AUTOMATED 3D VISION GUIDED BIN PICKING PROCESS FOR RANDOMLY LOCATED INDUSTRIAL PARTS

Carlos Martinez
ABB Corporate Research
Windsor, CT, USA

Heping Chen
Texas State University
San Marcos, TX, USA

Remus Boca
ABB Corporate Research
Windsor, CT, USA

ABSTRACT

Bin picking has been a research topic for years because of the challenges in image processing, robot motion planning and tool system. However, much of the existing work is not applicable to most real world bin picking problems because they are too simplistic or not robust enough for industrial use. In this paper, we developed a robust random 3D bin picking system by integrating the vision system with the robotics system. The vision system identifies the location of candidate parts, then the robot system validates if one of the candidate parts is pickable; if a part is identified as pickable, then the robot will pick up this part and place it accurately in the right location. An ABB IRB2400 robot with an IRC5 controller was chosen for picking up the parts. A 3D vision system was used to locate the parts. Experimental results demonstrated that the system can successfully pick up randomly placed parts in an industrial setting. This system provides a practical and robust solution for the industrial applications that require 3D random bin picking.

1. INTRODUCTION

In automotive manufacturing, most of the parts come in boxes or bins, in which the parts are randomly located. As a regular practice, the parts are unloaded either manually or automatically using some complex and expensive devices. The manual part picking has many limitations, such as health problems due to the weight of the parts, or limited throughput of the manufacturing. As the labor cost goes higher and higher, automated bin picking attracts more and more attention. However, the hard automated bin picking has other limitations such as cost, flexibility and quality. Therefore, random bin picking using industrial robots, which provide flexibility, high efficiency and high throughput, attracts more and more attention.

Vision-guided robots have been successfully used in the automotive industry in many applications such as painting, dispensing, and assembly. In this applications, the parts are presented in a rough known orientation. However, in many other applications the parts are packed in boxes or bins, so they are randomly located in an unstructured environments. Hence, randomly located part picking and placing is still very challenging.

Bin picking has been a research topic for years because of the challenges in image processing and robot motion planning. There has been many efforts in developing bin picking technology [1] [2]. Much of the existing work is not applicable to most real world bin picking problems because they are too simplistic or not robust enough for industrial use. For these reasons, most of the current solutions have only achieved limited success in 2D situations.

3D random bin picking technology provides the opportunity for significant cost savings and benefits. Since industrial robots can be used for picking up parts and delivering them to the right location, random bin picking technology will enable faster productivity, reduce capital costs, have less down time and reduce manufacturing errors. Compared to hard automation bin picking, 3D random bin picking reduces the capital and maintenance costs by utilizing generic and sustainable hardware, and removing the need of custom containers and transport mechanisms for the parts.

Because pure random bin picking is still a "holy grail" of robotics [3], there are many research and development efforts invested in this area. Most of the work is focused on image processing to obtain the part location, since this is the first step for bin picking [4] [5] [6] [7]. In this paper, we present a robust, 3D random bin picking system that includes a vision system capable of identifying the location of a part, and a robot

978-1-4799-7800-7/15/$31.00 ©2015 IEEE

system that validates parts and controls the robot to pick up a part and place it in the right location. This bin picking system integrates a 3D vision package with an ABB robot to provide a complete and robust solution. The vision system processes images of the parts in the bin. The part location is identified based on predefined features of the part. Since several grasping points are also defined on the part to provide different options for picking up each part, the position and orientation of the grasp points are calculated for each of the identified parts. After a part is identified, the robot system will validate if the identified part is pickable. In order to determine this, the robot system will generate a path to reach the desired grasp point to pick up the part. The robot will then verify that the generated path is reachable, as well as check that the different points inside the generated path are collision free.

In this bin picking system, a 3D vision system was used to locate the parts, and an ABB IRB2400 robot with an IRC5 controller was chosen for picking them up. Experimental results demonstrated that the system can successfully pick up randomly placed parts in an industrial setting. This system provides a practical and robust solution for the many industrial applications that require 3D random bin picking.

