On Application of Industrial Robot Based on Machine Vision in Recognition, Instruction and Assembly

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ABSTRACT

It is of great significance to apply machine vision technology into developing manufacturing industries. In this project, LabVIEW VDM was used in the design of online working system of based-on machine vision mechanical products, including intelligent identification, localization, guidance and assembly. The target objects of original images were extracted and altered through morphological opening-and-closing objectives and automatic median processing before accurately localize the target area through thickening and thinning; at last, randomized Hough transform was used to rebuild the shape to separate the overlapping round targets. Results showed that this system is reliable and accurate, the accuracy of screw installation reaching 0.01mm, that simultaneous multi-functional operation is possible in industrial robots, and that the overall-controlling software designed as a standardized protocol that can accept different industrial robots can improve the working efficiency and intelligence degree of automatic line.¹

INTRODUCTION

As one of the top 10 key fields to be rigorously developed listed in China Manufacturing 2025, industrial robot is an important mark of industrial automatic level and industry 4.0 [1]. Thanks to its high precision, reliability and applicability, industrial robots are widely applied in almost every industry, such as engineering, automobile, electronics and logistics [2]. To solve the problem of complicated assembly in mechanical products, industrial robots have been introduced. However, the uncertainty and fuzziness of these robots result in the lack of flexibility since the

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robots cannot accurately identify or timely adjust their movement trials without knowing the external information. Thereupon, vision technology was introduced to the production line of robots [3], which has greatly improved the flexibility and automation level of the production line.

Intellectualization in equipment manufacturing industry refers to the system that has such functions as perception, making decisions, controlling and executing, for which machine vision identification and guidance control is a key technique. The methods how to apply machine vision and mode recognition in the field of intellectualized equipment manufacturing have been put forward in [4]. The K-OPN integrated model of vision integrated application oriented to the assembly process of mechanical products is constructed in [5]. The visual guidance system in SCARA was designed in Literature [6], solving the problem of non-fixed location of work-pieces. Equal-area extraction and normalized shaping in the field of intellectualized equipment manufacturing were proposed in [7], which helps improve the recognition ability of work-pieces. And in [8], Expectation-Maximization (E-M) was proposed and machine vision was applied to detect PCB defects, realizing fast recognition of images.

In this project, considering the key procedures in the accurate assembly on automatic production line, identification, localization, guidance and control included, an intelligent online working system based on machine vision was designed. First, the location and shape of work-pieces were recognized and measured; and then, calculation results guided industrial robots to grasp, move, place, control and precisely install these work-pieces.

**SYSTEM STRUCTURE**

Using LabVIEW VDM, this project is aimed to realize the assembly on production line done by industrial robots with vision recognition system. With core kit of VDM being invented by NI, the field of machine vision is facing another revolution. The monopoly of expensive embedded intelligent camera that was produced by professional companies has been changed: workstation and ordinary industrial camera system can help develop powerful vision identification system, thus lowering the developing threshold. VDM core kit, together with LabVIEW, VC++, C# and .NET were used to design the algorithm so as to conduct various tasks such as machine vision images processing.

There are many options in the combination of industrial robot platforms with machine vision. In the project, ABB IRB120 robot and LabVIEW VDM with industrial cameras were adopted. The system was integrated on the workstation and communicated with industrial robots through Ethernet.
The machine vision system based on computer processing is in charge of judging the position of screw holes and the installation of screws, sending such information as position and shapes of screw holes and instructing industrial robots.

The system was designed through combining the practical factory use and corresponding automation working scenes, in which ABB industrial robot was the base and images workstation as the main machine. The structure of this system is composed by an integrated automatic system of sorting screws, a pneumatic system of grabbing screws, a control system of automatic assembly, a vision processing system and a automatic loading & unloading system. The system is shown in Figure 1.

Description of key parts:

Industrial robots: as the actuator of screw assembly, it is the smallest 6-axis robot in the family of ABB IRB120 with a repeating localization accuracy of ±0.01mm, an arm-spread radius of 580mm, 16-way input IO and 16-way output IO as well as port of Ethernet. It is an industrial robot with good performances.

Industrial camera: there is a visual input sensor in the camera; it is the Ethernet 500M camera produced by IMAGINGSOURCE (Germany); standard lens for white ring light source. It can provide a VGA, 60 fps output and 1280*960, 200fps output. Its reduction degree in colors is quite high, so it can produce better effect.

