Vision-based Object's Shape Determination for Robot Alignment

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***Abstract*—This study provides vision-based system solutions for a peg-in-hole problem faced by a fork lift like robot used to transport copper wire spools from a rack, in which the spools are arranged side by side to a specified place. The copper wire spool (a cylindrical object on which the copper wire is wound and have a rim at each end) is held by 3 cylindrical shafts; one of the shafts is inserted through the center hole of the spool and another two shafts is held at the bottom of the spool. The aim of the development of vision-based system is to enable the robot to pick up the spool autonomously. To enable the center cylindrical shaft to be inserted nicely through the center hole of the spool, the center point of the spool must be on the center line of the camera Field of View (FOV). The problem to be solved in this study is how to determine that the center point is overlapped with the center line of the camera FOV. Firstly, a circle with the same radius of the spool's rim was created at the center of the camera frame on screen, and then the spool's front rim was tracked until it is overlapped with the circle on the screen image to ensure it is on the line of the camera FOV. However, the scope of this paper is limited to copper wire spool detection, and the confirmation of the front rim overlapping conditions is based on real time video processing. The proposed system uses Circular Hough Transform (CHT), binarization, morphology and edge detection of the sampled images from real-time video recording. A Logitech Webcam C270, which has an autofocus camera and HD view with lower price is used. By integrating the Logitech webcam for windows with MATLAB R2016a, all computations, programming and processing of this project are done using the MATLAB. Several experiments had been carried out and from the result obtained, the system is able to track the spool and determine the correct position of the robot to pick up the spool.**

***Index Terms*—Circle Detection; Copper Wire Spool; Image Processing; Vision-based System.**

I. INTRODUCTION

Robotic manipulator is widely used in manufacturing process since it is a reliable system to maintain productivity and quality. Generally, tasks performed by the manipulators can be categorized to two types: grasping and insertion (peg-in-hole) [1–3]. For the grasping tasks, the robot manipulator is required to grasp an object on its outer side. On the other hand, the manipulator should hold an object using its fingers and insert into another object, such as inserting a few centimeters of a straight plug into an elastic rubber hose and inserting a shaft into O-ring. Almost all the above tasks are performed by 6 to 8 D.O.F robot manipulator equipped with a force or torque sensor to determine the grasping forces or the touching forces, which is very expensive and require complicated algorithm to be implemented. Some of the grasping tasks utilized a camera, or a camera with a laser range finder to confirm the orientation of the object. After the object is grasped, force or torque sensor will be used to autonomously adjust the grasping force or adjust the position of the peg, in the case of insertion process [4–6].

In this study, a simple structure of robot with 4 D.O.F, like a forklift, which will autonomously pick up a copper wire spool (a cylindrical object on which the copper wire is wound and having rim at each end) and bring it to other places. Instead of using a force sensor or a touch sensor, only a cheap camera, which is Logitech Webcam C270 is used. On the other hand, the proposed algorithm uses Circular Hough Transform combined with another image processing techniques; binarization, morphology and edge detection to track the spool and determine a stop position that enable the robot moving closer to the spool and insert the center cylindrical shaft through the center hole of the spool. Then, the spool is lifted and brought to another place. However, the scope of this study is limited to the development of the vision system and it is verified through simulations using real-time video recording.

A. Theoretical Background

The process of picking up the spool is guided by a web camera. Based on the images taken from real time video recording, the vision system guides the robot to stop at the correct position to pick up the spool. Based on the isometric projection perspective, the correct position is where the front and back circles (rims) of the spool share the same center. From the side view of the isometric projection, they are overlapped to each other and seen as one circle only (refer to Figure 1).

While the robot (web camera) moves to the location where the spools are located, it scans its side and searches for the spool. The spool will be detected starting from the point when it enters the field of view (FOV) of the camera. When the whole body of the spool enters the FOV, its two circles (rims) will be seen. As the spool reaches the center of FOV, the circles will be overlapping and finally share the same center point, as illustrated by Figure 2. Equation (1) defines the FOV of the camera, where the symbols used are shown in Figure 3. The implementation of the system involves a circle, which has the same radius with the rim of the spool is plotted at the center of the image frame of the camera. The robot is at the correct position when the circle of the spool is overlapped by the virtual circle.

