Introducing Robotics Vision System to a Manufacturing Robotics Course

Dr. Yuqiu You, Ohio University

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Introduction

Manufacturing systems are becoming more autonomous, requiring less operator intervention in daily operations. This is a consequence of today's market conditions, characterized by global competition, a strong pressure for better quality at lower prices, and products defined in part by the end-user. Industrial robots are good examples of flexible manufacturing systems. Manufacturing engineers need to integrate other technologies with the objective of extracting from robots the flexibility they can offer. Vision systems have been introduced and implemented on industrial robots to improve productivity and flexibility of manufacturing systems. Some typical applications with vision systems are work piece identification, work piece positioning, work piece dimension measurement, position compensation, surface painting, and vision tracking. Therefore, there is a need to introduce vision system technology to students in the Manufacturing Engineering Technology program.

There are three Robotics courses offered in the Manufacturing Engineering Technology program spanning from 200 level to 400 level to teach concepts, operation, programming, interfacing, and application developments of industrial robots, robotics kinematics, control theory, sensory, and vision systems. Robotics Interfacing Engineering is taught as a 300 level course to introduce robot actuators, sensory, fundamentals of control theory, and the integration of robot systems. This course integrates the engineering design of a specific robotics problem and implementation in the laboratory. The problem involves industrial engineering techniques, hardware interfacing, software interfacing, and control devices for designing and building an autonomous robot. An interdisciplinary approach is used. Recently, vision system technology has been introduced in this course as a new component for students to learn and practice.

This paper will describe the course design and lab activity setup to bring vision system technology in the course of Robotics Interfacing Engineering for students in the Manufacturing Engineering Technology program. A learning module of vision systems has been developed, the topics include types of images, image acquisition techniques, image processing techniques, image averaging and frequency analysis, moment calculation, system setup, introduction to 2D vision system configuration, and programming. A lab activity module of vision systems with a Fanuc robot has been designed to provide hands-on experience to students. The paper will demonstrate the hardware and software components of the vision system integration, camera calibration, software configuration, system communication and programming methods that students will learn and practice with the robot vision system. Students will be able to develop and implement a manufacturing robotics application with a 2D vision system integrated in the final lab project. Students also are required to compare the different vision system technologies, understand their advantages and disadvantages, and know the key issues and technology challenges in developing and implementing vision systems in manufacturing robotics applications.

Vision Processing and Analysis

The function of a robotics vision system is composed of three procedures, image acquisition, image processing, and image analysis. Image acquisition is the process of getting images using vision cameras: analog and digital. Image processing is the collection of routines and techniques that improve, simplify, enhance, or otherwise alter an image. Image analysis is the collection of processes in which a captured image that is prepared by image processing is analyzed in order to extract information about the image and to identify objects or facts about the object or its environment.

Even both analog and digital cameras are available, the most commonly used cameras in robotics vision system are digital cameras. Otherwise, a digitizing process is needed to prepare digital images for the vision system. The installation and configuration of a digital camera in a 2D robotics vision system will be demonstrated in a following section.

As mentioned above, image-processing techniques are used to enhance, improve, or alter an image. The intention is to remove faults, trivial information, useless information, and to improve the image. Image processing is divided into many subprocesses, including histogram analysis, thresholding, masking, edge detection, segmentation, region growing and modeling, and so on. Here, histogram analysis and edge detection are used to demonstrate the processes of image-processing techniques. A histogram is a representation of the total number of pixels of an image at each gray level. Histogram information can help in determining a cutoff point when an image is to be transformed into binary values. It can also be used to decide whether there are any prevalent gray levels in an image. For instance, suppose a systematic source of noise in an image causes many pixels to have one "noisy" gray level. Then a histogram can be used to determine what the noise gray level is in order to attempt to remove or neutralize the noise. Figure 1 below shows an image that has all its pixel gray levels clustered between two relatively close values. In this image, all pixel gray values are between 120 and 180 gray levels. As a result, the image is not very clear and details are not visible. If the histogram is equalized such that the same 16 gray levels present in the image are spread out between 1 and 255 gray levels, at intervals of 17 units. Then, due to the equalization, the image will be vastly improved. The histogram chart after equalization is shown in Figure 2.
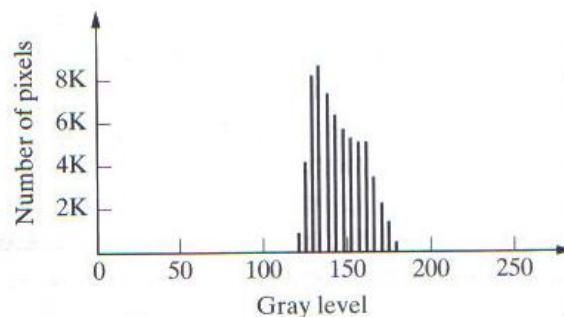

