Bin-picking robot system
—Application of 3D vision system

Operations for loading workpieces onto machine tools and handling workpieces between processes are important towards building a manufacturing line. In particular, the operations for picking workpieces in bulk need to be automated.

This paper describes a bin-picking robot system as a case of application of a 3D vision sensor developed by us.

Preface

At present, in machining processes for machine parts, loading of workpieces into the machine tools, transfer between processes, and other workpiece transfer operations between machining processes are often still dependent on manual labor. If this mechanical parts picking and transfer between machining processes were to be automated using robot systems, it could make the machining process layout and flow more flexible, and increase the rate of line automation as a whole.

In the materials processing production site, automation has been slow in coming for the workpiece bin-picking operations where workpieces are randomly placed in container boxes and other large part boxes. In particular, picking of forged parts, machine parts, and other heavy workpieces is a monotonous, repetitious operation that is a classic example of an unpleasant 3D (dirty, dangerous, and demanding) working environment. As a result, there is much demand for automation, and introduction of robot systems is eagerly awaited. In addition, if special equipment for arranging parts is used, such operations would not be able to handle multiple parts types, so a practical general-use industrial robot is needed. Furthermore, introduction of such a robot system necessitates development of vision technology to enable identification of complex workpieces in bulk.

At Kawasaki, we have various vision systems using stereo vision sensors and 3D laser sensors, etc., that are available as products for various robot applications in welding, assembly, inspections, and transport, etc.

For automation of workpiece bin-picking targeting forged parts, we have developed, based on our vision technology, a 3D vision sensor, a bulk workpiece recognition method, an online interference simulator, and a module controller for integrated control of various functions, and placed a robot system on the market that is capable of stable picking of random workpieces (Fig. 1).

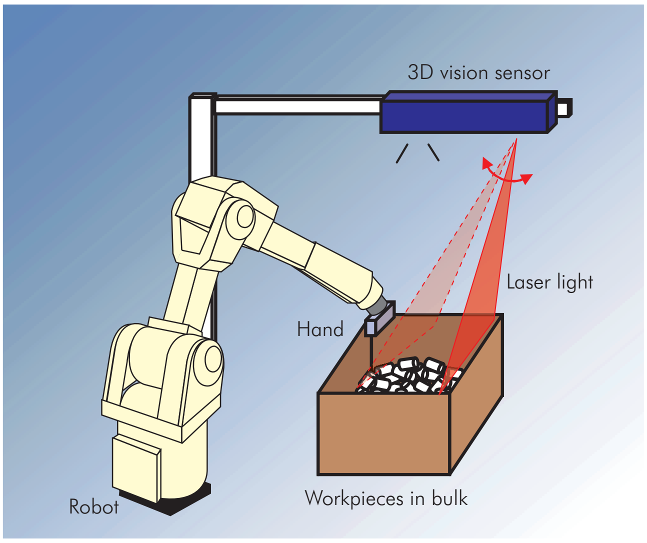


Fig. 1 Bin-picking robot system

1 Development issues and solutions

(1) Development issues

In ordinary picking operations, the method for recognizing workpiece positions and postures involves the use of cameras trained on workpieces laid out on a conveyor or other flat surfaces to perform 2D grayscale image processing. However, this method is limited in the range of picking automation applications, in that it requires workpieces to be arrayed in specified positions on the flat surface, or in a specified order, etc. For cases where bulk workpieces are randomly placed in container boxes, etc., bin-picking robot systems need to be able to recognize the 3D position and posture of each workpiece, and determine the workpiece to be picked. The main issues for automation of bin-picking operations are as follows.

① With diverse 3D positions and postures in randomly packed workpieces, individual workpieces are difficult to recognize against a background of piled-up workpieces.

② During workpiece picking operations, the robot or hand collides with surrounding workpieces or the container box.

③ Depending on the workpiece position or posture, some workpieces may be left behind within the container box.

(2) Solutions

As solutions to these issues, we have developed the following:

① A vision system capable of discerning changes in the surrounding lighting environment and the workpiece surface condition, and a stable bulk workpiece recognition method.

② Function for judging and avoiding potential collisions with surrounding workpieces.

③ Hand mechanism with diverse gripping patterns that keep residual workpieces to a minimum.

