Webcam Based System for Press Part Industrial Inspection

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Summary
Industrial inspection is one of the crucial factors to ensure quality of product before reach the market. The inspection tasks can be done by using visual system such as human vision or machine vision or combination of both. In this paper, we describe a system that capable to control quality of press part product. The scheme is based on CMOS web-camera (webcam) in a production line. The main objectives are to develop image processing algorithm which can measure the dimension of parts and decide whether it is accepted or rejected. In this research, we divide the system into hardware and software components. The result shows its possibility to be used as automated visual inspection system for press part quality control. The dimensions of the part can be obtained by calculating the pixel value.
Key words:
Visual inspection, press part, webcam

1. Introduction

Quality is one of the factors which determine the customer satisfactory and its interchangeability to replace other part. The process is done by comparing actual part and a set of requirement and its standard. The method for determine quality is divided into human inspection and machine inspection.

Human inspection usually executes measurement after part has been produced. In the traditional approach human or experts perform measurement using conventional instruments such as rules, calipers, and micrometers. In addition, current inspection can also be using other tools e.g. probe-based Coordinate Measurement Machine (CMM). CMM measures the dimension by contact the probe to the surface of part. The probe position will be measured by computer software and the result display at the monitor. CMM is not automatically move the probe to touch the point of measurement but needs of human action to manually move the probe into desired position. Another CMM type is using laser scanner as acquisition devices to replace probe-based type and categorized as real time inspection.

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In contrast, machine inspection performs the measurement while the part being produced on line production. The system integrates lighting system, acquisition devices or camera, computer, image processing software, and handling equipment. The camera will capture images under suitable lighting condition [1]. Then, the image enters the software to be analyzed and processed. Although most of typical camera is sensitive to the environment then it would be necessary to control the lighting condition. The lighting condition can be controlled using dimmer control based on the requirement of product being observed.

The result of image processing stages then enters the classification module to determine whether an actual part matches the requirement and its standard or not. If the part does not fit the quality, the output from this module will trigger the handling equipment to dissociate the part from production line simulation.

In this paper, a scheme of machine inspection system in presented. The method described allowed the dimension measurement by calculating the pixel value multiply the geometrical constrain. The method has advantages that the system is low cost and does not need of traditional measurement equipment such as calipers, ruler, and checking fixture.

The paper is organized as follow: section 2 gives the importance of Automated Visual Inspection (AVI) on industrial area. Section 3 reviews the basic theory of image and related image processing method for the application. The detail of methodology used for the system described in section 4, followed by result and discussion in section 5. Finally, conclusion is given in section 6.

2. Importance of AVI

Human inspection can perform complete quality inspection but it is a time consuming process and causes inconsistent result between operators [2]. Although it is the most common and simple inspection method but there are several disadvantages because human can suffer of illness, human error, and slow. On the other side, real time inspection offers many advantages such as increasing speed, accuracy and reliability. In addition, vision based systems have been implemented in the industrial sector all over the world [3].There are hundreds and thousands of different applications and many more are being developed or improved day by day [4].

As described above However, automated inspection system covers the full range of technical difficulty in computer vision [5]. Real time visual inspection is not a simply image processing problem but the system combines of many aspects as stated in earlier.

The other problem of applying automated inspection system is the cost. The commercial one starts from USD 30,000 up to USD 200,000 or even more [6]. In addition, companies who have installed them are unwilling to release details of their system or the cost savings because they want to maintain a competitive advantage over their rival [7].

The aim of this design is how to apply machine vision-based for press part inspection system. The design includes image acquisition, image processing software, handling equipment and simulation of line production in the manufacturing environment. The requirements of visual inspection for press part sorting is can measure the dimension of press part.

As stated earlier, the purpose of visual inspection system is to perform quality assurance by separating accepted part from rejected product. To do this, a careful planning should be taken in the design stage. The orientation is based of the object to observe. The system should cover the following aspects to perform total quality control [8].

1. Adaptive lighting control.
2. Flexible software development approach to accommodate changes in the future.
3. Networking system for communication between Decision Support System (DSS), Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), and Computer Aided Process Planning (CAPP) in manufacturing environment.

However, our main focus in this paper is the requirement for the computer vision. The system consists of digital image acquisition, computer, image processing routines, and handling mechanism.