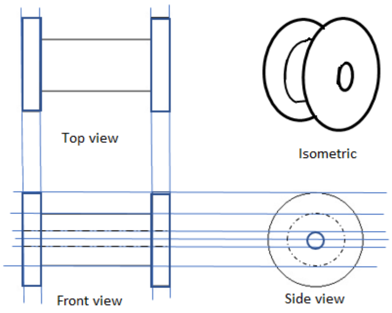


Figure 1: Isometric projection of a spool

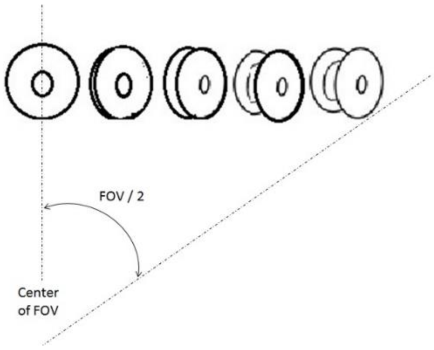


Figure 2: Different images of a spool according to its distance from the center FOV

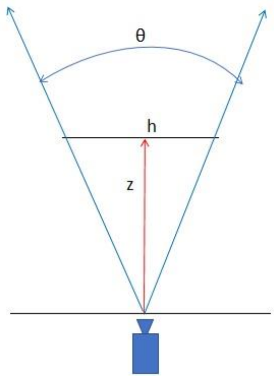


Figure 3: FOV of a camera

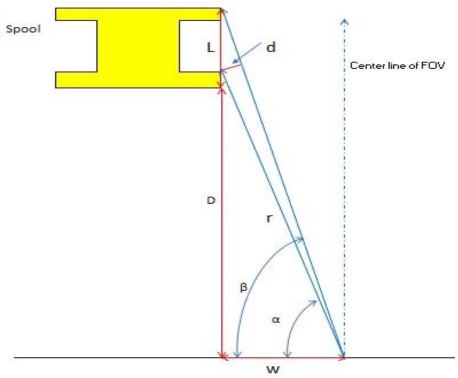


Figure 4: Different of center point between front and back circle

According to Figure 4, the difference in distance between the centers can be represented by Equation (2). The different distance, d becomes *0* when the spool is at the center of the FOV.

$$\vartheta = 2\tan^{-1}\left(\frac{h}{2z}\right) \tag{1}$$

$$d \cong \frac{(\beta - \alpha)}{360°} \times 2\pi r \tag{2}$$

B. Vision-based System

Vision-based system using camera has been used widely, especially in recognizing object because it is more reliable compared to other sensors, such as the temperature sensor and the light sensor [7]. Image processing method is one of the cheap algorithms that are widely used for research in the vision system [8]. The copper wire spool can be detected by using image processing techniques. Image processing requires image acquisition, image pre-processing, feature extraction and object decision. Many researchers use Canny edge detection method to obtain the correct results and reduce the noise of the image despite the method has flaw, in which it may not traverse all weak edge pixels [9]. However, vision system has some problems, such as the existence of dust, the need for extra lighting and distortion [10].

C. Circle Detection

The copper wire spool has a circular shape; thus, the system needs to find an alternative to detect the circular shapes. The most popular method used to detect circular objects and locate analytic curves in binary image favored for its tolerance to noise is the Circular Hough Transform (CHT) and its variants [11]. Many researchers proposed a new algorithm based on CHT, such as [12–14]. However, some of the methods are not suitable with this system as it uses offline image processing. Nupur et al. use the Mean Shift technique for image segmentation and the Modified Canny Edge Detection Algorithm for circle detection. However, the method was applied using Google earth images, which is not real time images although this research uses real time images. [15]. An innovative implementation of CHT using eigenvalues of covariance matrix for detecting circles proposed by Hossein et al. is robust and against noise [16]. Some of them use Open CV and C++ software because MATLAB cannot perform the system successfully [17]. Most of the current researches are for unknown and familiar objects.

II. METHODOLOGY

The overall detail of the shape determination of the vision-based object of the study is shown in Figure 5. Figure 5 shows the process flow of vision-based object's shape determination system. The steps of the proposed algorithm are as follows:

- Live video acquisition was connected using 'videoinput' command with 'winvideo' adaptor. The reference circle with coordinate center (320, 240) and radius (124 pixels) was previewed in live video with green color.
- Camera will detect the copper wire spool whenever the system detects big circle within the radius range that have been set in the system. The radius range for the big circle is 100 – 150 pixels. The big circle was previewed in red color.
- The screen will display "Spool detected" when the system detects the copper wire spool and no message will be displayed, whenever the copper wire spool is not detected.

- Copper wire spool is considered aligned with the robot when the coordinate center for big circle is overlapped with the coordinate center for reference circle.
- The screen will be displayed "Center aligned" when both centers overlapped and no message will be displayed, whenever both centers are not overlapped.
- The screen will be displayed "Robot can pick up the spool" when "Center aligned" was displayed on the screen. It means that the camera was aligned with the copper wire spool.