2 Development of bin-picking robot system

(1) Equipment configuration

The bin-picking robot system consists of a 3D vision sensor for recognizing bulk workpieces, an articulated robot for performing the picking operation, an electromagnetic hand for performing the grasping operation, and a module controller for performing integrated control of various equipment and operations sequences, etc. The equipment configuration is shown in Fig. 2.

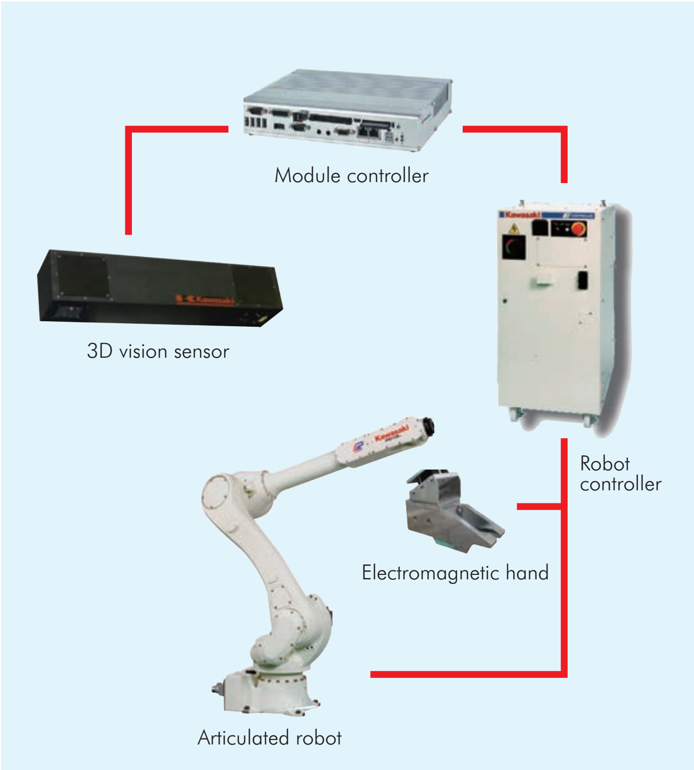


Fig. 2 System configuration of bin-picking system

Fig. 3 Laser Slit Scan Camera(LSC)

Table 1 Specifications of LSC

Item	Specifications:
Imaging distance (mm)	1,400 to 2,000
Measurement range (mm)	W800×D800×H600
Laser class	Class 3R
External dimensions (mm)	W610×D125×H125
Weight (kg)	Approx. 4.8

(2) 3D vision system

(i) Laser Slit Scan Camera (LSC)

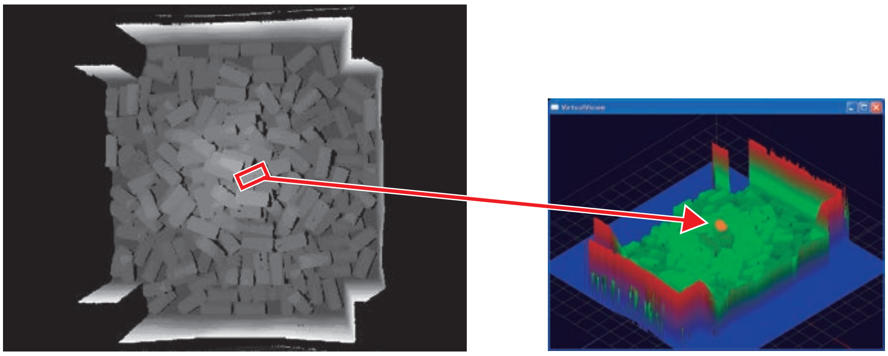
For the 3D sensing function for automation of bulk workpiece picking, we used a method for processing range images expressing height information in grayscale values. In this system, we used an active method projecting semiconductor laser slit light to obtain a range image that, unlike stereo cameras and other passive methods, enables height information to be obtained for edges and targets on patternless flat surfaces or curved surfaces. In addition, it can ensure stable imaging even with changes in the ambient light or reflection rates on the workpiece surface. For this product, we developed the 3D vision sensor Laser Slit Scan Camera (LSC) with a motor that drives a mirror to scan the laser slit light and obtain a range image. The LSC can measure the wide range of a large container box (W800×D800×H600 mm) with a single scan. An external view of the LSC is shown in Fig. 3, and specifications in Table 1.

