping of the target and also calculates dimension measurements for quality assurance. PICTOR is an intelligent camera system for object placing correction; it is used for the inspection of the robot grasping process to ensure reliable placing of the targets. SIMATIC is another stand-alone vision system for assembly verification. It monitors the assembly process and provides verification for overall assembly. All of the machine vision systems used in this assembly cell were commercial, off-the-shelf products. Fig. 2 depicts the overall system architecture.

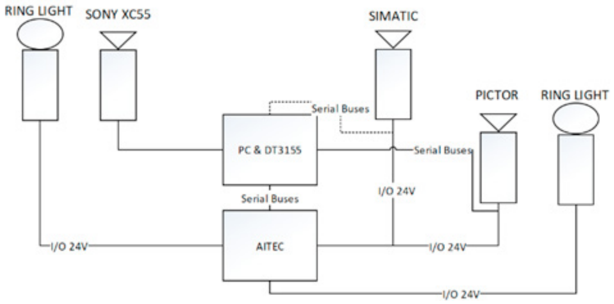
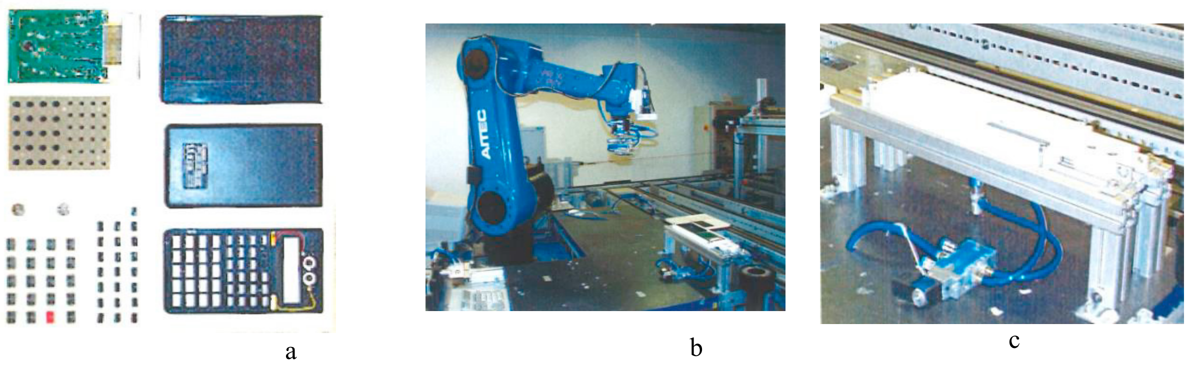


Fig. 2. System architecture.

2.2. Assembly Cell

The assembly cell was based on industrial robot Aitec Ars-10 (Fig. 3b). The Aitec robot has a gripper changing system and uses two customized grippers in the assembly. The grippers were a finger gripper and a vacuum gripper. The grippers were designed to pick and place all the components of the calculator (Fig. 3a). This assembly cell also had an assembly station where all of the components were placed in a pre-defined order.



a b c

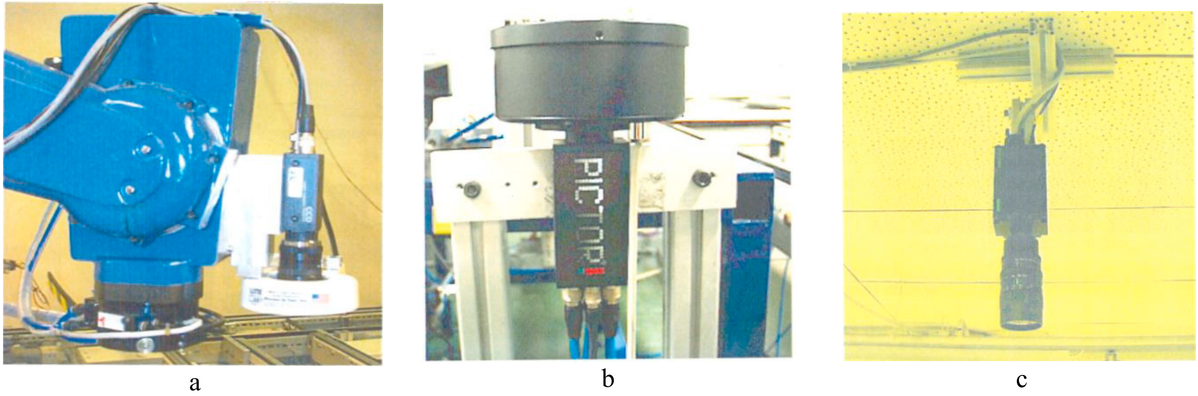
Fig. 3. Assembly cell: (a) 49 components of the calculator, (b) Aitec robot, (c) Assembly station.

