An Industry Based Student Project: Implementing A Machine Vision Systems For Robotic Application

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Abstract

This paper describes the details of an industrial based student project at Wayne State University. The objective of this project is to implement a machine vision system for a robot to pick up objects from the conveyer line and place them precisely in the drop-off fixture.

1. Introduction

Engineering Technology education emphasizes practical applications and hands-on experiences. Students in the MSET program at Wayne State University (WSU) are required to take a minimum four credits of Master's Project (ET-7999). The project requirements emphasize integration and application of knowledge to perform sophisticated tasks in practical industrial problems. The project research may be conducted at WSU or industrial sites.

This paper described a MSET project sponsored by local industry. The purpose of this project was to integrate a machine vision system to allow a robot at a tire rim factory to locate and determine the exact angular orientation of tire rims on the conveyer line shown in Figure 1. This was done so that the robot could pick rims off the line and place them precisely in the drop-off fixture. In order to allow the robot to successfully pick the rims off the conveyer with its gripper, every rim would have to be located within ±3mm. Each rim had a hole drilled somewhere around its perimeter as shown in Figure 2. This hole was required in order to insert the air valve in a later manufacturing operation. It was critical that the air valve hole be located within ±0.5° in order to assure that the protruding air valve stem would be aligned within one of the holes in the disc placed in the center of the wheel. All location operations had to occur within three seconds to maintain the rate of production required by the plant.

This project began by searching for a suitable vision machine system that would fulfill the application requirements. These requirements were a system that was accurate, reliable, maintainable, easy to use and reasonably priced. Once such a vision system was found, it had to be programmed to accomplish the two searches required of it. The robot then had to be programmed to request vision finds, receive and interpret the results, then use the resultant coordinates in production.

