A Cheap Visual Inspection System for Measuring Dimensions of Brass Gear

M. Jalili, H. Dehgan, and E. Nourani

***Abstract*—Dimensional inspection is one of the main sections of industrial parts production process. Machine vision is a modern method to inspect produced parts. Using machine vision has some problems in measuring parts dimensions and also these solutions are expensive for small industries. In this paper, problems of visual dimensional inspection have been explained and some solutions have been proposed to improve these systems performance. To do this, a visual inspection system has been implemented to control production quality of a brass gear. This system is an accurate, repeatable, fast and cheap solution for small industries. Experimental results show that the system more accurate and repeatable than the manual methods.**

***Index Terms*—Brass gear, dimensional inspection, machine vision.**

I. Introduction

Quality control is an integral part of various industries and dimensional inspection is one of the main sections of it. This process includes parts measuring and comparing them with acceptable quantities. Human can measures parts by measuring tools such as caliper, micrometer and gauges. Human inspection is slow, expensive, not reliable and may have error. Furthermore this inspection type cannot be integrated with production process.

In addition, there are some semi automatic tools to measuring like Coordinate Measurement Machine (CMM) that can be measure dimensions by touch some points of part by a prob. CMM is a very accurate tool and could be measure dimensions with precision but it has some limitation among CMM should be moved by human to touch the start points on measurement and it could not automatically do that [1]. The other limitation of CMM is that we cannot move big and heavy parts near to CMM to measure them.

One of the new systems in quality control is visual inspection. Consistency, repeatability, accuracy, versatility, reliability, integration of production line, speed, and cost effective are major properties of these systems [2], [3]. Visual inspection used for four types of inspection [4]:

1) Dimensional quality
2) Surface quality
3) Correct assembling (structural quality)
4) Accurate or correct operation (operational quality).

This paper focuses on dimensional quality inspection. In this method, by assistance taken images from parts and analysis of images, the desired futures extracted and compared with the control instruction and then a decision-making system chooses the acceptable and rejected parts. Futures include dimensions, geometry, positioning, direction, alignment, roundness and angles. Measure the dimensions of part is a complex application of visual inspection due to edge detection accuracy and factors such as light, part color and camera angle affect in the measurement accuracy.

In this paper, a practical example of controlling the dimensional and geometric of a brass gear of the car gearbox has been dissected. Through a practical example, in this case study, limitations of dimensional measurement with machine vision is expressed and in some cases, various problems of these systems is considered and for each problem proposed a hardware or software solutions.

This paper is organized as follows: In Section Ⅱ, the related works has been reviewed. In Section Ⅲ, the case study and its parameters must be controlled is expressed. In addition, the hardware requirements and software various stages are illustrated. In this section, to improve performance and accuracy of the system, some hardware and software solutions have been proposed. Experimental results of running the system are described in Section Ⅳ and finally the conclusions and future work are given in section Ⅴ.

II. Related Works

Dimensional quality control is one of the major fields of visual inspection system and some machine vision based solutions have been implemented [4]. An inspection system has been developed for the automotive fuel sender tube factory that three critical dimensions of fuel sender tube have been measured [5]. Foundation of online visual measurement systems has been studied and accuracy and repeatability of this method has been investigated on desired case study.

Another inspection system has been implemented to control quality of press part production [1]. The system acquires images by a webcam and processes them to identify certain objects such as circle and hexagonal. The focus of this work is on metal parts and some noise reduction and edge detection algorithms have been investigated.

In other work an online machine vision inspection system has been designed for detecting coating defects in metal lids during manufacturing [6]. The system can recognize circular object on images which take from metal lids on conveyer and detects defects on them. Inspection process is done through four steps: image acquisition, image enhancement, thresholding and object matching.

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Accuracy is the main factor in measurement. Leta et al. have discussed accuracy in an automatic visual measurement system [3]. The work has been noted two points about machine vision based measurement systems. First, the object must be thin, to decrease the height effect in the measurement; Second, a standard gage should be used to convert pixels to real measuring units.

III. System Description

This paper illustrates the dimensions and geometry control of brass gear of gearbox car. In "Fig. 1" an instance of this gear is shown.

A. Problem Definition

In the control instruction of this piece there is more than 43 control parameters that 12 parameters of them related to the dimensions and geometry control which their importance degree are A (very important) or B (important). In the control instruction, all parameters accuracy is tenth or hundredth mm. In the part manufacturer, caliper and "go" and "not go" gauges are used to control the various parameters and some parameters are forborne due to being time consuming and in some cases due to the measurement tools limitation. Also, large numbers of control cases causes to low percentage of parts are controlled by human with hand tools at the end of parts production line. These problems cause the high percentage of parts are returned from customers. Machine vision method in quality control increases the speed and precision of parts quality control but against, that is expensive. In this paper a practical and cheap machine vision solution is presented for small and medium industries. In this method, a commercial camera takes images of brass gear in three directions and taken images are processed on a PC by image processing software and parts parameters are extracted and a decision-making system decides the acceptance or not acceptance of different pieces. More in this section, hardware and software parts of the system is described.