Firstly, the choice of image acquisition devices is based on minimum requirement of pixel accuracy. For instead, low resolution web camera can be using because it is very cheap. The disadvantage is the high noise but can be smoothed in image processing routine. The result of image captured from the camera is significantly relies on lighting condition. We must avoid direct illumination to reduce specular effect of metal surface. Fortunately, the light intensity is controllable since we have indoor application.
Since we are dealing with real time application, the computer hardware to be used should be fast enough to calculate the routine task. The time consumes of accepted or rejected decision depends on the computer speed. Generally, the faster the computer, the less time required to process the data.

Finally, the part status is used to trigger the handling mechanism to separate accepted part from defected part over production line or vice versa. This scenario is commonly used for developing AVI system in manufacturing environment.

In addition, if there is a defective part, then the report can be transmitted to DSS to be analyzed. The visual inspection system should be integrated within other manufacturing process to perform total quality control and reduce cost of producing defective product. Figure 1 shows the typical networking system which is using wireless networking for Computer Integrated Manufacturing (CIM).

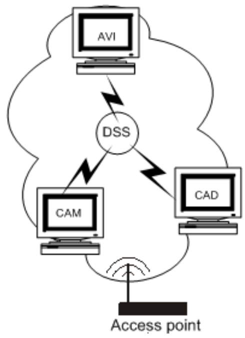

Fig. 1 Visual inspection networking system.

The DSS is aim to decide proper action if there is defective product detected. DSS will analyze the manufacturing process which causes the fail product. The wrong process could be from CAD, CAM or the CAPP. The CAD is aim to perform design analysis, test and evaluate the prototype, and production drawings. The CAM and CAPP is aim to select the proper material, process and equipment for fabricate the product. All over the system is integrated into a CIM which is aim to control the entire production process. CIM provides the data storage, sensing state and modifying the manufacturing process.

We also have been developing the production line simulation for testing the inspection system. The system is divided into hardware and software subsystem. The hardware subsystem as shown below consists of conveyor, lighting system, web camera, fuzzy logic controller, and sorter. The lighting system is using dark field illumination which is controlled by dimmer. The camera has resolution 480 x 640 pixels. The conveyor has maximum speed up to 10 meters per minute. The hardware controlled is AT89S52 microcontroller based. The handling equipment consists of plate metal mounted into stepper motor.

3. Theoretical Review

Camera records the particular scene and converts it into 2D image. The feature information of the image is convenient to be expressed in pixel coordinates. In this coordinate system, the image is treated as a grid of discrete elements, ordered from top to bottom and left to right, as illustrated by figure 2.

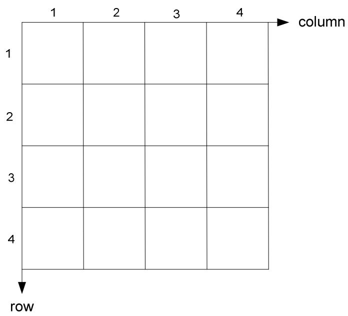

Fig. 2 The pixel coordinate system.

For pixel coordinates, the first component *r* (the row) increases downward, while the second component *c* (the column) increases to the right. Pixel coordinates are integer values and range between 1 and the length of the row or column.

The main aspect in the computer vision for inspection is the image processing processes. The routines is aim to extract the feature descriptors which characterize the part. There are two features to be extracted of our part sample, which are diameter and length. The following flow chart will show the algorithm of the visual inspection, which are using in the system.

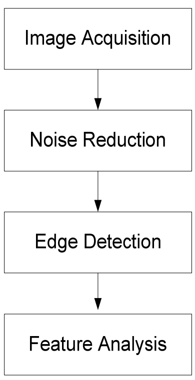

Fig. 3 Image processing stages.

1. Acquisition – *This step is aim capture and transmits the image from the scene to computer host.*
2. Noise reduction – *This step suppress noise introduce by acquisition process*
3. Edge detection – *This step detects sharply changes in image.*
4. Feature analysis – This step is aim to extract feature descriptors about dimension of part specification and compares feature descriptor from previous step and its standard requirement. Then, the part is claimed whether accepted or rejected.