2. Selection of Machine Vision System

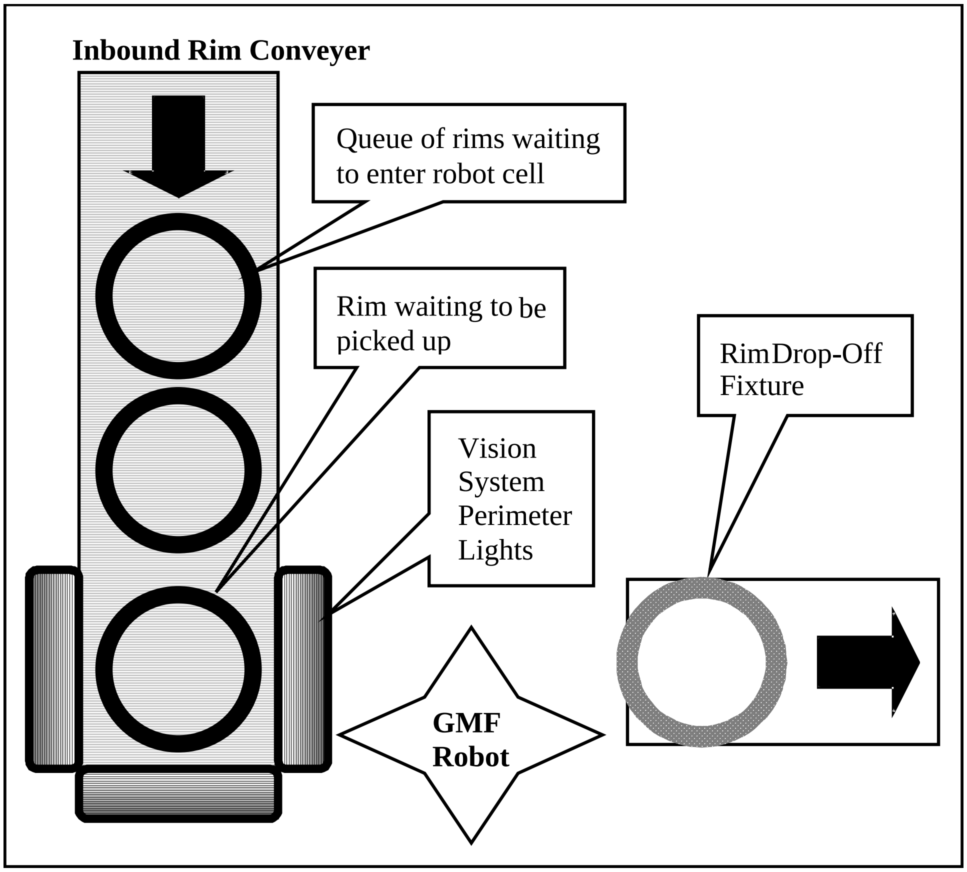

Figure 1: Rim Handling Work Cell Overview

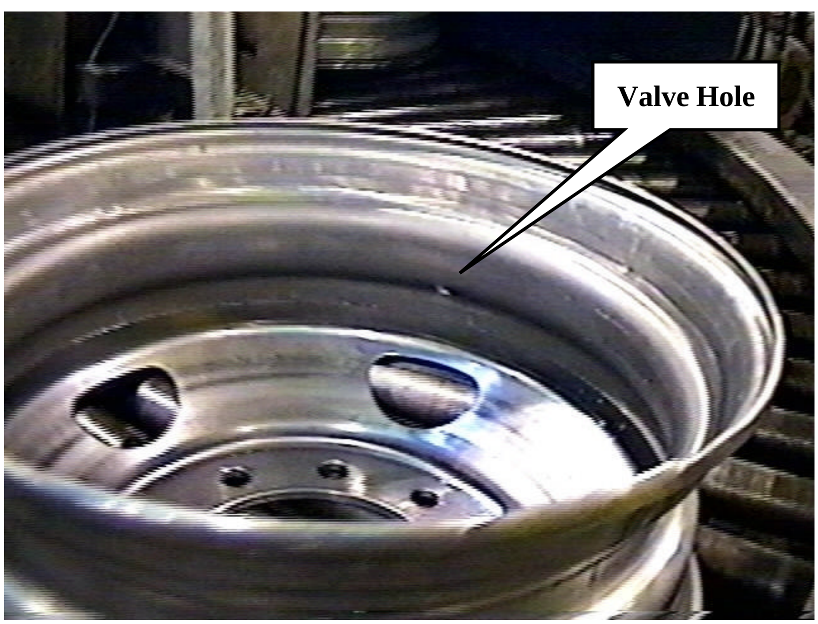

Figure 2: Rim With Disc Attached and Valve Hole Correctly Aligned

Selection of the machine vision system for this project was based on the following criteria: (1) image resolution adequate to locate features within approximately 2mm, (2) reliable and rugged enough to survive in the factory environment, (3) spare parts to be available for several years, (4) simple enough for plant personnel to maintain, and (5) low cost. A survey of available machine vision systems was conducted, and the system selected was the stand-alone type PVS-20 system from Phoenix Imaging in Livonia, Michigan. This system consisted of an IV-S20 vision engine and camera from Sharp Electronics integrated with 16 points of isolated digital I/O[1, 2].

The Sharp IV-S20 came with a progressive scan camera, which scanned 640x480 pixels each cycle. The camera needed to view the entire rim, so the viewing area was 22 inches (539mm) square. This was the entire area the 640x480 pixels needed to cover. Therefore, the theoretical resolution of the vision system was 1.12mm/pixel.

$$R_{mm} = \frac{\text{Field of View}}{\text{Pixel Number}} = \frac{539\text{ mm}}{480\text{ pixel}} = 1.12_{\text{mm/pixel}} \tag{1}$$

This resolution met the requirement of approximately 2mm resolution, but the PVS-20 also supported sub-pixel resolution. Sub-Pixel resolution was a method of automatically deriving resolution less than one pixel by comparing gray levels across neighboring pixels. This improved the resolution by another 50% to 0.61mm.

3. Vision System Programming

The rim transfer robot needed to know two pieces of information:

- The exact location of the rim, so the robot knew where to pick it up
- The angle of the valve hole on the rim, so the rim could be placed on the drop off fixture at the correct angle.

The vision system had to be programmed to find both of these pieces of information when directed by the robot. The robot had to be programmed to receive and properly interpret this information.