Fig. 1. Brass gear.

B. Hardware

As A machine vision system is composed of the following components:

1) One or more cameras for image acquisition and, if necessary using an appropriate lens for preparing clear images
2) Light source, which plays a key role in providing better images.
3) Frame grabber for transferring images from camera to PC
4) PC for storing taken images
5) Software platform that responsible for processing and extraction of parameters of parts.

In addition, equipment such as conveyor, parts detector on the conveyor belt and parts separator can be added to above components.

The choice of image acquisition devices is different in various applications and based on the pixel accuracy and image rate requirement. For measurement applications, the high image resolution is commonly required. As respects external diameter brass gear is 63 mm and that is the largest length measured at the part and the most accurate measurement is hundredth of a millimeter, if each pixel is considered hundredth of a millimeter, length and width of gear should be 6300 pixels and we need a camera with at least 6300 * 6300 pixels or 36 mega pixels for its image size. Such a camera with this resolution actually does not exist. To solve this problem, we use the sub-pixel to raise accuracy 10 times by software techniques. Moreover, NI Vision Builder program that be used in processing section of this system has been recommended it is better to use double precision for measurement applications [7]. That's why 12600 pixels instead of the 6300 pixels are used. If 10 sub pixels instead of every pixel are used, the whole needed pixels in every dimension reduces to 1260 pixels and a camera with a precision at least 1260 * 1260 pixels is need. Camera with high accuracy and high data transfer rates is expensive and the cost of image transmission equipment also is high. For this purpose and for prototyping, the commercial camera Canon Power Shot S5 are used that has 8 megapixel accuracy and its images are 2448 * 3264 pixels [8].This camera is equipped with a lens which is 12 times enlarge possible. In experiments conducted, FOV is considered to 2235 pixels that its actual size is 63 mm and with regard to use sub pixel instead of real pixel, precision of measurement system reaches 0.003 mm. Using this camera, given its low price versus industrial cameras, for small-scale industry is cost-effective. However, using this camera has some problems. The first problem related to image processing software was not able to identify the camera.

In this system, the NI Vision Builder program, a software for machine vision is used that has more in this section explanations about it are presented. To resolve camera identification problem by the NI software, another program is developed that uses Canon SDK to control the camera, takes pictures and transfers them to NI software. The colored images have been taken by the camera is converted to gray-scale images by software.

Another problem in this camera is the low images transfer rate that this limitation is due to low speed in USB transmission interface. Considering that the rate of parts quality control is low, this problem is not a major limitation. Although in large industries that have high rates of production is a major limitation, causing percentage of controlled parts is reduced. The system can take an image and save it on PC within 3 seconds. This is a major improvement versus manual methods.

Lighting one of the most important factors in the success of projects is machine vision and its importance in measurement applications are doubled because the lack of proper lighting creates imprecise edges in the image and measurement gives the wrong sizes. Sometimes various types of light source from specific angles and certain radiation intensity should be combined so that proper lighting to be done. For example, the use of back-light causes the light intensity changes is strong in the external edges and edge detection in image processing software for these edges is possible easily and accurately. But the problem of back-light is that the inside area of part is dark and detection of its edges is not possible. In this system, a double row circular light is used when the bottom row of light is turned on, its functionality as same as back-light and outside edges are recognizable; when the top row of light is turned on, the internal area of gear is bright and its edges are detectable. To build a uniform light ring, LED s should be used that they are arranged in the equal distance on the ring. The light intensity should be similar to all LEDs. So the amount of electricity for each LED should be equal and a constant-current circuit for interconnecting the LEDs should be used. The high number of LEDs and being circular light causes the unwanted shadows on the various parts of gear are not created. If the irradiation of external light sources is prevented, the irradiation from light source of system is similar on every gear. This cause the test conditions are uniform for all gears and the system repeatability rises.

In this system, a foundation metal container is used to stable the different components of system. The gear in a fixed place in the container is held and camera and light source can be on a metal shaft in the desired location to be fixed. In “Fig. 2” the container has been shown. Parts control approximately is separated from the production line and is done at the end of the production line. It is a semi-automatic and placing and removing parts to be performed by an operator. Of course, changes easily can be applied to combine it with the product line and placing and removing parts to be performed automatically.