3. Integration of Multi-Camera vision System with a Robot Assembly Cell

3.1. Eye-in-hand Camera, Object Detection, and Pose Estimation

The PC-based machine vision system was installed in the robot arm (Fig. 4a). It worked as an eye-in-hand camera and provided coordinates to the robot as to where to pick the components. A fluorescent ring light was installed around the eye-in-hand camera. This kind of lighting equipment gave good fit conditions for the machine vision system.

The hardest task in the installation of this eye-in-hand system was the calculation of coordinates from work coordinates (component) to the camera coordinates and finally to robot coordinates [3], [7]. Camera coordinates also had to be changed from pixels to millimeters [8]. These coordinate manipulations were accomplished using the eye-in-hand and the robot together as a measurement system. Components of the PC-based machine vision system included: DT3155 frame grabber, Sony XC55 camera, Stocker & Yale Model 10 Lighting, and Visual Basic algorithms.



a b c

Fig. 4. Three-camera vision system: (a) Sony XC55 camera, (b) PICTOR camera, (c) SIMATIC camera.

3.2. PICTOR Camera, Placing Correction

The intelligent camera PICTOR was installed as near as possible to the assembly station (Fig. 4b). The purpose of the camera was to ensure accurate placement of the components in the assembly station. Picking of the components can cause positional inaccuracies; these inaccuracies are compensated with PICTOR, which gives the robot offset coordinates from the predefined position of the current component. The offset coordinates are gauged relative to the gripper. A red LED ring light was used with the PICTOR. A lens was selected with a 12.5 mm focal length.

3.3. SIMATIC Camera, Assembly Verification

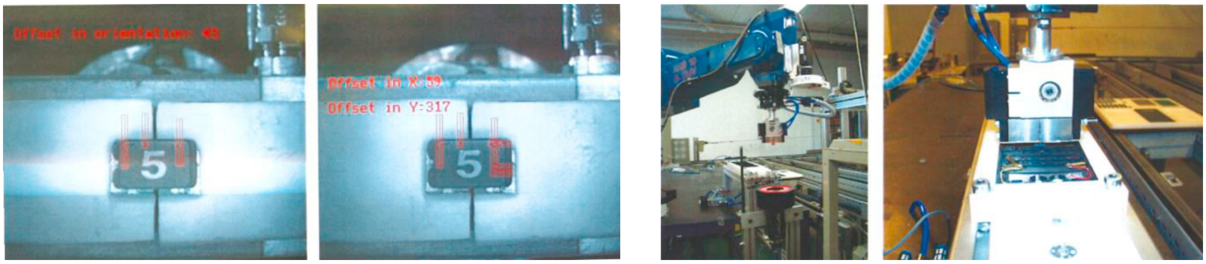
The third machine vision system was used for assembly verification tasks. This system was also an intelligent camera, like PICTOR, called SIMATIC VS710. This camera can be flexibly installed into various systems because of its PROFIBUS DP interface. The SIMATIC camera was installed on the ceiling of the laboratory, above the assembly station (Fig. 4c), so that collisions with the robot could be avoided. No extra lighting was installed with this camera, because the fluorescent ceiling lighting of the laboratory was enough. A 75mm CCTV lens was selected according to the spatial resolution requirement.