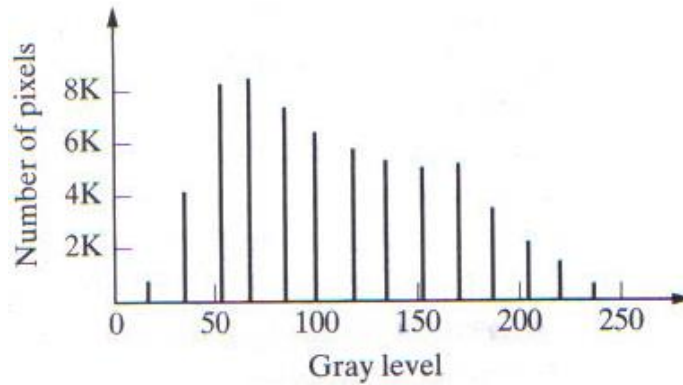
Figure 1. Example of an image histogram chart

Figure 2. The histogram chart after equalization

Edge detection is a class of routines and techniques that operate on an image and result in a line drawing of the image. The lines represent changes in values such as cross sections of planes, intersections of planes, textures, lines, and colors, as well as differences in shading. Some techniques are mathematically oriented, some are heuristic, and some are descriptive. Edge detection is the one most popularly used in robotics vision systems. Different techniques of edge detection yield slightly different results; thus, they should be chosen carefully and used wisely. Two examples of edge detection techniques demonstrated here are masks and a search technique. Edges in an image create higher frequencies in the spectrum and can be separated by high-pass filters. Masks can be designed to behave like a high-pass filter, reducing the amplitude of the lower frequencies while not affecting the amplitudes of the higher frequencies as much, thereby separating the noises and edges from the rest of the image.

Another simple routine that are easy to implement and that yield continuous edges can be used for binary images is a search technique, dubbed left-right (L-R) technique. This technique can quickly and efficiently detect edges in binary images of single objects.
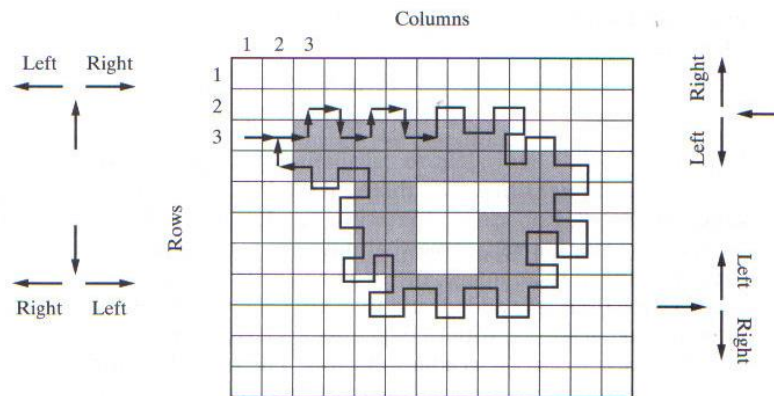

Figure 3. Left-right search technique for edge detection

Imagine a binary image as shown in Figure 3. Suppose that gray pixels are "on" and white pixels are "off". Assume that a pointer is moving from one pixel to another, in any direction. Anytime the pointer reaches an "on" pixel, it will turn left. Anytime it reaches an "off" pixel, it will turn right. As shown in the Figure, the process continues until the first pixel is reached. The collection

of the pixels on the pointer's path is one continuous edge. Other edges can be found by continuing the process with a new pixel.