Screw sorting machine: the machine can automatically put screws in order, making it easier for robots to grab them.

Manufacturing area and loading & unloading area: this is the assistant part that facilitates the screw assembly as well as loading and unloading.
TABLE I. SYSTEM INDICATION.

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Visual frame rate</td>
<td>15fps</td>
</tr>
<tr>
<td>Fastest recognizable motion speed</td>
<td>3m/s</td>
</tr>
<tr>
<td>File of vision</td>
<td>102°</td>
</tr>
<tr>
<td>Control cycle</td>
<td>5ms</td>
</tr>
<tr>
<td>Assembly speed</td>
<td>60</td>
</tr>
<tr>
<td>Localization accuracy</td>
<td>0.01mm</td>
</tr>
<tr>
<td>Power source</td>
<td>AC220V</td>
</tr>
<tr>
<td>Air source</td>
<td>0.8Mpa</td>
</tr>
<tr>
<td>Product net weight</td>
<td>500kg</td>
</tr>
<tr>
<td>Boundary dimension</td>
<td>1360<em>800</em>1700mm</td>
</tr>
</tbody>
</table>

Cylinder fixed system: the work-pieces are fixed to avoid shaking during the assembly. Performance indicators of this system are displayed in TABLE I.

VISION PROCESSING ALGORITHM

A. Morphological Transformation

Particles of images can be extracted and changed through morphological transformation which is mainly the function of binary morphology applicable for the basic morphology of binary images. After the binarization, the images were processed and polished.

Targets of corrosion: the erosion processing reduced the size of each particle. Structure elements were used to process these particles once their pixel neighborhood was 0.

Targets of expansion: the dilation enlarged every particle. Once their pixel neighborhood was 0, structure elements would be put into play.

Opening objectives: this operation can make the particle profile smoother. Its mechanism is: erosion is followed by expansion, so this operation usually helps cut the narrow gap and remove the smaller points isolated, the tiny rags and extruding features.

Closing objectives: this operation also makes the profiles smoother. It is a couple with the opening operation but their procedures are the opposite: dilation goes first before corrosion. It is usually used to remedy the narrow gaps and long wide gaps, remove smaller holes isolated and fill up the cracks on the profile line.

Automatic median: automatic median value based on structural elements simplifies objects. This function works with opening and closing operations. The effect is shown in Figure 2 below.
If \( I \) is the original image, the intersection of opening and closing operation in extracting the image through function of automatic median will be:

\[
\text{Auto-median}(I) = \text{AND} (\text{OCO}(I), \text{COC}(I)) \tag{1}
\]

or

\[
\text{Auto-median}(I) = \text{AND} (\text{DEEDDE}(I), \text{EDDEED}(I)) \tag{2}
\]

\( I \) is the original image, E-erosion, D-dilation, O- opening and C-closing.

Shapes of targets can be changed through Thickening by adding designated matched pattern objects in the structure elements. Thickening is used to fill up holes and smooth objects with square edges. Larger structure elements are allowed to use more specific templates.

Thickening function is used to extract the union of original images and transformed images. Transformed images are set up by a designated structural element through the thickening function by a Hit-Miss function. In the binary relationship, a Hit-Miss Transform is added to restore the original image.

If the central coefficient of structure element is 1, thickening function is not applicable, when H-M function can only change the known particle’s pixel from 1 to 0. However, extra thickening function will help return the pixel. If \( I \) is an image, there will be:

\[
\text{Thickening} (I) = I + \text{hit-miss}(I) = \text{OR}(I, \text{hit-miss}(I)) \tag{3}
\]

In Figure 3, image A is the original binary image, image B is the thickened image.
Thinning can change the shape of objects by removing designated matched pattern objects in some structure elements. It is quite effective in removing the one-pixel isolated points and objects with square edges. Similarly, larger elements are allowed to use more specific templates.

Thinning function is used to extract the intersection of original image with its transformed function which is formed through H-M function. In the binary relation, this operation is finished through removing the transformed image through H-M transform from the original image.

If I is an image, there will be:

\[
\text{Thinning}(I) = I - \text{hit-miss}(I) = \text{XOR}(I, \text{hit-miss}(I))
\]  

(4)

The central coefficient of structural elements is not allowed to be 0, when H-M function can only change some known particle’s pixel from 1 to 0. But the subtraction in Thinning function will restore these pixels to 0.