2. RANDOM BIN PICKING SYSTEM

The random bin picking system includes the vision system, the robotics system, their communication and tooling. The vision system identifies the part location from the captured images of the parts. The identified location is sent to the robot controller to control the motion of the robot to pick up the part. Figure 1 shows the general setup of the random bin picking system.

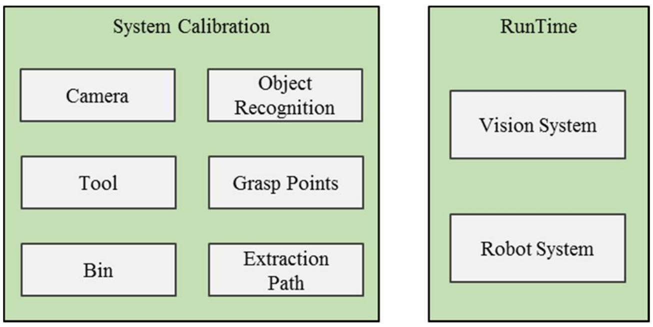


Figure 1. The bin picking system for randomly located objects

There are two main steps in this bin picking system. The first step consists of preparation of the system, consisting of the bin, camera, tool, part's features and grasp points, and the robot extract path. The 3D camera system is calibrated to establish the relationship between the camera frame and the robot frame. Similarly, the relationship between the tool (gripper) and the robot frame is also calibrated. The bin is configured by specifying the dimensions and calibrating its position relative to the robot. Then, the part features for the object recognition and grasp points are trained in the vision system by using a 3D image of the part that will be picked. Several grasping points can be defined on a part to make the system more flexible for picking. This will provide the calibration data of the part that will be used to compute the position and orientation of a parts identified in the bin. Finally, an extract path needs to be configured, so the robot system can generate a path at runtime to validate and extract the parts identified by the vision system. The second step is more related to the runtime, in which the vision system will identify parts and their grasp points, and the robot system will pick up parts after validating that such part is pickable from the specific grasp point. A part is pickable as long as the generated path is inside the limits of the robot, and each of the points inside this pat are collision free.

More details are described in the following sections.

2.1. CAMERA CALIBRATION

The relationship between the camera frame and the robot base frame has to be calibrated in order to calculate the part location for the robot to pick up the part. The camera is mounted on the tool as shown in Figure 2. The camera used in this bin picking system is a Bumblebee2 from Point Grey [8].

Figure 2. A 3D camera is mounted on the robot tool.

Since a 3D camera system is used for bin picking, a 3D calibration has to be performed. To increase the calibration accuracy, the robot is controlled to move to 50 locations while the images of a standard calibration pattern are taken, as well as the robot locations where the image was taken. Two examples of the images are shown in Figure 3.

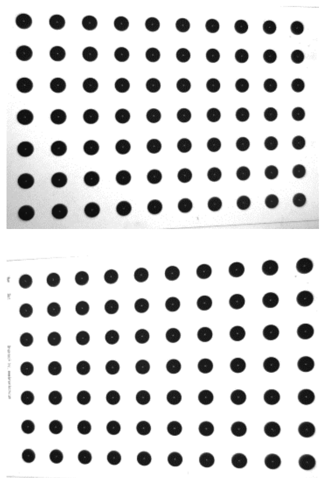


Figure 3. The captured images of a standard calibration pattern.

After processing the images of both the right and left cameras of the 3D camera system, the location of the black dots can be found. Using the robot locations, the dot locations from the images, the relationship between the robot base frame and the camera frame can be obtained.

2.2. Tool Calibration

The tool is designed to have one or two grippers. Since the vision system can identify multiple parts at once, a tool with multiple grippers could increase the efficiency and reduce the cycle time. The tool with one and two grippers are shown in Figure 4.

