Further Perspective of Machine Vision in Industrial Robot Systems

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Abstract. With the rapid development of automation systems and artificial intelligence, industrial robots have played significant roles in automated production processes. Due to the improvement of computer chips, more and more vision algorithms are able to run in industrial robot systems. Increasingly, robotic systems based on visual recognition are replacing those based on traditional sensors. However, there is much work to be done in real situations. This research focuses on the application of machine vision in the field of industrial robot systems. It first gives the overall summary of industrial robot systems and machine vision as well as their applications. Then it gives an example of a sorting system and expounds its strategy. Finally, it turns out that machine vision can be widely used in industrial robot systems because of its excellent performance, although there are still existing problems to be solved in it. Those problems may be solved by further development of algorithms.

Keywords: Industrial Robots; Machine Vision; Sorting Systems.

1. Introduction

Industrial robots are essential components in production lines [1]. Traditional automation systems are normally controlled by PLC systems, which are comparatively simple and don't rely on strong chip performance. Later, advanced industrial single-chip microcomputers are installed to improve the performance. Those microcomputers gather information from sensors, process the signals, and give digital feedback. With the development of machine vision, more and more jobs are completed by cameras combined with traditional sensors, even without sensors. Frank S. Cheng and Andrew Denman [2] used a system based on a 2D camera to implement a robot's operation of grabbing and placing objects. The system has a perfect performance compared to traditional systems because it can identify the position of 3D objects precisely and effectively. With the help of software, the system can control the robot Tool Connector Point (TCP) to meet all kinds of requirements. However, the application of machine vision is still limited in certain cases, such as grabbing and placing. On account of the actual industrial production environment, it still cannot take the place of traditional sensors in all cases. Where else can machine vision be used? How to use machine vision in other aspects of industrial robots? The discussion of those questions is significant for future development in both industrial robots and machine vision.

This research tries to figure out the further application of machine vision in industrial robots, on the basis of the current technology. It will first expound on the related terms. The definition of industrial robot systems is introduced and three examples of them are attached to demonstrate the typical categories as well as the major application of them. Then, the main process of machine vision is introduced. It can be roughly divided into three steps, image capture, digital processing, and machine learning. Those steps enable the system to recognize the surrounding environment in order to give feedback to the control system or the subsequent processes. To clarify the relationship between industrial robot systems and machine vision, an example of robotic system established from machine vision is then given to reveal that it is powerful and efficient to use them in practice. Furthermore, further application of machine vision in the different systems will be discussed. it will discuss about the possible reasons for its limited scenarios and disadvantages, like in sorting systems and industrial inspection. Some possible solutions are also given to lay a foundation for the future development of the new generation of robot systems.

2. Related Works

2.1 Industrial Robot Systems

In recent papers, different sorts of industrial robot systems have been manufactured. Wireless climbing robots were made to handle severe situations. They can be used in industrial inspection, shipbuilding, etc [3]. Flying robots simplify the process of industrial inspection. They are equipped with various kinds of sensors so that they can complete the inspection precisely [4]. Articulated robots are most commonly used during the whole process of production. They simulate the human's arm in order to instantly and accurately complete movement like grabbing and placing. Other categories of robots are also changing people's life.

Wireless climbing robots use a certain method to attach to surfaces of different materials. They were designed with light materials like aluminum so that they can support the control system [5]. The way that they are capable of attaching to different surfaces can be classified into three categories, negative pressure, magnetic adhesion, and friction [5]. With this character, those robots have access to the unreachable places of humans and other normal machines. As shown in Figure 1, Wireless climbing robots have been applied to industrial storage tank inspection, surface cleaning, and even wall painting [6].

Fig 1. Climbing robot for visual inspection [5]

Flying robots are also called unmanned aerial vehicles. According to Thomas Moranduzzo and Farid Melgani[7], corrosion damage of industrial plants can be detected by UAV, though the measurement accuracy is needed to be improved. For example, the DJI M30T equipped with 16x optimal zoom camera, thermal camera, wide camera, laser rangefinder and cellular enables high quality image transmission and processing. With the help of software, people can gather accurate information and analysis in emergency rescue, overhead power line inspection, city mapping, etc.

