中國機械工程學刊第四十一卷第四期第 417~425 頁(民國一百零九年)
Journal of the Chinese Society of Mechanical Engineers, Vol.41, No.4, pp 417~425 (2020)

A Multi-view Image Capture Machine Design and Image Fusion Processing for Golf Ball Surface Inspection

Ku-Chin Lin* and Fu-Wen Hu**

Keywords：multi-view image capture mechanism, image processing, image fusion.

ABSTRACT

The difficulty in vision technology application to 3D spherical objects lies in image capture and the post processing technology as image fusion. In this research, we design a multi-view automatic image capture machine, which consists of a storage device for golf balls to be inspected, two control mechanisms for ball fixing, one mechanism for ball rotation, four CCD cameras with adjustable viewing angle mechanism, and lighting devices. PLC+PC programmable control system is used to control the overall system and image capture timing of the machine. Digitized image capture, coordinate transformation analysis, and image fusion technology application are done by LabVIEW software. With this, the complete image of a whole golf ball can be obtained for further quality inspection. The technology developed in this research can be used in automatic inspection of the surfaces of golf ball, softball, and all kinds of balls.

INTRODUCTION

The defect types on the surface of a golf ball are manifold. They could be logo defects, stains, printing misalignment, holes, inferiority, poor printing color, etc., which account for more than 90% of all defect types. To make an adequate automatic inspection system for the similar cases is more difficult than for a flat surface; therefore, the current inspection of golf ball relies heavily on manual work.

Paper Received November, 2018. Revised January, 2019. Accepted March, 2019. Author for Correspondence: Fu-Wen Hu

* *Professor, Department of Mechanical Engineering, Kun Shan University Tainan, Taiwan, ROC.*

** *Ph.D. Student, Department of Mechanical Engineering, Kun Shan University Tainan, Taiwan, ROC.*

Consequently, golf ball manufacturers are prevented from making a complete inspection system for premium golf balls.

All types of defect are on the surface of a golf ball. To inspect it, we have to capture a complete and high resolution image of the ball surface. However, most current literature about automatic defect inspection deals only with the inspection of flat object or the surface within certain angle of view. Qiang et al. (2015) explored the automatic inspection method for a wide area of flat PCB, in which straight line image registration technology is employed to obtain accurate image stitching and fusion, and solve the problem of wrong artifact resulting from uneven lighting. Most existing technology recorded in literature only address the application of image fusion for flat objects. Rani et al. (2013) explore and compare the simple methods as Minimax, Principle Component Analysis (PCA), and Weighted average method. In general, the simple method as Minimax does not guarantee to eliminate the wrong artifact after image fusion, thus is unable to obtain good fusion image. PCA method requires image feature information to obtain the accurate image stitch and fusion. Krishnamoorthy et al. (2010) explores Pyramid Decomposition and Discrete Wavelet Transform (DWT) fusion technology. The former provides spatial domain and frequency domain positioning information; the latter reserve the advantage of general fusion technology. But both methods require more complicated calculation to achieve the results.

(Chung, 2005; Lin, 2003) deals with the issue of golf ball surface inspection Lin, inspection by using a high resolution CCD camera, integrated with a direct roller rotating a ball revolving mechanism. The requirement of wide-angle ball surface inspection is achieved by this image servo positioning controller. However, the method of image servo ball positioning requires vast image data for calculation, which means time-consuming; therefore, its inspection speed is not sufficient to replace human inspection. In addition, the contact wear on rollers after operation for a long time could result in slippage between rollers and golf balls, and inspection speed would further slow down.

Accordingly, this study presents a new method, which will not require a time-consuming image servo positioning control unit, and it can increase the speed of golf ball surface defect inspection substantially. High resolution image capture for ball surface is subject to depth of field limitations of the lens; therefore, this research suggests multi-view images capture to obtain a complete image of ball surface. Given the diameter of a typical golf ball and the image resolution required by the defect inspection, this study uses 4 high resolution CCDs, integrated with a controller of 2-stage single-direction ball rotation mechanism. Contact wear on rollers is never an issue. In the end, through the process of multi-view image stitching and weighting average image fusion, a high resolution complete ball surface image is obtained.

THE DESIGN OF A MACHINE FOR BALL SURFACE IMAGE CAPTURE

Given that the diameter of a typical golf ball is about 42.75 ~ 42.95 mm, the image resolution for defect inspection has to be about 0.054 mm/pixel. Owing to high resolution requirement, in every image captured only the partial circular area around image center is in focus and clear enough for further process to obtain the complete image. Therefore, this research employs 3D drafting software to design every view angle for image capture and the number of image needs to be captured. The ball rotation mechanism and controlling idea can then be finalized.