Image analysis is a collection of operations and techniques that used to extract information from images. Among these operations and techniques are object recognition, feature extraction, analysis of the position, size, orientation, and other properties of objects in images, and extraction of depth information. Objects in an image may be recognized by their features, which may include, gray-level histograms, morphological features such as area, perimeter, number of holes, etc., eccentricity, cord length, and moments. In many cases, the information extracted is compared with a prior information about the object, which may be in a lookup table. The techniques widely used for robotics vision systems include identification of morphological features and moment calculation.

The basic morphological features used for object recognition and identification are: 1) the average, maximum, or minimum gray levels can be used to identify different parts or objects in an image; 2) the perimeter, area, and diameter of an object, as well as the number of holes the object has, can be used to identify the object; 3) an object's aspect ratio (the ratio of the width to the length of a rectangle enclosed about the object) can be used for identification; and 4) the thinness (the ratio of diameter to the area) of an object can be used for identification.

In binary images, objects are represented by pixels that are turned on, and the background is represented by pixels that are turned off. A general moment equation has been created to calculate different levels of moment values which are used for object recognition and identification.

$$M_{a,b} = \sum_{x,y} x^a y^b$$

$M_{a,b}$ is the moment of the object within the image with indices a and b, x and y are the coordinates of each pixel that is turned on within the image, raised to power of a and b. In such a case, a routine based on Equation will first determine whether each pixel belongs to the object, if so, will then raise the coordinates of the location of the pixel to the given values of a and b. the summation of this operation over the whole image will be the particular moment of the object with a and b values. $M_{0,0}$ is the moment of the object with a=0 and b=0, thus called Level 0 Moment. $M_{0,2}$ means that all x values are raised to the power of 0, all y values are raised to power of 2. All combinations of values between 0 and 3 are common. Level 0 Moment can be used to identify the number of pixels of the object, and can be used to calculate the area of an object within an image. Level 1 Moment is used to calculate the summation of each pixel area multiplied by its distance from x or y axis. Thus, this moment can be used to calculate the x and y coordinates of the center of the area of the object. Level 2 Moment is used to calculate the moment of inertia of the object within an image, thus, identifying the orientation of the object. Higher order moments such as $M_{0,3}$, $M_{3,0}$, $M_{1,2}$, etc., can be used to identify objects and their orientations. Small differences between objects or a small asymmetry in an object could be detected by means of higher order moments.

A 2D Robotics Vision System

Vision systems have many different applications in manufacturing automation, sometimes in conjunction with robotics operations and robots. Some popularly applied applications in manufacturing systems include workpiece identification, workpiece identification and positioning, workpiece dimension measurement, position compensation, surface painting with laser force sensor, and vision tracking. In this Robotics Interfacing Engineering course, a 2D robotics vision system with a Fanuc robot has been setup and used as the physical setting for lab activities related to vision systems, as shown in Figure 4.
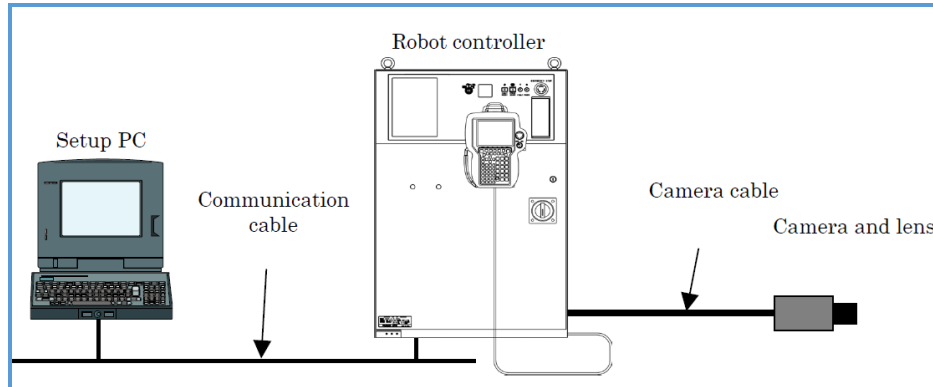
Figure 4. Physical setup of a robotics vision system