C. Software

Software is a critical part of machine vision systems that is composed to three main stages: 1- Image acquisition 2- Image processing 3- Feature analysis [1]. In image acquisition stage, images are transferred from imaging device to PC by a program. Many of machine vision softwares have an image acquisition section that can detect the camera and camera interface and prepares images to processing section by capturing images from camera. This camera's interface is USB and an add-on component should be installed to machine vision software to support the USB. After instillation the add-on, a streamed video can be captured by software but resolution of its images is low because the data transfer rate is low with USB. To take high resolution images, offline mode should be used. It means that an image is taken by camera and is stored in its memory and then it is carried to PC by an USB port. For this purpose, an application has been developed using the SDK of camera that can connect to the camera and do some operation such as optic zoom, take picture, transfer image to PC, read and write camera memory and change camera settings. After the image was captured, processing software processes it and extracts its features. NI Vision Builder has been used for this purpose can run in two modes: configuration and inspection. In configuration mode, a controlling process is developed in several stages using a visual design environment which has many useful tools for image improvement, image conversion and edge detection and so on. After configuration, software runs in the inspection mode and the desired features are extracted from the image and finally acceptability of parts is evaluated. It is not possible to fetch all desired gear properties from only one taken image, but images should be prepared from three directions of it: top, bottom and side track. Sample images in three directions from gear are shown in Fig. 3.

For this reason, the whole control process is divided into three separate stages. General algorithm is as follows: First, the image processing software sends a message to the image acquisition program through TCP/IP port to inform it to take an image from the top side of gear and save it in a specified location on the PC. Image acquisition program accesses to the camera by SDK and sets essential camera settings such as optical zoom and then takes an image from top side of gear and store it on pre-specified location and finally sends a message to image processing software to notify successful operation. Obviously, before taking image, the appropriate commands will be issued to lighting control for illuminating back-light. NI program loads stored image into inspection environment and runs different processing steps for image to extract the some gear parameters. Then a message for rotation the gear is shown to operator and operator rotates the gear within the container So that the other side of gear is toward the camera and presses a key to continue the program running. This step repeats for two times to take images from bottom and side track and then to process and extract other parameters.

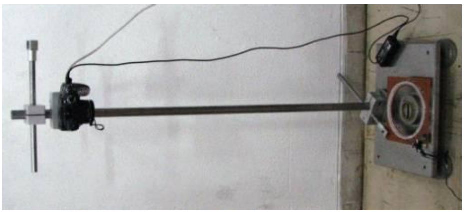

Fig. 2. Container

Fig. 3. Brass gear from 3 directions

During the three stages, the values of all parameters of gear are measured and then these values are evaluated according to the instructions of control and the results are displayed in a monitor. Measured values can be stored in a database to generate different statistical reports. Furthermore, analysis of these values can help to detect defects in the production process. NI software is shown in Fig. 4.

D. Measuring Improvement

To improve system performance, some methods have been used that they are described in the following.

1) Use Fixture

Because the edge detection to be done more carefully, fixture is used to fix the gear in Whereabouts. This fixture is shown in "Fig. 3". As can be seen there are two pin on the fixture and two slots of gear are fixed by them. Gear is circular and it cannot be fixed in three points because there is only one circle in three points. The third slot free to cover the various gears of different sizes. The gear can be stood in top and down mode on this fixture. For image capturing from gear slot, a hole is embedded in the fixture that the gear is placed in it. To take place for the various gears of different sizes inside the hole, it should be made in the maximum tolerance of valid gears sizes. Fixtures can make to determine the approximate location of edges and edge detection is done with confidence.

2) Use Pattern Recognition

Use fixtures can make the approximate location of edges is fixed. But to determine the exact location of the edge software techniques are used. One of these techniques is pattern recognition which is supported by NI program. In this technique, by specifying a unique part of the image as a pattern in the configuration mode of program, can be identified exact location and direction of the objects on the image in inspection mode. In inspection mode, the pattern is recognized on the image and all of edge detections and other processes locations are relocated by this base reference.

3) Raising the Number of Edge Detections

Using the two previous techniques, allowing the edge zones are specified more precisely. NI program has an edge detection tool which can determine every edge along a drawn line. In configuration mode, an operator draws a line on the image by this tool and in inspection mode, program detects all edges along the line. On edge detection, desired edge may not be uniform and when a gear is measured several times, the edge is detected on different places and measured numbers will be different each time; even in some cases, no edge may not be found. This can reduce system repeatability and in some cases causes error in measurement. To resolve this problem, Instead of using one edge detection line in a region to identify the edge, several of them are used. For example to obtain distance of two parallel edges, several edge detections are done along two edges and different values are obtained. These values are checked and values are very different from other values are removed. The average of valid values will be recorded as desired value. An example of this technique is shown in "Fig. 5".