Figure 2 shows a model of an articulated robot. It consists of rotary joints. Those joints allow the flexibility of movement. As a result, a large range of tasks can be performed. According to the International Federation of Robots, annual installations raised by 9% on average each year from 2015 to 2020[8], which demonstrate the rapid expansion of articulated robots. However, there are also disadvantages. According to L. Bin, R. Xuewen and L. Yibin, there are still limitation in the high-speed movement ability of articulated robots in either computer simulation stage or the constructed experimental prototype [9]. The improvement of algorithms may help to solve this problem.

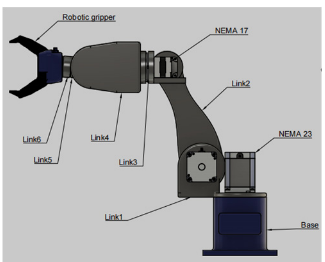

Fig 2. Articulated robots

2.2 Machine Vision

Machine vision can be roughly divided into three parts: image capture, digital processing, and machine learning [10]. The combination of those three components gives the robot a human-like vision. Hiroshi Sako[11] has demonstrated that the machine's recognition rate can be promoted by using the strategy of multiple hypotheses and information integration. So, to some extent, it can take the place of some traditional sensors. Figure 3 shows the general process of the machine vision.

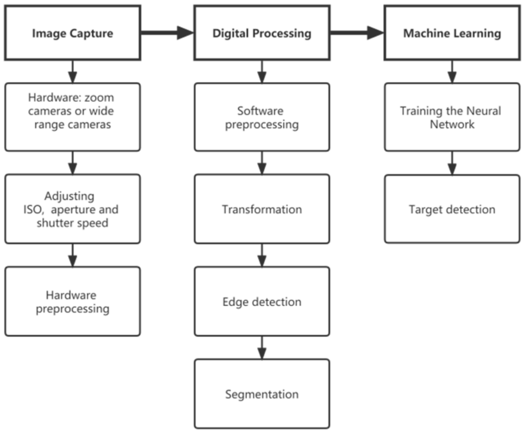

Fig 3. General process of the machine vision

Images are captured by cameras. The result of the machine vision depends 85% on the quality of the captured picture [12]. The capturing device can be zooming cameras or wide-angle cameras. Cameras with lightweight and cheap prices are popular in the field of machine vision. By adjusting the value of ISO, aperture, and shutter speed, it is also possible to capture clear pictures even in dark places. Using the RAW format, the pictures contain more details so that it's easier for the later process. With the help of exposure compensation, the images are suitable for edge detection and noise cancellation. Also, smart cameras with an automatically adjusting system enable rapid capture and pretreatment by filtering algorithms in the hardware layer.

During digital processing, through software preprocessing, noise has been reduced to a large extent. A temporal delay was introduced by Gerard de Haan to realize the noise reduction in IC [13]. Motion compensation is also utilized in the recursion loop process of the noise filter to improve its performance. Then, image transformation is executed to fulfill the later requirements by matrix rotation and translation. After that, the edge of the target object is detected for segmentation. Specific filters are firstly used to realize enhancement, which sharpens the edges of the objects. By smoothing and localization, the exact edge pixels of the object are found [14]. Segmentation such as semantic segmentation and instance segmentation is finally applied to classify the objects encompassed by their edge pixels from each other.

After digital processing, objects are separated. Machine learning is then utilized to identify the exact category of each object. Different algorithms have been invented to improve its accuracy. One of the most effective algorithms is the convolutional neural network (CNN). A neural network normally consists of an input layer, a hidden layer, and an output layer. In CNN, the hidden layer is composed of convolution layers, ReLU layers, polling layers and a fully connected layer[15]. Large amounts of data are inputted from the input layer to train the inner structure of the hidden layer, including the convolution kernel, so that the network has strong robustness.

3. Discussion

3.1 Example of a Sorting System

In industrial production, objects may be placed on the conveying belts at random. It's hard for traditional sensors to sort them in order very precisely. Thus, machine vision is widely used for industrial sorting systems. In 2021, S. Chen [16] designed a sorting system based on machine vision. The paper focused on both the theoretical and experimental design of the system. The system consists of a camera-based image capturing unit, a transmission unit, a data processing unit, and a control unit.