As shown in Figure 4, the Fanuc robotics vision system includes a camera and the communication cable between the camera and the robot controller, and a PC with a communication channel with the robot controller. The communication between the PC and the robot controller is through a network router and Ethernet cables. Therefore, TCP/IP addresses have been setup to establish the communication between the PC and the robot controller.
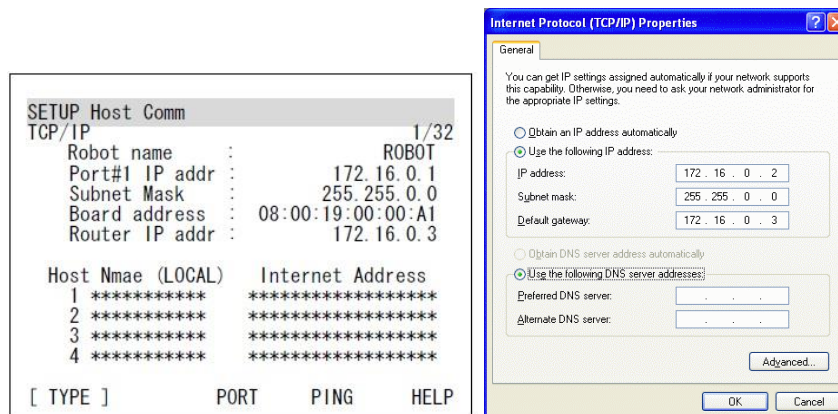

Figure 5. Communication Configuration between the PC and the robot controller

The purpose of a 2D robotics vision system is to enable the robot to identify parts with different shapes and recognize their locations on a 2D plane. The physical setup is shown in Figure 6.
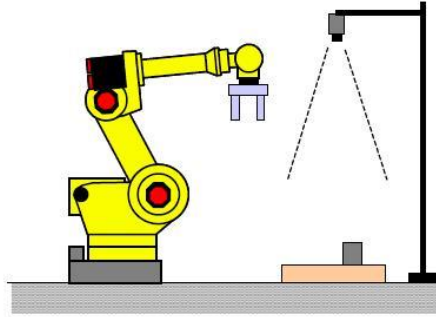
Figure 6. The work plane setup of the vision system

In order to let the robot controller recognize the work plane and identify the correct location and dimension of parts, two user frames must be setup on the robot. One is the user application frame, which is used for robot motion control, and it must be parallel with the target workpiece plane as shown in Figure 6. Another is the calibration grid frame, which is a user frame for camera calibration. This frame is used to recognize the positional relationship between the grid and the camera, lens distortion and focal distance. Then the camera needs to be calibrated by using a grid to teach the robot the information of camera position. The grid calibration process is shown in Figure 7.
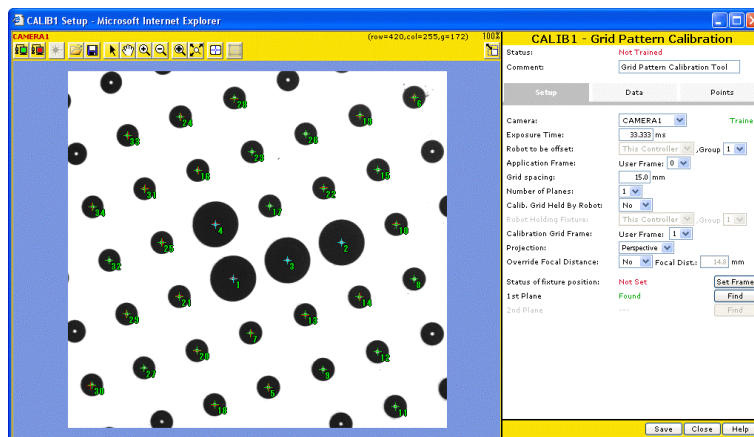