4) Increase Uniformity of Parts

During heat treatment, stains on the gear come up and may trigger the errors in measurement. To solve this problem, parts are washed with dilute acid which removes stains effects. However, using the previous techniques can reduce the negative effects of stains.

IV. Experimental Results and Methods Improvement

There are two main factors in evaluating measurement systems: accuracy and repeatability [5]. Accuracy means that how much difference is between measured values with this method and the real parts values. Repeatability means that how much difference is between measured values from a part in several separate measurements in same condition. Whatever these two criteria in the measurement system are high, system reliability is increased. If accuracy is high, there is no reason for the high repeatability and vice versa. To measure accuracy, 50 gears are selected randomly and desired parameters are measured by instrumentation such as CMM which gives the exact sizes. Then these gears were measured by machine vision and manual methods. For comparison of two methods the average difference between the two systems with the actual size is calculated.

Fig. 4. NI vision builder

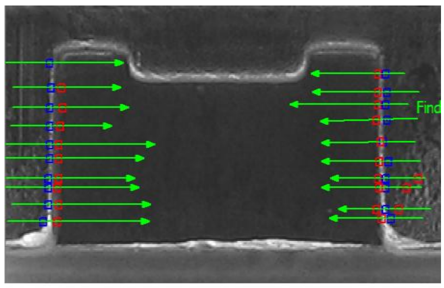

Fig. 5. Raising the number of edge detections in measuring the side track of gear.

$$e_d = \frac{\sum_{i=1}^{N} \left| VC_i - VM_i \right|}{N} \quad (1)$$

where e_d is the average difference between the two systems and N is the total tested gears and VC is the measured value by CMM and VM is the measured value with manual or machine vision method. The results of these calculations are shown in Table I. As be seen in some cells of the table is used hyphen mark indicates that the parameter measurement is not possible by manual method.

Results show that in the parameters measurement which is used back-light, the edge detection is done carefully and measured values are closer to the real values and accuracy is high.

For compute repeatability, 20 parts is selected randomly and all of them are measured 10 times and average and maximum difference is computed. The following formulas for calculating the average and maximum differences are used:

$$r_{avg} = \sum_{i=1}^{N} \frac{\sum_{j=1}^{M} \frac{|VC_i - VM_{ij}|}{M}}{N} \quad (2)$$

$$r_{max} = \max_{i:1..N} \left\{ \max_{j:1..M} \{ |VC_i - VM_{ij}| \} \right\} \quad (3)$$

where r_{avg} is the average difference between measured values of CMM and our methods and r_{max} is the maximum difference between measured values of CMM and our methods. N is the number of gears is measured and M is the numbers of test that in our test case N is 20 and M is 10. VC_i is the measured value of ith gear by CMM and VM_{ij} is the measured value of ith gear in jth test with manual or machine vision method. The results of these experiences are shown in Table II.

TABLE I: FOR MANUAL AND MACHINE VISION METHODS

Parameter number	e_d for machine vision method(mm)	e_d for manual method(mm)
1	0.0658	0.0784
3	0.1196	0.1568
4	0.0264	0.0344
5	0.0605	0.0674
6	0.0028	0.0045
8	0.0874	0.1067
9	0.1377	-
10	0.1631	0.1828
14	0.1514	-
15	0.1344	-
16	0.1166	0.1469
23	0.1956	-

TABLE II: RAVG AND RMAX FOR MANUAL AND MACHINE VISION METHODS

Parameter number	r_{avg} for machine vision method(mm)	r_{avg} for manual method(mm)	r_{max} for machine vision method(mm)	r_{max} for manual method(mm)
1	0.0595	0.0805	0.0934	0.1171
3	0.1372	0.1497	0.1676	0.1633
4	0.0308	0.0439	0.0583	0.0621
5	0.0731	0.0742	0.0913	0.1039
6	0.0021	0.0047	0.0083	0.0109
8	0.0967	0.1033	0.1104	0.1255
9	0.1298	-	0.1665	-
10	0.1559	0.1732	0.1911	0.1973
14	0.1471	-	0.1837	-
15	0.1483	-	0.1921	-
16	0.1201	0.1493	0.1620	0.1725
23	0.2006	-	0.2375	-

Results show that like accuracy parameter, repeatability is top in the gears parameters which have precise edge detection in their images.

V. CONCLUSION AND FUTURE WORKS

In this paper a visual inspection system was presented for dimensional control of brass gear that is a cheap visual inspection system and suitable for small industries. During this case study, the problems of visual measurement systems were reviewed and some software and hardware solutions were suggested to improve system performance. Experimental results show that this system is faster, more accurate and more repeatable than manual measurement systems. Repeatability and accuracy is high in measuring parameters which have sharp edges. Future works can focus on measuring parameters which illumination on them is difficult.

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