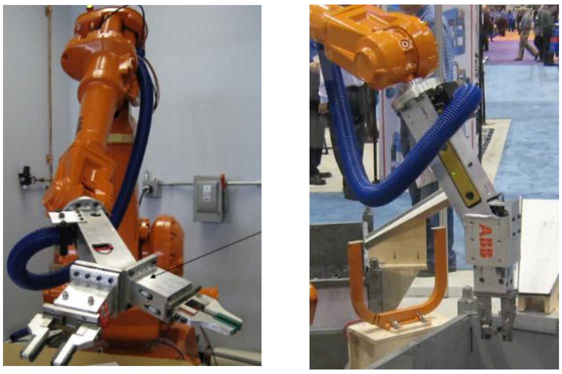


Figure 4. (Left) A tool with two grippers. (Right) a tool with one gripper.

However, having multiple grippers increases the possibility of collisions. The final design is determined based on the footprint of the tool, gripper, part and bin.

After the tool is mounted on the robot end-effector on axis 6, it has to be calibrated. This tool calibration is used to establish a relationship between the actual tool and the robot based frame. A four point method is used to calibrate the robot tool [9]. The robot tool is moved to four different points, and in each point the tool tip is on touch the tip of a fixture as shown in Figure 5.

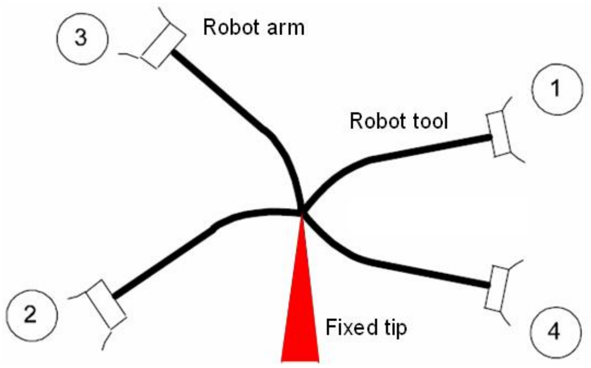


Figure 5. The ABB four point tool calibration method.

After the four points are recorded, the ABB robot controller can automatically calculate the tool location relative to the robot end-effector, which intrinsic is relative to the robot base frame. For the tool with two grippers as shown in Figure 4, each gripper is calibrated individually.

2.3. Bin Configuration

A bin is located in the robot workspace as shown in Figure 6.

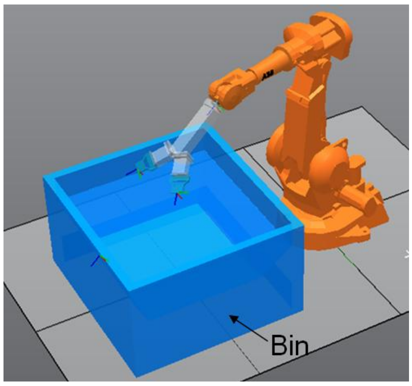
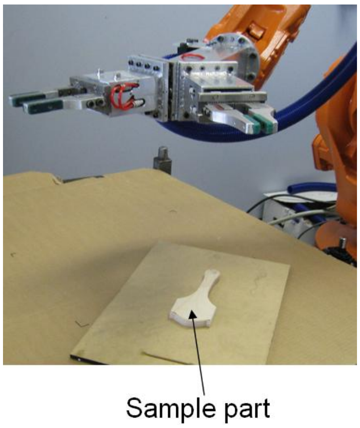


Figure 6. A bin and an ABB IRB2400 robot. The bin configuration data include the bin dimension and position relative to the robot.

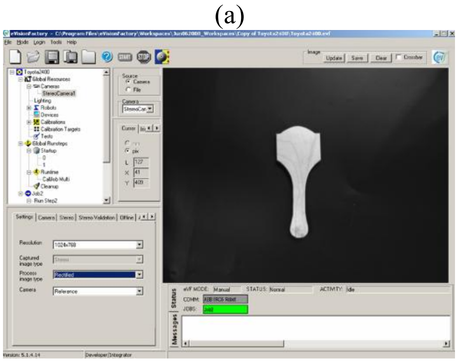
The location and dimension of the bin have to be configured, since this information will be used at runtime by the vision system to limit the areas where parts will be found, and by the robot system to validate that the points inside the generated path to extract part do not collide with the tool. There are two methods to configure a bin: manual and automatic. In the manual method, the bin can be configured by jogging the robot to touch several points on the bin. Since the bin's top surface is typically flat, three points are usually enough to build the top surface model of the bin. The bin thickness and height can be measured and directly input into the configuration file. In the automatic method, the camera takes several images of the bin. The bin top surface, the thickness and the height can be calculated from the 3D vision system. However, this method requires to define the feature of the bin before. This makes this method more complicated.