Figure 7. Camera calibration

Once the camera has been calibrated, the vision system is ready to record part models that will be used for part identification and position calculation. Figure 8 shows a part model has been recorded, and then the part can be identified by the vision system by matching the newly captured image with the record part model. Also, the position of the current part will be calculated based on the recorded position and the offset measured from the captured image. The result of the part matching and offset calculation will be sent to the robot controller and used by the robot to make decisions on part identification and retrieve the part if needed.
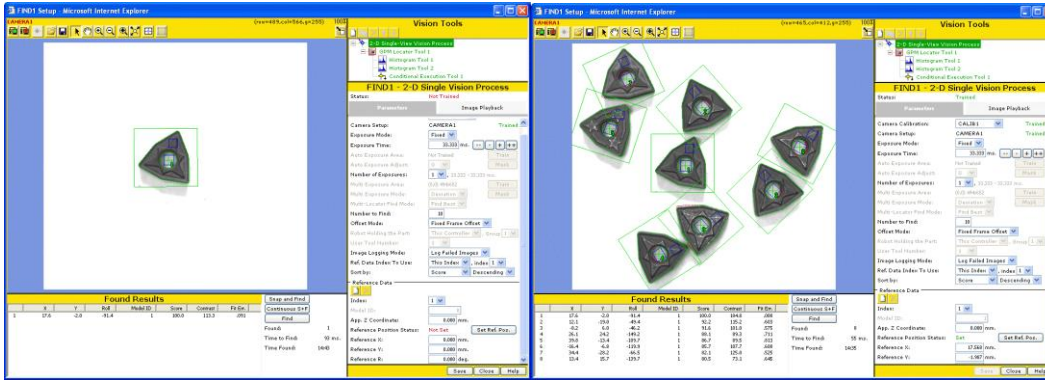
Figure 8. Recording a part model and identifying parts

Lecture Design and Lab Activities

A vision system module has been developed to integrate the lectures and labs of robotics vision system technology into the Robotics Interfacing Engineering course. The module contains five lectures and a vision system project. The topics of the lectures are listed in table 1.

Table 1:

	Lecture Topics
Lecture 1	Introducing to robotics vision system applications
Lecture 2	Image acquisition and digital image
Lecture 3	Image processing techniques
Lecture 4	Image analysis techniques
Lecture 5	Vision system and programming

The project was designed to provide students an opportunity to develop an automated manufacturing process with an integrated vision system. Students would gain expertise and experience in vision system setting up, system configuring, and programming. Students also could have recognized the advantages of utilizing vision systems in manufacturing systems. The project setup contains a Fanuc robot, a robotics vision system, a conveyer, an Allen-Bradley Micro1000 PLC (programmable logic controller), and a personal computer. With the implementation of the 2D robotics vision system, the robot is able to identify parts with different shapes and sort them automatically. The setup of the manufacturing process is shown in Figure 9.
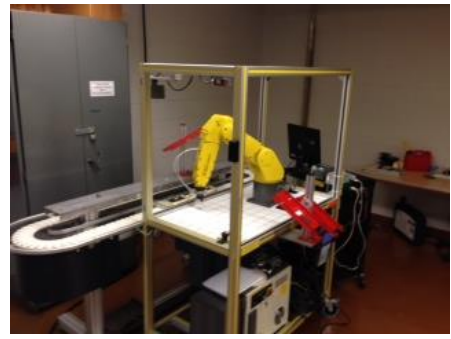

Figure 9. An automated manufacturing process with robotics vision

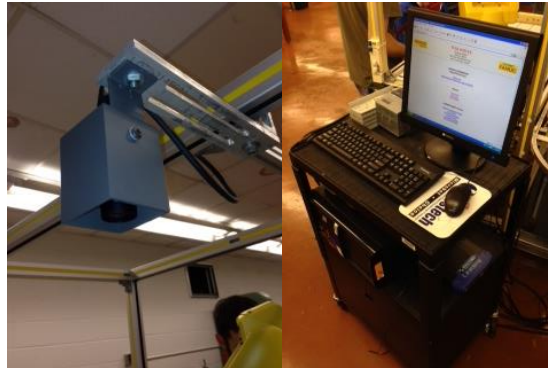The camera and the PC for robotics vision setup is shown in Figure 10.