3.1 Acquisition

Notice that the image quality is significantly influence by the illumination. Fortunately, the lighting can be set fixed for industrial inspection. Under illumination, part surface will reflect some amount of intensity from the light source. Then some part of reflectance light will be recorded by Complementary Metal Oxide Semiconductor (CMOS) sensor cell and converted into electric signal. Unfortunately, each optical sensor will introduce statistical nature which attaches noise in image and creates discrepancies of interpretation. CMOS-based camera has 10 times of pattern noise than CCD [9]. However, we can suppress the noise in by using filtering technique.

3.2 Noise Reduction

After image acquisition process, the image is converted into grayscale from RGB mode. This is necessary since we do not need the color information. We assume that the noise can be a modeled as additive and random. In this step, we use Wiener filter to estimates the local mean (μ) and variance (σ^2) around each pixel and described as follow [10].

$$\mu = \frac{1}{NM} \sum_{n_1, n_2 \in \eta} a(n_1, n_2) \tag{1}$$

$$\sigma^2 = \frac{1}{NM} \sum_{n_1, n_2 \in \eta} a^2(n_1, n_2) - \mu^2 \tag{2}$$

3.3 Edge Detection

Edge is a sharply changes of intensity in image. The techniques can be classified based on first order derivative and second order derivative. First technique is using gradient vector and estimate the gradient direction e.g. Roberts, Sobel, and Prewitt. The second technique is using zero-crossing of the Laplacian or non-linear differential expression.

The significantly differential change at the image gradient can be used to detect any edge of each region. A well known algorithm is the Sobel operator which detects the vertical and horizontal changes in image. The operator is using two 3x3 kernels which are convolved with grayscale image.

$$G_x = \begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix} * I \quad \text{and} \quad G_y = \begin{bmatrix} +1 & +2 & +1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} * I \qquad (3)$$

The letter I denotes for image source, G_x and G_y denotes for images which contain the horizontal and vertical derivative approximation where * stands for 2-D dimensional convolution operation. Other edge detectors such as Roberts operator is similar to the Sobel operator which shown below.

$$G_x = \begin{bmatrix} +1 & 0 \\ 0 & -1 \end{bmatrix} * I \quad \text{and} \quad G_y = \begin{bmatrix} 0 & +1 \\ -1 & 0 \end{bmatrix} * I \qquad (4)$$

However, one the most commonly used method for edge detection is Canny edge detector. It consists of the following steps:

- Smooth an image with a filter.
- Calculate the gradient (magnitude and orientation) of the smoothed image.
- Apply non-maximal suppression.
- Perform hysteresis thresholding.

3.4 Feature Analysis

The edge detection algorithm showed above is should be performed for every pixel of the image. This increases the amount of time to perform the calculation. There is another technique that is simpler and faster based on the idea that different object level or regions have significantly different grey levels. One method that is relatively simple, does not require much specific knowledge of the image, and is robust against image noise, is the following iterative

In classification, the feature vector is treated as input. The information represented by the vector represented is determined. There are many techniques of classifiers include Bayesian, rule-based, and neural network. However, in this paper, we used the rule-based method only. Rule-based systems classify data to if-then rules. This method use causality to perform classification of object. For example shown in the following rule:

IF feature 1 > reference + tolerance THEN reject
IF feature 1 < reference - tolerance THEN reject
Otherwise THEN accept

This rule would reject an object which is out of its tolerance.

4. Methodology

In this research, the system has following boundaries. Firstly, image processing consists of following techniques such as image filtering, image enhancement, edge detection, feature extraction, feature analysis, and recognition. The software developed using visual C++ 2008 Integrated Development Environment. The computer is HP Pavilion a6260d Home PC which has windows vista operating system. The lighting system is consists of 150 watt halogen bulb and dimmer control. The parts being inspected are shown in the figure 4, 5, and 6. The first part has rectangular shape and consists of four holes. The second part has circle shape with one hole at the centre. The third part has six edges and one inner diameter.

The hardware controller is using DT-51 petrafuzz module from innovativeelectronic based on AT89S52 microcontroller. The camera is using Proview 5132 sensonic CMOS web-camera. The conveyor has maximum speed at 10 meters per minute. The handling equipment consists of pinset mounted into stepper motor and controller from KHG electronics version 1.5.

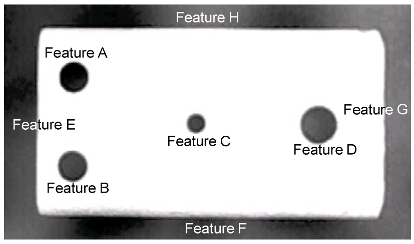

Fig. 4 Rectangular.