2.4. Object Recognition

Since there are many parts in a bin, the vision system has to differentiate one part from another. Therefore, the edge information is used to recognize a part and then the 3D surface information is used to calculate an accurate location of a part in a bin. A part is selected to be the sample as shown in Figure 7.



(a)



(b)

Figure 7. (a) A sample part. The image of the sample part is taken by the camera mounted on the tool. (b) The image of the sample part.

After processing the image of the part, the edge information can be obtained. Because no all edges are useful for part recognition, the extracted edges are modified and only the useful edges are used for part recognition as shown in Figure 8.

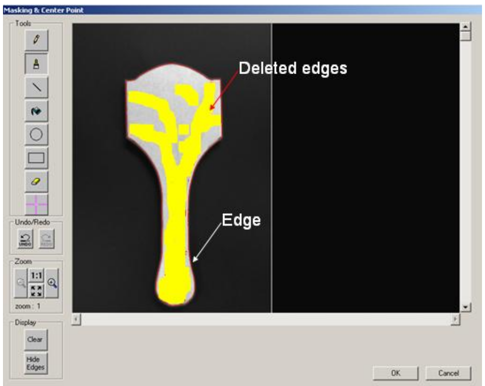


Figure 8. Some edges of the part are deleted and only the useful edges are left for part recognition.

After identified the part, we have to define the 3D model of the art. This 3D data model will be used at runtime to calculate an accurate location of the part.

2.5. Grasp Point

Now that the vision system has obtained the 3D model of a part, the grasp points can be defined using the same 3D model. The grasp points are defined by marking the areas where the gripper will approach and pick the parts. At runtime, the vision system will validate a grasp point by checking that there isn't another part in the marked areas for the grasp points in the 3D image obtained at runtime. Since the designed gripper has two fingers, two areas have to be marked for each grasp point, as shown in Figure 9.

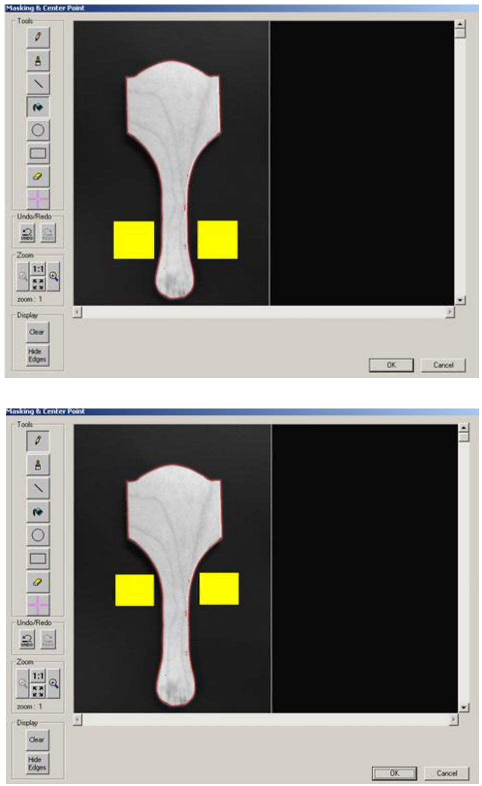


Figure 9. Two different grasping points defined by marking the areas close to the part.

As shown in Figure 9, multiple grasping points can be defined. Multiple grasping points increase the flexibility and efficiency of the developed bin picking system since the robot will have more options to pick up a part. However, the number of grasp points is restricted by the tool's dexterity [10].

For each graph point, the user must jog the robot with the tool to the part used to create the 3D model, and save this position as the master position. This position will be saved reference to the part, which at runtime will be translated and oriented to the robot frame.