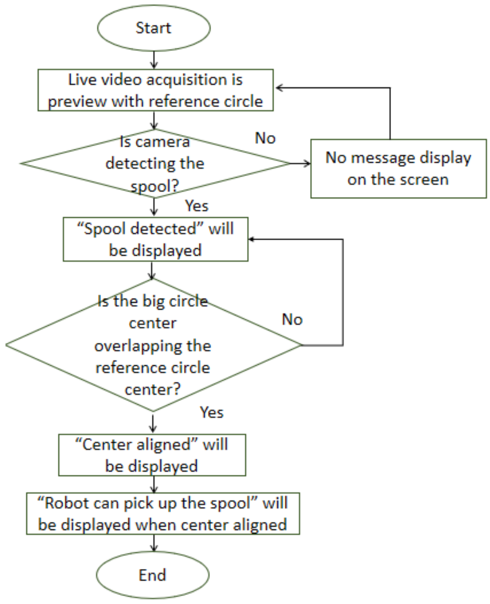


Figure 5: Flowchart of vision-based object's shape determination

A. Copper Wire Spool Detection

As shown in Figure 6, the images are acquired using Logitech HD Webcam C270 and processed using MATLAB programming platform. The resolution of the video used in this system is 640×480 pixels. The real-time video needs a proper image segmentation technique to overcome the lighting intensity problem that affects the original color of the object [18]. Thus, the erosion and dilation methods were applied in this system. Next, Canny edge detection method was applied to obtain accurate edges of an input image [9]. The video input of this system is in grayscale color space to reduce computational costs [17]. CHT was applied after image processing. The copper wire spool was considered as detected, whenever the system detects a circle within the radius range that has been set in this system.

After the image has been applied with morphology method, the copper wire spool will be detected using CHT method with different radius value. The circle of a virtual spool with a radius of 124 pixels displayed on the screen serves as a reference circle. The circle that needs to have a radius ranges of 100-150 pixels.

Figure 6: Logitech HD C270 Webcam

Table 1
Specifications of Logitech HD C270 Webcam

Feature	Description
HD requirement	2.4GHz Intel Core 2Duo = CPU 2GB = RAM
USB type	USB 2.0
Focus type	Fixed
Focal length	4.0 mm
Frame rate (max)	30 fps @ 640×480

B. Camera and Spool Orientation

The camera and spool orientation is determined using image processing technique. The copper wire spool and camera are considered aligned when the center of big circle overlap and the reference center is calculated by using (X,Y) coordinates. Due to slight errors, which are the radius of reference circle and the other circles that might be a little bit different, the distance between the center can be accepted within the error range ±3 pixels. The reference center coordinate is (320,240) pixels. The screen will display "Center aligned" when the camera and the spool are aligned. The mathematical equation to determine the orientation of copper wire spool and camera is shown in Equation (3).

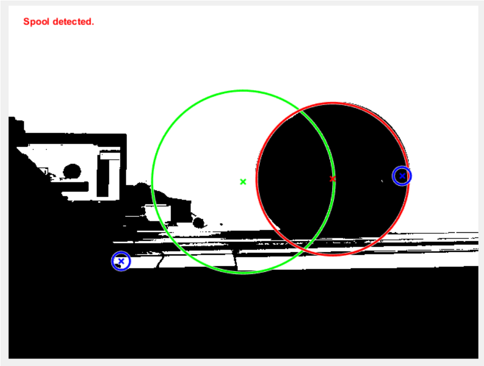
$$Dist.center = ((320 - X1), (240 - Y1)) \quad (3)$$

Nomenclature

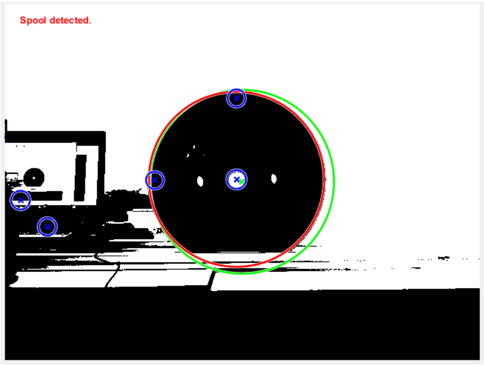
X1,Y1	= Big circle coordinate
320,240	= Reference circle coordinate

III. Experimental Results and Discussion

From the results shown in Figure 7(a) and (b), the copper wire spool was detected whenever the system detects the big circle within the range of radius as explained in the Methodology. The screen display "Spool detected" when the system detects the copper wire spool. The system is displayed in binary images rather than in grayscale or RGB images so that user can monitor the screen easily. However, there are some errors due to lighting and noise that are difficult to be eliminated during the image processing. The noise has been reduced using the Canny edge method.