(ii) Bulk workpiece recognition method

We have developed a bulk workpiece recognition method targeting cylindrical-shaped forged parts. In this recognition method, the workpiece targeted for gripping is picked

(a) Forged parts workpiece

(b) Image of region partitioning process



(c) Range image and result of grip target workpiece detection

Fig. 4 Images of bulk workpiece processing based on a range image captured with the 3D vision sensor, enabling calculation of the 3D positioning and posture. In addition, we eliminated the need for a template image model used in normal image recognition processes, enabling recognition of diverse workpiece postures.

The bulk workpiece recognition procedure is as shown below.

① Edge detection and partitioning process
The edges of each workpiece are detected from the range image, and region partitioning process is performed. An external view of forged material workpieces is shown in Fig. 4(a), and an image after region partitioning process is shown in Fig. 4(b).

② Feature quantity calculation
After the region partitioning process, labeling is performed for each sub-region, and feature quantities are calculated for the height, area center, surface curvature, and area, etc., of each extracted sub-region.

③ Detection of workpiece targeted for gripping
The workpiece targeted for gripping is determined from the sub-region extracted using the region partitioning process, and the 3D coordinates of the gripping position, and the workpiece tilt and rotation angles are calculated. The range image, and detection results for a workpiece targeted for gripping, are shown in Fig. 4(c).

(3) Online interference simulator

In previous bin-picking robot systems, when the robot approached the workpiece targeted for gripping, it would occasionally collide with workpieces surrounding the target workpiece or with the container box, causing the system to stop. To solve this problem and enable stable picking operations, we applied the interference check function of the Kawasaki robot simulator to develop an online interference simulator. The online interference simulator has the following features:

① Uses 3D measurement data obtained with the LSC to enable detection of robot collisions before performing the approach operation.

② Evaluates 3D positions and postures of workpieces, and the robot posture, to determine the most efficient priority sequence for workpieces targeted for gripping.

③ Determines the robot posture for the shortest robot operation time.

Operations screens for the online interference simulator are shown in Fig. 5.