<u>Vision Program: Find Rim</u>

Since the rim entered the robot cell on a conveyer, the rim was guaranteed to be flat and at a known height as shown in Figure 3. Because the rim was flat and at a known height (Z), the robot only needed to find the horizontal (X) and vertical (Y) coordinates of the rim in three-dimensional space.

The PVS-20 supported several image processing algorithms[3] that were suitable for finding the X and Y coordinates of the rim. The algorithm selected for locating the rim was based upon Reference Image Location. In this approach, a particular section of the rim was pre-defined as the "reference area", and the vision system was programmed to locate this reference area in the image. Once the reference area was located, the relative location of the rim with respect to the camera can be determined.

To implement this algorithm, the image of a rim at a known location was first used to “train” the vision system. A “reference area” and a “searching window” in the image as shown in Figure 4a were manually defined. In this figure, the small solid rectangle is the reference area and the larger dashed-line rectangle is the searching window. The center of the reference area was defined as the reference point for future applications. The image of the reference area, as shown in Figure 4b, was stored in the vision system as a template image.

When the Find Rim program was executed, the vision system took an image of the rim on the conveyer and ran a template-matching routine[4, 5] in the searching window to locate the “reference area” in the image. It was done by locating the area that is the closest match to the template image. Once it was located, its offset distance, ΔX and ΔY, from the pre-defined reference point, X_{ref} and Y_{ref}, can be measured by the vision system. Therefore, the coordinates of the rim, X_{obj} and Y_{obj}, can be computed by

$$X_{obj} = X_{ref} + \Delta X \quad (2a)$$

$$Y_{obj} = Y_{ref} + \Delta Y \quad (2b)$$

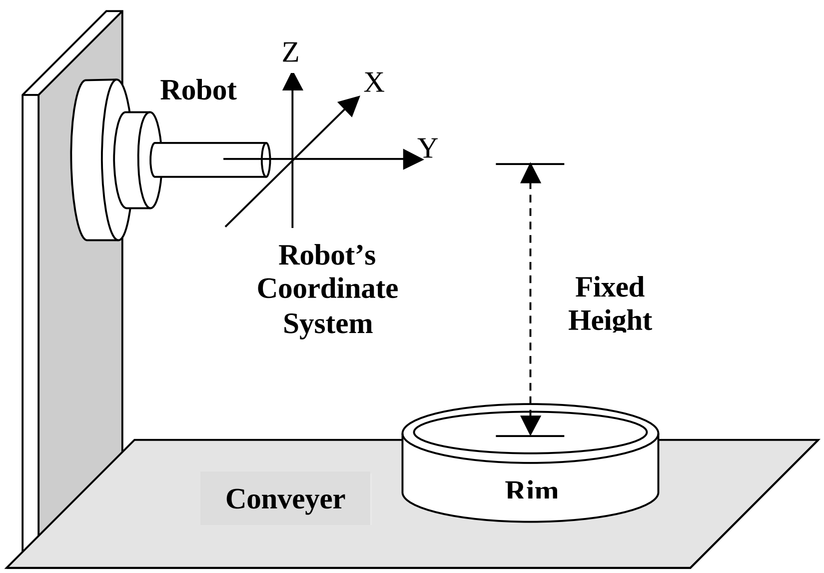

Figure 3: Rim on Conveyer in Front of the Robot

As shown in Figure 4b, the template image was taken from the right edge of the rim. This particular section of the rim was selected because its high contrast in the left-right direction provides the most reliable results for template matching technique. This was desirable because for this particular application, the greatest movement would be in the left-right direction from the

camera's point of view because this was the direction of the conveyer's movement.
Once the vision system successfully found the rim and transmitted the results to the robot, the robot gripped the rim and moved it to the ideal position at the end of the line. This was done to facilitate the next step, finding the valve hole angle.