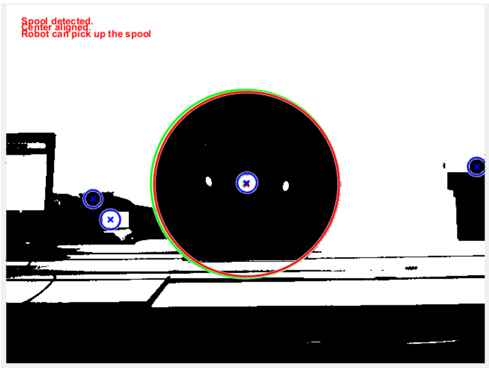
(a)



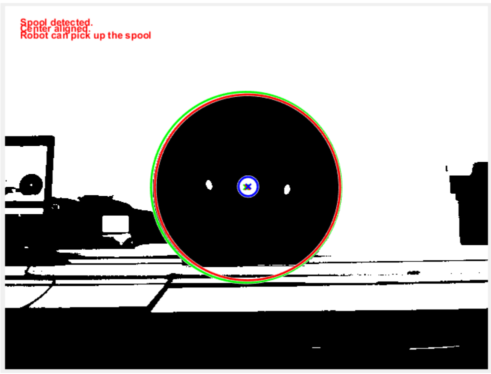
(b)

Figure 7: Spool detected in many situations

Figure 8 shows that the big circle center that overlap with the reference center and the screen displayed “Center aligned” and “Robot can pick up the spool”. When the big circle center overlaps with the reference center, the camera and the copper wire spool are considered to be aligned.



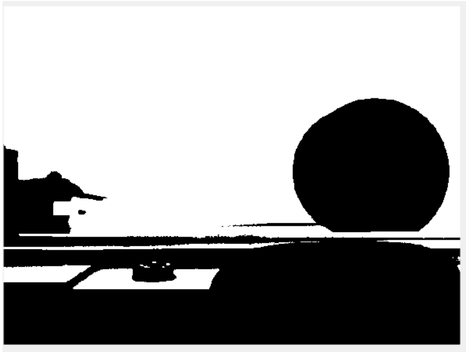
(a)



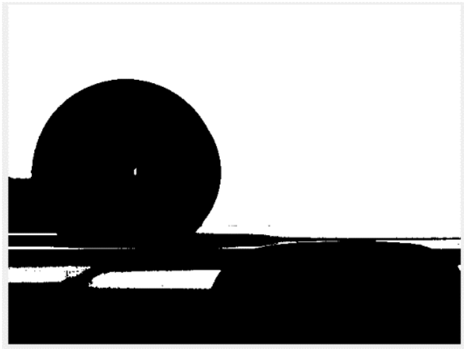
(b)

Figure 8: Center aligned

The image in Figure 9(a) and (b) show that the system cannot detect the copper wire spool and the screen will not display anything.



(a)



(b)

Figure 9: Spool not detected

Table 2
Comparison of The Results Produced by The System and Actual Measured Value

No.		Distance between 2 circles (cm)		Error (%)
		Actual measured	Experiment	
Right	1	35.0	33.21	5.11
	2	25.0	24.74	1.04
	3	15.0	16.32	8.80
	4	10.0	11.11	11.10
	5	5.0	4.62	7.60
Center	6	0.0	0.08	-
Left	7	5.0	4.93	1.40
	8	10.0	8.87	11.30
	9	15.0	14.86	0.93
	10	25.0	25.51	2.04
	11	35.0	33.65	3.86

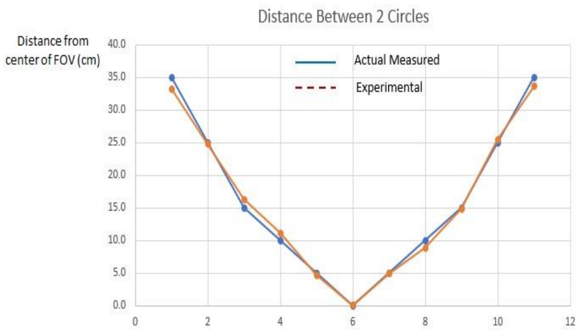


Figure 10: Comparison between theoretical and experimental results

Figure 10 and Table 2 show the results obtained from the experiment and actual measured value. As can be observed, the error rate was quite big. The big errors are due to lack of absolute parallel between the camera and the spool.

Furthermore, the back circle affects the system that determines the circle of the front rim. Although this system created a reference circle at the center of the image frame, the correct position of the spool can be determined. However, for the precise picking up process, the small hole at the center of the spool must be utilized so that the correct position and the yaw angle of the spool can be determined.

IV. CONCLUSION

This paper proposed an effective solution to the peg-in-hole problem without using sensors such as the force and torque sensor. The results show that the proposed system could track and determine the correct position for the robot to stop moving forward before proceeding to pick up the spool, by determining the difference of the distance between the circle of front rim and the virtual circle plotted at the center of the image frame. Further work will use the small hole at the middle of the spool that can provide higher accuracy of the stop position.

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