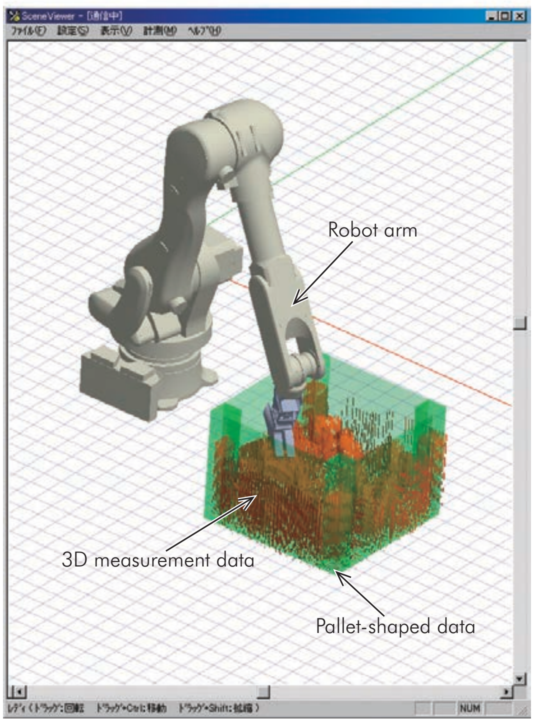


Fig. 5 Online interference simulator screen

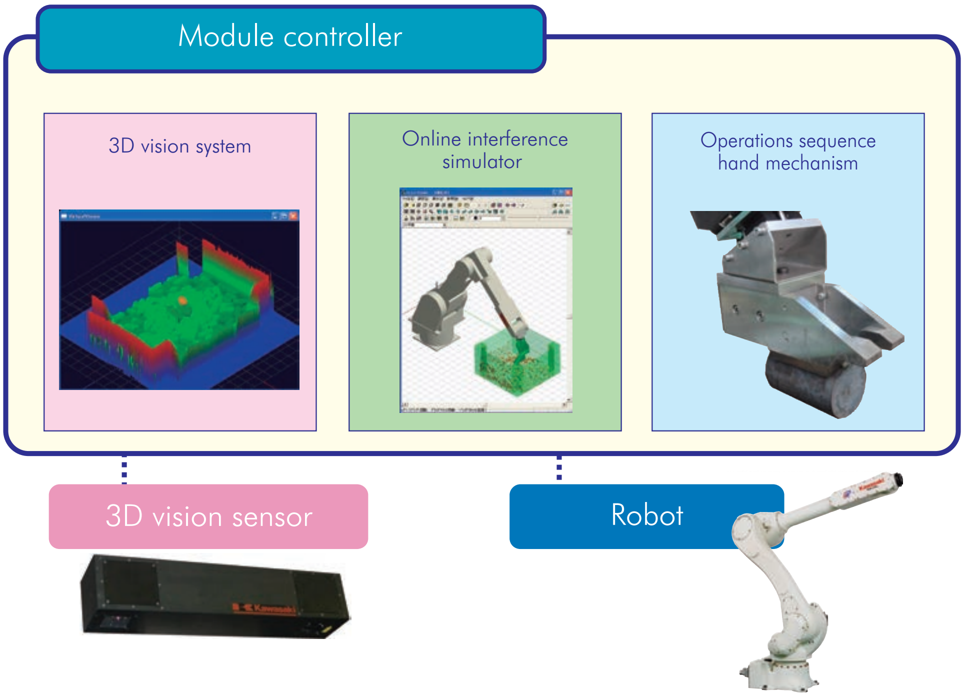


Fig. 6 System configuration of module controller

(a) Normal grip (b) Front edge grip (c) Bottom surface grip

Fig. 7 Views of electromagnet hand

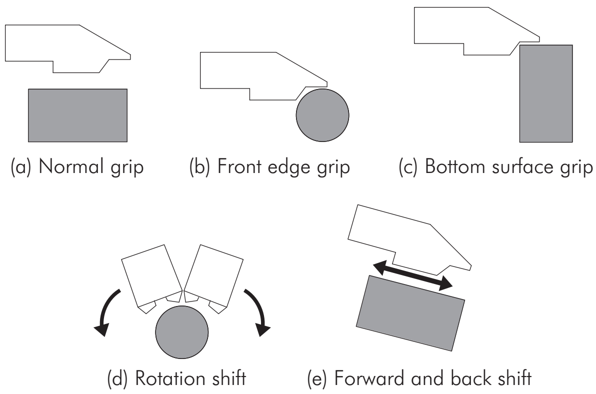


Fig. 8 Approach operation of electromagnet hand

(4) Module controller

We have developed a module controller for integrated control of the various functions in the bin-picking robot system. The module controller is the core of the robot system, and is standardized for construction of mass production-type robot systems for integrated control of the 3D vision system, online interference simulator, operations sequence, hand mechanism, and various sensors, etc. In addition, we provide a library based on a universal language (C# language) that enables easy customization for each customer, and reduces the robot system development time. The module controller system configuration is shown in Fig. 6.

(5) Electromagnetic hand

Normally, if cylindrical-shaped workpieces are loaded in bulk inside container boxes, workpieces near the walls of the container box are not picked until the very last, and sometimes get left behind without being picked. To resolve this problem, we developed an electromagnetic hand with multiple gripping patterns for the same workpiece targeted for gripping, minimizing the problem of residual workpieces. In addition, we used the online interference simulator to perform simulations of multiple gripping patterns, in order to automatically calculate approach operations that avoid hand collisions and enable picking of bulk workpieces. Views of the electromagnetic hand and its gripping patterns are shown in Fig. 7, and approach operation examples are shown in Fig. 8.

Fig. 9 Bin-picking system for forged part

3 Application example

We introduced a bin-picking robot system to a forged parts manufacturing line. This system can perform stable recognition of workpieces even with oxidized scaling or rusting of surfaces of forged part workpieces. In addition, the robot can continuously pick workpieces without colliding with surrounding workpieces or with the container box. The bin-picking system for forged parts is shown in Fig. 9.

Concluding remarks

Kawasaki has developed a 3D vision sensor, a bulk workpiece recognition method, and an online interference simulator based on our vision technology, to achieve a bin-picking robot system for practical application and placed it on the market. In the future, as a robot application using 3D vision sensors, we plan to engage in robot system development that moves beyond the handling sector to include the assembly and inspection, etc., of precision machine parts and electrical machine parts, which currently depend on manual labor because of the difficulty of automation.

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