The ball rotation mechanism includes a 2-stage ball surface image capture mechanism, a CCD camera assembly, the 2 stations for image capture, computer processing unit, and product packing.

Here is the list of the mechanisms: (1) main body, (2) hopper, (3) track for ball inspection, (4) stepping motor, (5) top camera, (6) ball clamping unit, (7) track and gate, (8) ball clamp unit, (9) ball clamp elevator unit, (10) product tracks (2 sets), (11) ball clamp in/out unit, (12) bottom camera, (13) front bottom camera, (14) front top camera. The final two units are lighting unit and correction fixture. The whole mechanism is shown in Fig. 1.

Two Stage Ball Positioning Mechanism

When a ball is transferred to stage 1, a pneumatic cylinder, which is used to fix the ball, is installed in a fixed position between a set of top-and-bottom clamp. A stepping motor is used to rotate the ball for image capture at the next stage.

The mechanism of the first stage image capture contains two CCD cameras, which are front top and front bottom cameras. Either of them is fixed along the direction images to be captured, and performs their duty. The stepping motor rotates the ball horizontally, pauses 10 times at every 36°, where 10 overlapping images are captured.

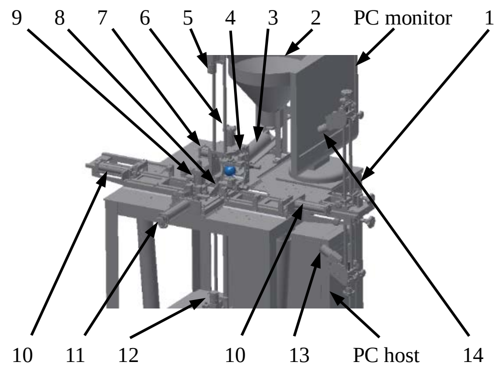


Fig. 1 Mechanisms of the whole machine.

Another mechanism transfers balls from stage 1 to stage 2 positions with two pneumatic cylinders, i.e. H cylinder and V cylinder. The former is to move the ball along left-and-right direction. The latter moves the ball along up-and-down direction.

Two more cylinders and two clamps, which are front and back cylinders, and front and back clamps, are designed to clamp the ball when it is transferred upwards. Adjusting nut is used to adjust the center position of ball and the clamping force the clamp applies on ball.

The mechanism of the second stage image capture contains two CCD cameras, which are top and bottom cameras. Either of them is fixed along the direction images to be captured, and captures images of ball surface. Either camera captures one image of the ball, which has no need to rotate at this stage.

Lighting Device

Under normal lighting, most ball surface will cause light to produce concentration effect. Given that dimples scatter throughout the surface, which is also covered with varnish layer, brightness noise will reflect off the surface under lighting. Concentrated light spot and brightness noise are likely to erode away the features of target image, which causes high escape rate. As a result, the captured images could be unable or hard to process. To resolve this problem, we design two sets of lighting sources with adjustable height and direction in this machine. We direct the light to a shade, and ball surface will receive even lighting. Cameras can finally capture images with stable and even lighting.

Calibration Fixture

When a ball is transferred from stage 1 to stage 2, the center of the ball has to be in line with the line connecting the centers of top and bottom CCD cameras. In addition, the top and bottom centers at the two stages must be consistent; therefore, two sets of calibration fixtures are installed in the machine, one at stage 1 and one at stage 2. One additional set is CCD camera positioning fixture.

The calibration fixture at stage 1 is able to position ball center instantly at stage 1, which is the golf ball center between up and down, and between left and right. However, the center between front and back needs to be adjusted with an adjustable nut.

The calibration fixture at stage 2 is able to position ball center instantly at stage 2, which is the golf ball center between up and down, and between left and right. However, the center between front and back does not need to be adjusted because it was already done at stage 1.

The CCD camera positioning fixture is able to calibrate the positions for the 2 cameras at front top and front bottom.

View Angle Error Correction in the Process of Machine Installation

In spite of the aforementioned CCD camera positioning fixture, minimal errors in view angle could still be possible. We may need some mathematics to help us correct the error, that is △OPQ is similar to △OP′Q′, as shown in Fig. 2.

$$\frac{D}{d} = \frac{X'}{X} \quad \text{---(1)}$$

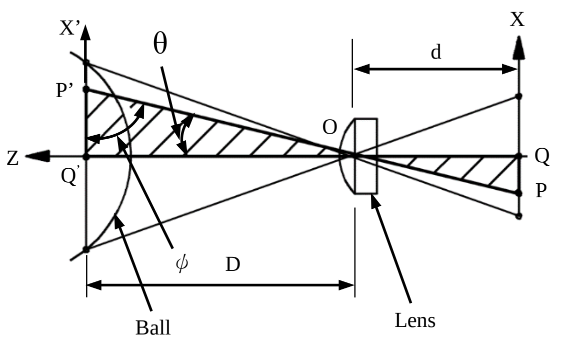


Fig.2 Positioning error correction of every view angles.