In Figure 4, the application of Thinning function is displayed, which shows that the discrete single pixels in the top left corner have been removed.
B. Circle Detect Operator

Circle detect operator is able to locate the center and radius of circular particles in the image. In circular function, randomized Hough transform was used to rebuild the shape of particles and separate overlapping circular particles with the assumption that particles were originally circular. Particles are considered as a group of overlapping discs that to be separated. Every particle is supposed to be traced [9]. The basic principle of circle detect function is shown in Figure 5. The practical effect of circle detect function is shown in Figure 6.

![Figure 5. Basic Principle of Circle Detect.](image)

![Figure 6. Practical Effect of Circle Detect.](image)

TEST AND RESULTS ANALYSIS

In this system, software scripts were designed according to procedures before forming LabVIEW VDM code; and then information like coordinates and screw
size were sent to the robot for operation. Vision recognition and guidance in the assembly include 9 steps:

Step 1: To filter useless areas. The camera firstly recognized those targets that need processing. There were a large amount of useless objects and areas which would disturb the recognition. Mask function was opened and ROI area was selected.

Step 2: To change color images into grey ones before the binarization through correction algorithm so as to improve the speed and accuracy of recognition.

Step 3: To make judgment about assembled screws and unassembled ones according to the size of holes.

Step 4: Image particles in assembled area were downsized through morphological erosion algorithm and then tiny particles were filtered. Make sure the erosion algorithm must be reliable. Parameters in Erode objects function were: size of elements is 9, times of erosion 1 and structure elements are circular.

Step 5: To remove all disturbing particles. Automatic median was firstly used to remove tiny particles in the image and then thickening made the particles smooth before the thinning processing that remove larger disturbing particles.

Step 6: To locate the position and diameter of screw holes. Coordinates were drawn according circular function. Parameters include minimum radius of 4 and maximum radius of 11.

Step 7: To instruct the robot to grab work-piece.

Step 8: Move and localization.

Step 9: Assembly completion.

To avoid misjudgment of vision recognition, basic parameters in LabVIEW VDM were set as: camera exposure is 0.025 and distance between holes is 15.

The system began with the recognition of the number and position of screws to be assembled; and then the robot grabbed the screw and put it in the right hole under guidance. Accuracy error was put into statistics where 100 assemblies in 8 groups in 24 assembly sites were taken into consideration. The test revealed that this system is applicable to recognize any work-piece in the assembly of screws accurately with the largest absolute error of 0.01mm and average absolute error of 0.005mm, which meets the requirements of high-precision product assembly. Its speed reached as fast as 60 pieces/min. A dozen of days later, the system still worked stably, so it is good in performance.

Key Designing And Innovations Of The System

A. AUTOMATIC ASSEMBLY AND TRANSITION

Industrial robots were used in the project. Compared with traditional equipment, the Industry manipulator can change the objects and position and order of coordinates anytime while industrial robots can program anytime, so the robot is multi-functional at the same time. The assembly and transport are usually supposed
to be done simultaneously, so pre-programming plays an important role in controlling and instructing the robot.

B. A STABLE VISION ALGORITHM

Screw assembly and transition needs a piece of equipment that can check the difference and controlling accuracy of products along the assembly line. Machine vision is more accurate and stable at this aspect. The accuracy of assembly can reach 0.01mm with the help of morphological transform and circle detect operator.

C. DOMESTIC AND FOREIGN SUPPORTS

The participation of industrial robots in the project seems to be a problem due to the high price of industrial robots and different policies. However, on the whole, a robot that is compatible. In this project, programming of the whole control system and that of industrial robots are quite independent from each other; the independent controlling system of robots requires an independent programming environment, so a standard protocol has been written, making any robot compatible if programmed accordingly.

CONCLUSIONS

In this research, machine vision was applied into automatic assembly line. Based on LabVIEW VDM and with an intelligent platform build by industrial camera and robot, an algorithm was put forward based on morphology to extract and localize target objects and randomized Hough transform to separate overlapping circular target objects. The automatic system is quite accurate, fast, reliable, highly intellectualized and contactless. Its assembly accuracy reaches 0.01mm. Besides, its control software was designed to be a standard protocol that can be applied to various hardware platforms. The system proposed in this project has real-time performance and robustness and further studies will focus on its large-scale and batch production as well as on accuracy improvement through reducing the error in camera calibration, transformation of coordinates and end actuator.

ACKNOWLEDGEMENTS

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REFERENCES