3.4. Communication Interfaces

The communication between all the devices is vitally important for such heterogeneous subsystems. Serial communication was used among vision systems, the robot, and the PC. The PC was working as the communications node. Most of the data from different devices went through this PC to the robot and back. The same PC program that was handling the PC-based machine vision system was also handling all events coming from different devices and acting according to them. The robot outputs were also used to control lighting and the assembly station and to trig the PICTOR camera. The robot controlled the PICTOR camera with four outputs. A combination of these four outputs told the PICTOR camera which component was in the gripper. This assembly cell was working alone without any high-level process control or factory network. If this kind of assembly cell is installed on a factory floor as a part of production line, it is possible to connect it to the factory network.

4. Results and Discussion

The workflow in the robot cell consisted of 49 (number of components) similar cycles. The workflow started when the robot drove over to the component; the eye-in-hand machine vision system detected and located the component, extracted the component's coordinates, and converted them into robot coordinates. The robot picked the component and moved it over to the PICTOR camera (Fig. 5c), which was beside the assembly station. The PICTOR camera extracted offset (x,y,ɵ) values between optimal and current component position, as shown in Fig. 5a and 5b. After the robot received the offset values, it placed the component into the assembly station (see Fig. 5d). The SIMATIC camera validated that the component was correctly assembled.



a b c d

Fig. 5. Assembly Process: (a) Offset in orientation, (b) Offset in position, (c) Inspection by PICTOR, (d) Peg-in-hole assembly.

The biggest result was an assembled pocket calculator and an assembly cell that could repeat the assembly. The assembly cell was built to demonstrate that machine vision could be successfully used in a light assembly. Some problems occurred due to the lighting conditions of the laboratory. Machine vision systems can very poorly cover or adapt to changes of light. This fact is not emphasized enough. Some methods and systems have been developed to compensate light changes, but a more reliable way to handle this problem is to always keep the light as even as possible. The lighting can be very difficult to design if components under inspection are made from various materials and colors. Shiny and transparent materials are the worst cases.

Mechanical connections of the cameras and the lenses could be better designed to meet the requirements of modern machine building. High-speed robots and assembly cells are in mechanical connection to the camera systems; vibrations from these machines can cause unexpected problems. Camera connections can loosen, and even if connections are tightened again, the calibration information of the machine vision system can be corrupted. Lenses should always be locked to prevent changes in the lens focus or in the lens shutter.

The accuracy of the machine vision system is quite complex to calculate because so many factors affect it, such as light, lens aberrations, lens focus, camera connection, electrical connections, movements, vibrations, etc. One conclusion is that machine vision can be used as a tool for measurements, but the accuracy obtained must be verified after all the components of the machine vision system have been connected together.

Locations of the cameras in the assembly cell should be carefully designed. The wrong placement of a camera can cause much more programming and calculating than expected. The cycle time can be reduced due to careful planning of the assembly cell and the workflow.

Programming of the machine vision systems is getting easier, but some of the systems still need an expert to elicit the best out from them. Other systems can be programmed very intuitively and straight-forwardly. Bad experiences and results can occur if a machine vision system and the vendor for the system are selected in a hurry.

5. Conclusion

The multi-camera machine vision system is designed to provide visual guidance for the robot to automatically complete the assembly of a pocket calculator, and it can be easily modified for assembly of any products. The state-of-the-art algorithms for object detection, pose estimation, object identification, and touch-free quality measurements are developed to a process control layer of an assembly line. Overall, the experiment demonstrated that such multi-camera machine vision can be used successfully in automated assembly to guide an assembly robot through the assembly process, which becomes more reliable and flexible as a result. In addition, the system produced data for process control—i.e., dimension measurement of the components as circuit board inspections, which could be used in statistical process control (SPC) tasks to control cells producing the components.

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