2.6. Extraction Path

There are multiple methods to define a path based on a grasp point: manual or automatic. In a manual method, the robot system allows to configure a generic path to enter and exit the bin. This path will be translated and oriented referenced to the grasp point selected by the vision system. Figure 10 shows an example of this generic path.

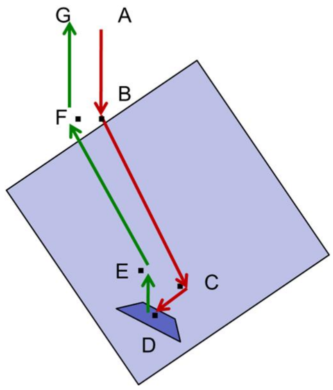


Figure 10. Generic path used to extract a part from the bin

2.7. Vision System and Robot System

At runtime, the vision system and the robot system provide different services that allow the bin picking operation. The vision system processes the 3D images and looks for parts that are free to be picked, as well as checking that this part has valid grasp points. As shown in Figure 11, the grasp points can be displayed in the vision system screen to validate during a test the grasp points' definitions.

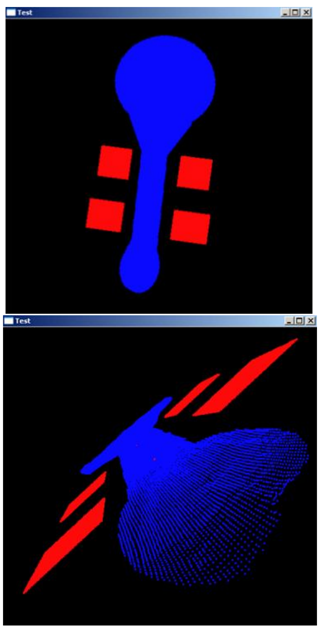


Figure 11. The built 3D model using the vision system.

The robot system provides the services to check if a part is pickable by generating the extraction path, verify that this path is reachable by the robot, and that the points defined in the generated path are collision free. Once a candidate part is identified as pickable, the robot will move along the generated path and extract the part of the bin. Since the grasp point is a known position, all parts could be dropped in the same orientation. All these services were available as an interface from any PC application, so other vision systems could access these them.

3. SYSTEM IMPLEMENTATION

This bin picking system has been implemented to pick up parts. The vision system locates the grasp points, which are then sent to the robot system. After a grasp point for a part is validated, the robot moves the tool to pick up parts continuously to empty the bin. An ABB IRB2400 robot with an IRC5 controller is chosen to implement the developed technology. The vision system developed by BrainTech (currently under the name of Robotics Vision Technologies [11]) is used for image processing to obtain the locations of the grasping points.

To test the developed system, some parts were randomly put on a surface with different locations and orientations. Figure 12 shows the grippers picking up two parts. Since there are two grippers mounted on the tool, many issues have to be considered, such as path planning to rotate the tool, gripper selection for corresponding grasping points etc.

This developed system was implemented to pick up other industrial parts such as cam rods, and other heavy metal parts using a bigger robot, the ABB IRB6400 robot. The cycle time ranges from 16s to 30s, and this should match the industrial requirements. The implementation results demonstrate that the developed system is reliable and robust to industrial installation. A modified system with a single gripper to pick industrial parts was shown in industrial expo in Chicago [12] [13]. This system presents the sensing and hardware domains needed to provide an integrated bin picking solution [10].

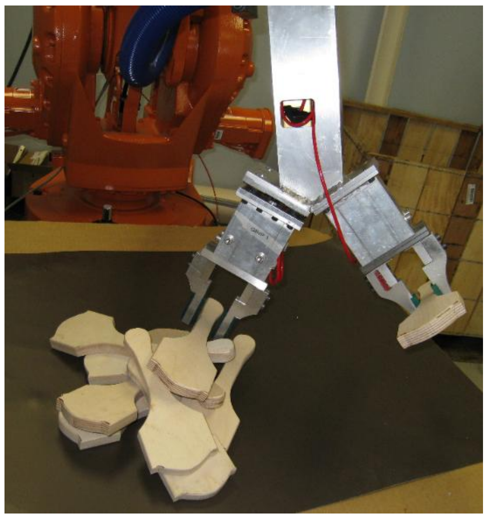


Figure 12. The developed bin picking system is implemented to pick up randomly located parts.