The feature description of the part is shown in the table 1.

Table 1: Feature description of rectangular part parameter

Rectangular Part			
No	Name	Shape	Parameter
1	Feature A	Circle	Diameter A
2	Feature B	Circle	Diameter B
3	Feature C	Circle	Diameter C
4	Feature D	Circle	Diameter D
5	Feature E	Left _Edge	Line E
6	Feature F	Bottom _Edge	Line F
7	Feature G	Right _Edge	Line G
8	Feature H	Upper _Edge	Line H

The feature of the part denoted as letter.

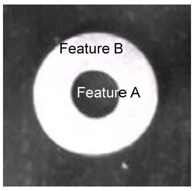

Fig. 5 Circle.

Table 2: Feature description of circle part parameter

Circle Part			
No	Name	Shape	Parameter
1	Feature A	Circle	Diameter A
2	Feature B	Circle	Diameter B

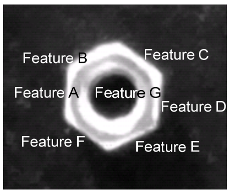

Fig. 6 Hexagonal.

Table 3: Feature description of hexagonal part parameter

Hexagonal Part			
No	Name	Shape	Parameter
1	Feature A	Edge	Line A
2	Feature B	Edge	Line B
3	Feature C	Edge	Line C
4	Feature D	Edge	Line D
5	Feature E	Edge	Line E
6	Feature F	Edge	Line F
7	Feature G	Circle	Diameter G

4.1 Software Development Approach

The methodology is described as follow. Firstly, the software development uses waterfall model which has configuration as follow [11], [12]:

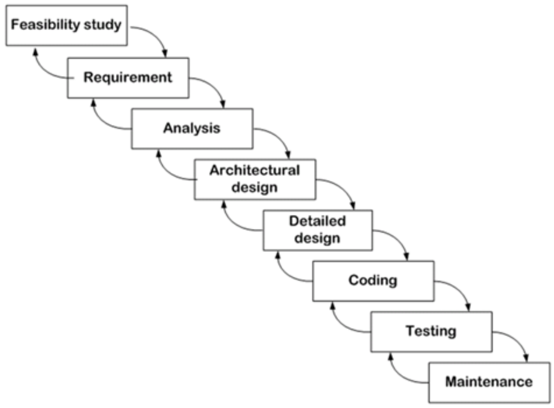

Fig. 7 Waterfall model of the software lifecycle.

The waterfall has stages as follow:
Feasibility study – Explore whether a solution is attainable within the given set of constrain.
Requirement – Description of behavior of the system to be develop.
Analysis – Evaluate the requirements create model of how the system works under given condition.
Architectural design – concerned with the overall form of solution.
Detailed design – Develop description of the element from previous phase.
Implementation (coding) – Create realization of the abstract design into software system.
Testing – Validation the implemented software against its original requirements.
Maintenance – Repeat all the task of previous phase to check consistency with its design plan.

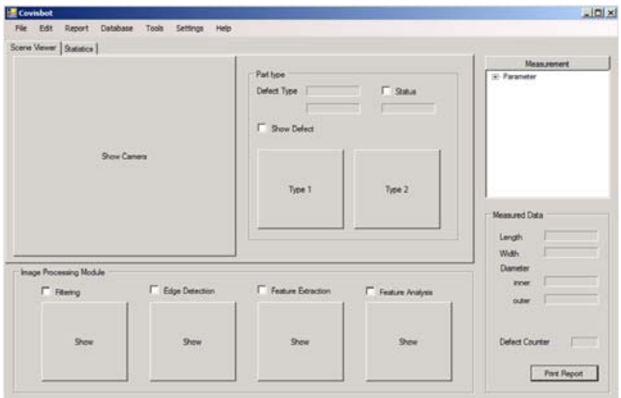

Fig. 8 GUI for inspection system.

The Graphical User Interface (GUI) shown in figure 8 is developed under C++.NET 2008. After the software finished, the testing will extended using black box model. This testing is aim to the check the expected output by give certain input.