(a) (b)

Figure 4: (a) Setting up Reference Area and Searching Area (b) Sample Template Image

Vision Program: Find Valve Hole

Each tire rim had a hole drilled in it where the air valve was to be added later. In order for the air valve to be usable, the air valve stem had to protrude through one of the holes in the disc which filled the center of the tire rim. In order for the valve hole to be located at a hole in the disc, it had to be very precisely located when the robot placed the rim in the drop off fixture. The "Find Valve Hole" vision program was developed to find the angle of the valve hole in the gripper.

The Find Valve Hole program was developed based on Center of Gravity algorithm[3, 4, 5]. This program located an object (valve hole) by first creating a binary image of the scene to separate the lightest object from the background. Once the object was highlighted in the image, the relative location of the object with respect to the camera was determined based on the center of gravity center of area covered by the object.

Before the Find Valve Hole program was run, the rim had already been located, picked up and moved to a known location by the robot. The robot's gripper was designed to cover the entire top of the rim and block out all light from above. This made the valve hole the most significant source of light within the rim and therefore much easier to be separated from other features of the rim. Figure 5 shows a binary image of the rim. The bright white object in the upper right-hand corner between the two circles was the image of the valve hole. Since the rim was at a known position, the valve hole could be found within the pre-defined searching area between the solid circle and the dashed circle as shown in Figure 5.

During the development of this vision program, a reasonable intensity threshold value was determined which highlighted the valve hole reliably throughout the entire 360^{o} rotation of the rim. The vision system was then programmed to ignore all but the largest found within the search area. Test runs also determined that the typical size of a binarized valve hole image was between 150 and 200 pixels, so the vision system was programmed to accept only objects that have an area between 50 and 300 pixels.

Once the valve hole was located, its offset distance, ΔX and ΔY, from a pre-defined center point can be determined. Therefore, the angular position of the valve hole with respect to the center point can be computed using Equation 3.

$$\theta = \tan^{-1}\left(\frac{\Delta Y}{\Delta X}\right) \tag{3}$$

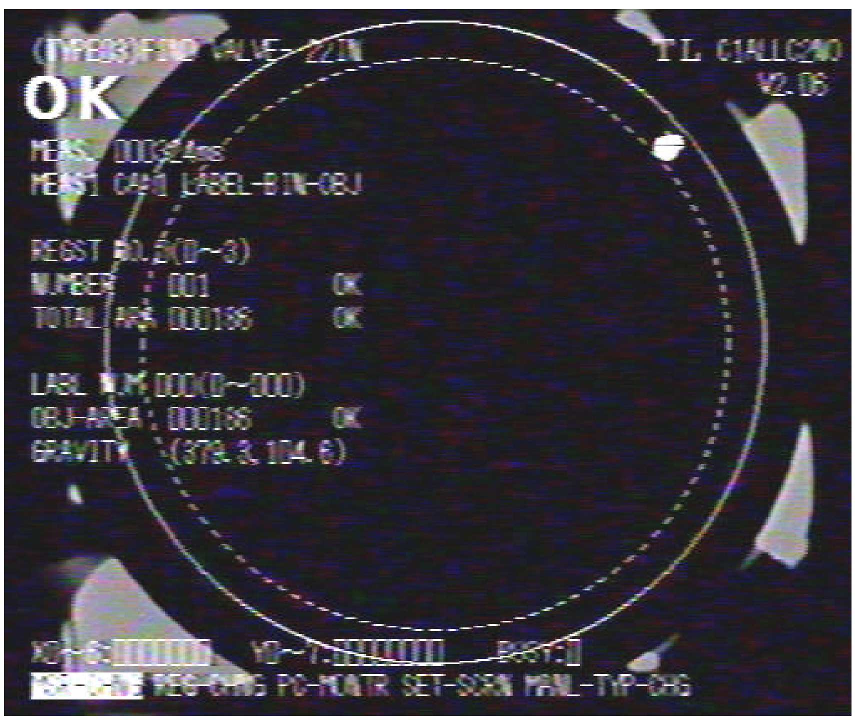

Figure 5: A Binary Image of the Rim

4. Calibration of Vision System

When integrating a machine vision system with any other piece of equipment, nothing is more

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important than calibration. The machine vision system can send the coordinates of features found to the robot, but the robot must be able to convert the vision system's coordinate system into its own in order to use that data. In order to address this requirement, several calibration routines were created to calibrate the robot to the machine vision's coordinate system. These were designed to be as intelligent as possible and require minimal operator intervention.