4. CONCLUSION

This paper presents a bin picking system to pick up randomly located parts in a bin and deliver them into the right location. The system integrates a 3D vision system with an ABB robot to provide a complete and robust solution. The part location is identified based on predefined features of the part and the calibration data. Several grasp points are defined on the part to provide many options for picking up each part with higher efficiency. After a grasping point is validated, the robot system generates a path to pick up the part. An ABB IRB2400 robot with an IRC5 controller was chosen for picking up the parts. One of the goals of this technology demonstrator was to show how the robot system could provide the required services to perform a bin picking application. These services were available in an interface, so different vision systems could be connected to the robot system to implement other vision applications. In order to adapt this solution to pick up different parts, the components of the sensing domain need to be re-train to identify the new parts to be picked. In addition, the components of the hardware domain must be re-evaluate to guarantee that the robot and the tool are able to pick up and reach parts inside the bin.

Experimental results demonstrated that the system can successfully pick up randomly placed parts in an industrial setting. This system provides a practical and robust solution for the many industrial applications that require 3D random bin picking.

ACKNOWLEDGMENTS

The authors would like to thank Biao Zhang (ABB Corporate Research, USA) and Srinivas Nidamarthi (ABB Inc.) for their insights and contributions in preparing this paper. Also we would like to thank ABB Corporate Research Centre for supporting our development and BrainTech for the vision system eVF.

5. REFERENCES

[1] M. Berger, G. Bachler and S. Scherer, "Vision Guided Bin Picking and Mounting in a Flexible Assembly Cell," in Thirteenth International Conference on Industrial and Engineering Application of Artificial Intelligence and Expert Systems, 2000.

[2] Y. Yanagihara and T. Kita, "Parts Picking in Disordered Environment," in IEEE International Workshop on Intelligent Robots and Systems, 1991.

[3] B. Brumson, "Robotics Online," 13 March 2014. [Online]. Available: http://roboticsonline.wordpress.com/tag/bin-picking/.

[4] K. Rahardja and A. Kosaka, "Vision-based Bin-Picking: Recognition and Localization of Multiple Complex Objects using Simple Visual Cues," in IEEE/RSJ International Conference on Intelligent Robots and Systems, 1996.

[5] C. Hema, M. Paulraj and S. Yaacob, "Object Localization using Stereo Sensors for Adept SCARA Robot," in IEEE Conference on Robotics, Automation and Mechatronics, 2006.

[6] A. Takenouchi, N. Kanamaru and M. Mizukawa, "Hough-space-based Object Recognition Tightly Coupled with Path Planning for Robust and Fast Bin-picking," in International Conference on Intelligent Robots and Systems, 1998.

[7] K. Ohba and K. Ikeuchi, "Recognition of the Multi Specularity Objects for Bin-picking Task," in IROS, IEEE, 1996.

[8] Point Grey, [Online]. Available: http://www.ptgrey.com/products/bumblebee2/bumblebee2_xb3_datasheet.pdf. [Accessed 17 March 2014].

[9] ABB Robotics, Operating Manual - IRC5 with FlexPendant, 2014.

[10] National Institute of Standards and Technology, "2012 Proceedings of the Performance Metrics for Intelligent Systems (PerMI '12) Workshop," in Publication, NIST Special 1136, 2012.

[11] Robotic Vision Technologies, [Online]. Available: http://roboticvisiontech.com/. [Accessed 14 March 2014].

[12] "TrueView Bin Picking with ABB Robot," [Online]. Available: https://www.youtube.com/watch?v=d57xv9lWY8E. [Accessed 13 March 2014].

[13] "Bloomberg," [Online]. Available: http://www.bloomberg.com/apps/news?pid=conewsstory&tkr=LG9:GR&sid=aqQY59JrwV2k. [Accessed 13 March 2014].