Figure 10．The camera and the PC for system setup

Student groups have designed two parts with different shapes. Firstly, students were required to setup and calibrate the vision system for a 2D vision application by applying what they have learned from the lectures. The 2D images of these two parts were recorded by the camera and saved in the computer as Model 1 and Model 2 (as shown in Figure 11). The two models' level 2 moment value then were calculated and saved through the image analysis. As one part coming along the conveyer (as shown in Figure 12), the camera will capture the images of the part and sent to the computer. The vision system then identifies the part by comparing the level 2 moment value of the captured image with the recorded one.
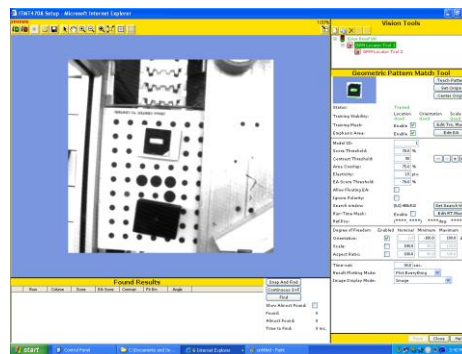

Figure 11. Models' moment values have been analyzed and recorded

Figure 12. A part on conveyor to be identified by the vision system

After the comparison, the result is saved in a vision register and sent to the robot controller. The vision register has been programmed in the robot program, therefore, the robot then will be triggered to pick up the part and place it at the correct part holder. Figure 13 shows two different parts have been identified by the vision system and placed in their correct receivers.
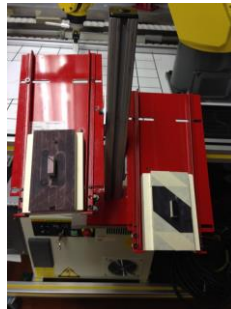

Figure 13. Two different parts been identified and placed

In this project, students configured the system by wiring all the Ethernet and discrete communications, programmed the PLC controller and the Fanuc robot, and tested the whole system in production mode. Students feel that this project represents a real life manufacturing set up and practical problems that may occur. Through much trial and error they have concluded that a vision system can be successfully integrated with a PLC controller and Fanuc robot in several different fashions and orientations all to produce an effective manufacturing system.

Among the 20 students in this class, 18 of them have mentioned in their course evaluation forms that the vision system module has brought them great hands-on experience in integrating newer technologies in manufacturing systems.

Conclusion
A robotics vision system module has been developed with five lectures and a project activity which provide the opportunity for students to explore the technologies that have been applied in building industrial robotics applications, learn principles and theories in different technologies, practice with motion control, PLC programming, PLC interfacing, vision system configuration and programming, and experience with computer and networking technologies like setting up the TCP/IP server and the vision system. There are two groups working on two systems. One group

has successfully implemented the system integration and achieved their goal, while the other group encountered some technical problems. The problems students have encountered include incorrect wiring of PLC with the robot's input/output, not enough accuracy for the captured image from the vision system, incorrect communication setup between the robot and the vision system, etc. The problems have been solved eventually through better understanding the wiring schematics, reconfiguring the vision system, reprogramming the PLC controller, and adding better lighting for the workstation for better image quality. The class has 19 students, and all students have learnt the fundamentals of vision system through lectures while10 out of 19 students have worked through the vision system project. In the class evaluation, 95% of the students indicated positive learning experience about the vision systems. Students' comment feedback shows that these robotics vision system modules can motivate students' interest in manufacturing automation, help them gain hands-on experiences by applying multiple disciplines.

References
[1] Robert N. Bateson (2002), Introduction to Control System Technology, 7th Edtion, Prentice Hall.
[2] J. Norberto Pires (2007), Industrial Robots Programming: Building applications for the factories of the future, Springer Science and Business Media, LLC.
[3] Niku, B. S. (2001). Introduction to Robotics: analysis, systems, applications. New Jersey: Upper Saddle River Prentice Hall.