Find Rim Calibration

In the calibration process, the robot initiated the Find Rim program to locate the rim in the image. The robot then gripped the rim and move a pre-defined calibration distance, ΔY_{mm}, in robot's -Y direction. The Find Rim program was executed again to locate the rim in the new location. The horizontal and vertical displacement of the two rim locations, ΔX_{pixel} and ΔX_{pixel}, in the image plane can be calculated. Therefore, a set of scale factors for converting camera's Y coordinates to robot's Y coordinates can be determined using Equations 4a and 4b.

$$\Phi_{YY} = \frac{\Delta Y_{mm}}{\Delta Y_{pixel}} \tag{4a}$$

$$\Phi_{YX} = \frac{\Delta Y_{mm}}{\Delta X_{pixel}} \tag{4b}$$

The same procedure was used to determine the scale factors, Φ_{XX} and Φ_{XY}, for converting camera's X coordinates to robot's X coordinates. Therefore, after the Find Rim program locates a rim in the image, the vision system can convert the pixel coordinates in image plane, X_{pixel} and Y_{pixel}, to robot's coordinates in mini-meters, X_{mm} and Y_{mm}, using Equation 5.

$$\begin{bmatrix} X_{mm} \\ Y_{mm} \end{bmatrix} = \begin{bmatrix} \Phi_{XX} & \Phi_{XY} \\ \Phi_{YX} & \Phi_{YY} \end{bmatrix} \cdot \begin{bmatrix} X_{pixel} \\ Y_{pixel} \end{bmatrix} \tag{5}$$

Find Valve Hole Calibration

In this calibration procedure, the robot was first manually operated to move the rim to the drop off fixture, with the valve hole in the ideal position. This valve hole location is set as the reference point for zero degree position. The robot then rotated the rim (no horizon or vertical movement) to a number of evenly spaced positions. At each rotation, θ_{robot_n}, the coordinates of the rim center, $X_{rim\_center\_n}$ and $Y_{rim\_center\_n}$, and the coordinates of the valve hole center, $X_{hole\_center\_n}$ and $Y_{hole\_center\_n}$, were determined. In this project, eight positions, with a 45 degrees increment each rotation, were used. Once the data were collected, a very accurate center coordinate of the rim, X_{rim_center} and Y_{rim_center}, were be obtained by taking the average of the eight measured coordinates. At each rotation step, the angular position of the valve hole measured from the image was determined by

$$\theta_{measured\_n} = \tan^{-1}\left(\frac{Y_{hole\_center\_n} - Y_{rim\_center}}{X_{hole\_center\_n} - X_{rim\_center}}\right) \qquad (6)$$

Since the actual rotation angle of the grip, θ_{robot_n}, was known, an average angular error can be calculated using Equation 7. This value was used for the Find Valve Hole program to compensate minor errors.

$$\theta_{average\_error} = \frac{\sum_{n=1}^{N}\left(\theta_{robot\_n} - \theta_{measured\_n}\right)}{N}\ , \qquad (7)$$

where N = 8 for this application.

5. Conclusion

This project was completed in one year. The machine vision system was first programmed and tested in a laboratory. After installation in the tire rim factory, the system was found to be accurate within the required tolerance. The reliability was excellent, failing in less than 1% of searches due to the rim being oriented at a certain angle. All failures were corrected within five seconds by the robot program, which automatically activated the conveyer for a short time to slightly move the rim and retried the vision search.

This project provided the opportunity for students to apply machine vision and robotic technology in industrial applications. There were many challenges in addition to vision and robot software programming: A market survey had to be done in order to select the appropriate vision system for the application. A test stand had to be constructed to allow the vision and robot software to be tested and demonstrated. The final report had to provide technical details but avoid confidential industrial information of the companies involved. These works further provided the industrial experiences that students would need in their workplaces.

6. Acknowledgements

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