4.2 Experimental Setup

The complete design of the intelligent real time inspection system is shown in figure 9. The system is divided into hardware and software frameworks [13]. The hardware framework is the production line simulation which consists of conveyor, press parts, CMOS web-camera, lighting system, fuzzy logic controller, and handling equipment or sorter. Assume that conveyor has direction from the left to the right. While part is moving over conveyor, camera will capture image part and transfer it into computer via USB port. The image then processed and analyzed by the software. If the inspection result reports that the quality doesn't fits its requirement and standard, then the fuzzy logic controller will receive warning signal from computer and trigger the handling equipment will dissociate the part from the production line.

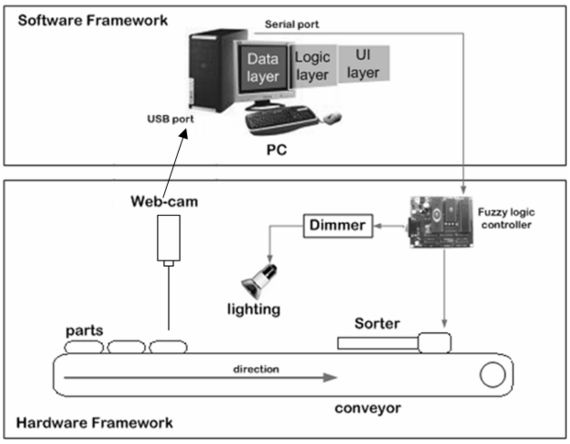

Fig. 9 AVI system for press part sorting.

The software framework is using three-tiered model. It consists of three tiers which are data, logic, and user interface which can be implemented on a single machine or client/server based machine. This approach is important since the quality control, product prototyping, and maintenance management system is integrated in a computer-based system. In the real manufacturing environment, it is necessary to transfer data or information from one computer into others at different location. For example, the inspection report should be transfer to the engineers and machinists that perform the prototyping product components for feedback and to the maintenance management system to give actual information of manufacturing process.

5. Result and Discussion

The system has been tested with environment that simulates the manufacturing process as closely as possible. The results of image processing algorithm described in the following section.

Filtering

The results of images part after applied wiener filtering are shown in figure 10.

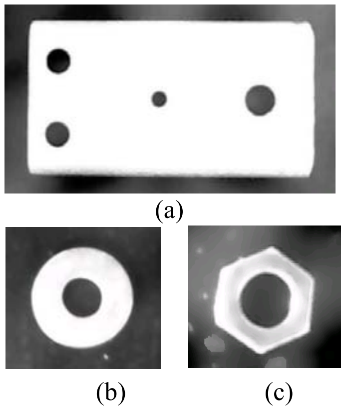

Fig. 10 Wiener filtering result.

Edge Detection

Now, we have better image from noise reduction step. This step is aim to detect edge or sharply changes of brightness in image.

Sobel Operator

The edge detected by Sobel operator is shown in figure 11.

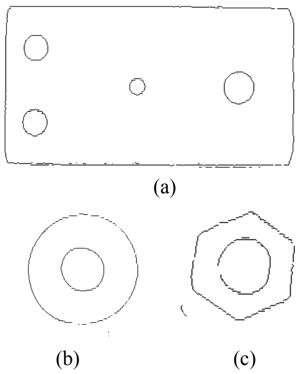

Fig. 11 Threshold 0.11, 0.15, 0.12 respectively for (a), (b), and (c).

The rectangular image is edge detection with threshold 0.11. In the circle image, both inner and outer diameters of the circle are detected by set the threshold value equal as 0.15. In the hexagonal image, the features are detected by set the threshold value equal to 0.12.

Roberts Operator

The edge detected by Roberts operator is shown in figure 12.

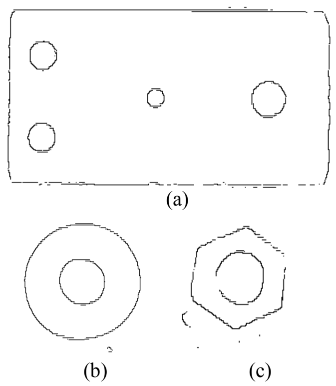

Fig. 12 Threshold 0.11, 0.10, 0.10 respectively for (a), (b), and (c).

The rectangular image is edge detection with threshold 0.11. In the circle image, both inner and outer diameters of the circle are detected by set the threshold value equal as 0.10. The same goes for hexagonal image.