Figure 4 shows an example of sorting system based on machine vision. Random objects are transmitted on the conveying belts. It will first enter the camera-based image capturing unit. An intense light source is placed above the unit to provide an appropriate environment for the built-in camera to capture images. Then, the images will be read by the computer in the data processing unit. In order to recognize objects in different directions, noise cancellation, transformation, edge detection and segmentation are applied to classify all the objects into different categories. A CNN is then used to identify the exact position of each object. Each node of the hidden layer in the neural network has a weighted value. Those weighed values are trained by large scales of input data so that the neural network is able to separate different objects from each other. In this system, the number of neurons is set to 20[16]. After 300 cycles of training, the system has strong robustness.

After obtaining the exact position of the object, the information will be given to the controller unit. The controller unit is directly connected to an articulated robot. The articulated robot has four joints. With the rotation of each joint, the robot arm is able to reach every position in the target coordinate system. An electromagnetic sucker is installed on the first joint as Tool Connector Point (TCP). The controller unit will analyze the dynamic position of the data processing unit and use an algorithm to convert it to the rotation angles of each joint. With the help of the algorithm, the rotation angle of joint 1 and joint 2 are relatively minimized. Analogously, if the vertical distance has been changed between the original position and the target object, the algorithm will also generate a linear trajectory to ensure the articulated robot reaches the destination optimally. All four joints are controlled by the same algorithm so that the efficiency of the sorting system is maximized.

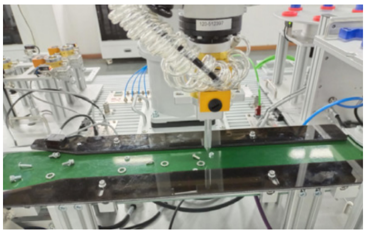

Fig 4. An example of sorting system based on machine vision [16]

3.2 Further Application of Machine Vision

The sorting system gives a perfect example of the application of machine vision in industrial robots. The neural network provides excellent performance to recognize different objects and. The control unit converts the coordinate to the joints of the robot and enables the robot arm to sort different objects on the conveying belt. Besides, machine vision can also be applied in other fields, like cloth handling systems, industrial inspection, etc. But there are also limitations in the application scenario of machine vision.

In cloth handling systems, it has a more complicated situation. Since cloth is soft, it cannot be recognized and picked up as simple as the previous sorting systems for rigid objects. The cloth itself may be randomly folded, so the robot arm cannot grab it in the same motion for each different cloth. According to S. Hata [17], three steps are respectively can be applied to ensure that every cloth is in the right position and direction, including picking up, grasping one corner and grasping one edge. It finally turned out that it has a large possibility of success (99%) in picking up step and grasping one corner step, but the success rate of grasping one edge step is comparatively low (84%). The reason for this is mostly the limitation of algorithm. The current algorithm in the cloth handling system uses a pattern to distinct the edge of the cloth. However, it is not effective for the edge recognition because the algorithm may confuse the edge of the cloth with the stripes on the cloth. Thus, in order to improve the performance, a neural network may be trained to distinguish the edges and stripes. With this neural network the success rate can be improved.

In industrial inspection, machine vision has the advantage of high efficiency. According to J. Jia.[18], a higher production rate can be provided on the basis of 100% accuracy of inspection. Due to the excellent performance of control unit and stable neural network, reliable technical processes are supported. However, unlike traditional sensors, image capture relies a lot on the light condition. Therefore, suitable light equipment is also significant, especially in the inspection of translucent material. One of the solutions is to work with a laser radar. The laser radar will roughly scan the surface of the object and gives an approximate position of the exception. With the rough position, the light equipment will illuminate the area, and the camera will recognize the exact situation of the exception.

4. Conclusion

In this paper, the application of machine vision in industrial systems is introduced. There are various kinds of industrial robots, such as wireless climbing robots, flying robots and articulated robots. They free a lot of people from their jobs. Machine vision is based on image capture, digital processing and neutral networks. It gives machine ability to recognize different objects from each other. The example of a sorting system reveals that machine vision in industrial robots improves efficiency to a large extent.

Machine vision can also be applied in other fields. In cloth handling systems, machine vision contributes to adjust the position and direction of cloth, preparing for the later steps. But it’s hard for machine vision to distinguish the edge of the cloth from the stripes on the cloth. This may be solved by training a specific neutral network for it. In industrial inspection, machine vision improves the efficiency on the basis of high-level accuracy. But light condition really matters for cameras to capture images. In dark environment, a laser radar can be used to help locate the position of exceptions.

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