Canny Operator

Canny operation shows better result which is showed in figure 13. Canny is more precise than others such as Sobel and Roberts operators. The rectangular image is edge detection with threshold 0.35. In the circle image, both inner and outer diameters of the circle are detected by set the threshold value equal as 0.90. In the hexagonal image, the features are detected by set the threshold value equal to 0.60.

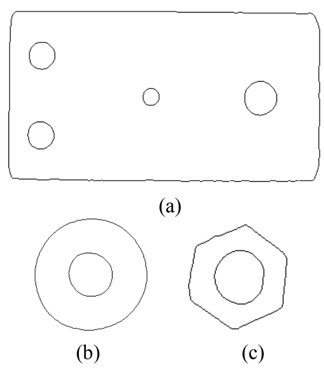

Fig. 13 Threshold 0.35, 0.90, 0.60 respectively for (a), (b), and (c).

Feature Analysis

In classification, the feature descriptor is compared with its requirement and standard. The comparison is based on the tolerance of part design. If the result shows that significant or intolerable error such as out of length and diameter, then the part should be dissociated before entering the assembly process. For instead, we use if-then rule to classify accepted and rejected part. Rule-based systems classify data to if-then rules. This method use causality to perform classification of object. For example shown in the following rule:

IF feature diameter < 95 and > 85 THEN part is rejected
Otherwise, part is accepted

This rule would reject hexagonal part if the diameter is not in the range of 85-95 mm. The software algorithm developed and simulated using MATLAB.

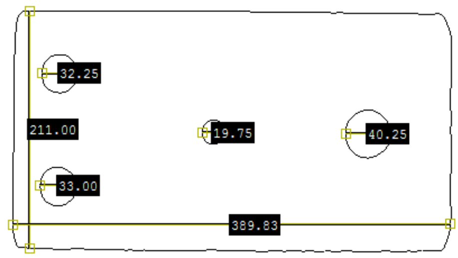

Fig. 14 Feature extraction of rectangular part.

The image of rectangular type is decomposed into region by applying Canny operator. The line inside region shows the longest path of area interest. The value is the number of the pixel that builds the line. Figure 14 shows the values of feature parameters are 389.83 pixels for length and 211.00 pixels for width. The diameter of four holes is 40.25 pixels for right hole, 19.75 pixels for centre hole, 32.25 pixels for upper-left hole and 33.00 for lower-left hole. The dimension of length, width and circle of the part can be obtained by multiplication between the value and constant that related to the position of camera and part. The same thing can be applied for the circle part.

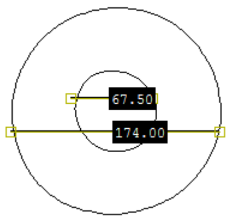

Fig. 15 Feature extraction of circle part.

Figure 15 shows the value of feature parameters are 174.00 pixels for outer diameter and 67.50 pixels for inner diameter.

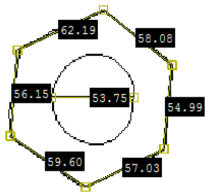

Fig. 16 Feature extraction of hexagonal part.

Figure 16 shows the value of feature parameters are 53.75 pixels for inner diameter and 56.15, 62.19, 58.05, 54.99, 57.03, 59.60 pixels respectively for feature A, B, C, D, E, and F.

The dimensions obtained from pixel measurement then converted into length of mm. The result then compared with the actual value to get the error of measurement. If the error is tolerable under the standard and part requirements then the part will be accepted. Otherwise, handling equipment will dissociate part from production line simulation.

6. Conclusion and Future Work

We had compared both of inspection method in industrial application. The real time inspection method can be expected to improve quality control in manufacturing environment. However, the implementation of computer vision in manufacturing is not simply image processing problem. The real time visual inspection is an integration system of lighting system, image acquisition, computer, controller and handling equipment. The results show that the dimension can be calculated using image processing algorithm which measures the length, width, edge, and diameter of press part.

The results show the potential of the system to be implemented in metal-based industry. It is shown that the above algorithm can be used to perform real time visual inspection system. The routine consists of digital image acquisition, noise reduction, edge detection, and feature extraction. However, future work is necessarily needed to inspect another parameter of press part such as straightness, flatness, roundness, angle, profile, and weight for part with more complex shape.

Acknowledgments

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