IMAGE CAPTURE, STITCHING, AND FUSION

Image Capture

In this research, we use CCD color cameras and zoom in lenses to capture digital images, and obtain the quality and defect information of logo printings and color on golf ball surface and injection. For spherical objects, depth of field becomes an issue in image capture. In actual test, clear image of the sphere only shows within a limited round field, as shown in Fig.3. To capture the clear image for the complete ball surface is a must in this research, we use multi-view partial image capture and image fusion to meet this requirement. Four cameras, two at 60° front-up and front-down inclination angles, and two other directly above and directly below, combine to capture the complete image of the ball surface, as shown in Fig.4.

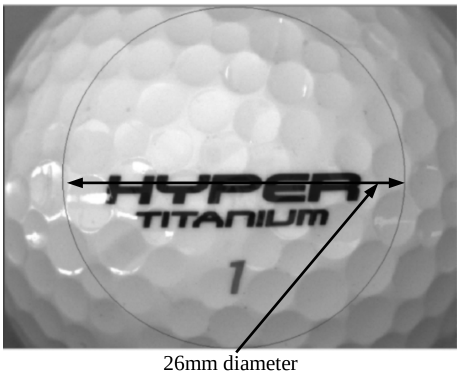


Fig. 3 The circular image to be captured from ball surface.

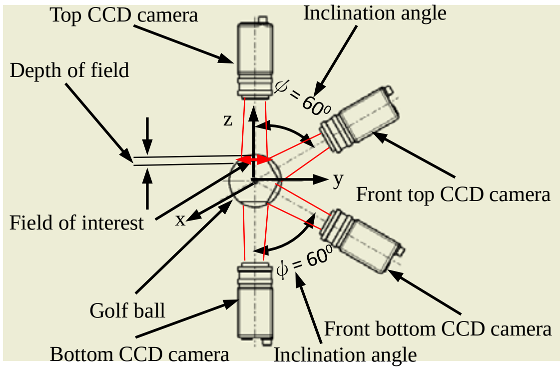


Fig.4 Diagram of golf image capture by 4 CCD cameras.

Sophisticated computer simulation and arrangement suggest that 4 cameras have to capture 12 overlapping images, which contains common pixels. The complete ball surface is divided into these 12 overlapping sub-regions. In this research, they are called top view region (which is captured from the north pole of the ball), bottom view region, and other regions, as shown in Fig. 5. On top and bottom positions, two cameras are installed to capture images. They are top camera and bottom camera. Two other cameras, which are front top and front bottom, are enabled to capture images of other regions by integrating with stepping motor.

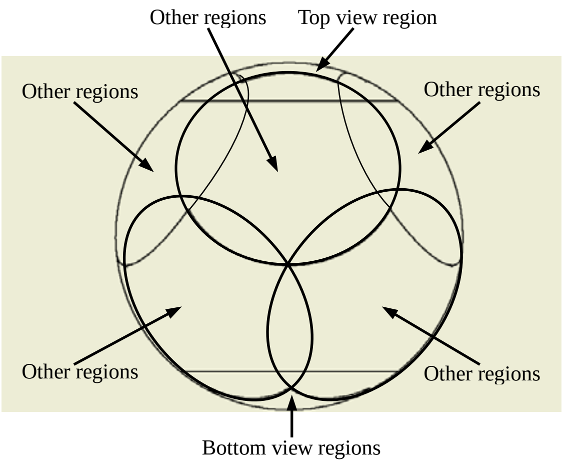


Fig.5 Diagram of multi-view image capture for spherical surface.

The sizes of captured images are determined by image clarity required by inspection quality and depth of field. The diameter of a typical golf ball is 43mm, which is the typical example in the design. To ensure image quality, a circular area is essential for image capture. In this research, the diameter of this circle is 26mm, ref. Fig. 3. The image quality within the specified circle is deemed to be acceptable for further application.

To reduce the numbers of image that needs to capture, the optical axis of the front top camera has to tilt 30° downwards, which is at a 60° inclination angle. The optical axis of the front bottom camera has to tilt 30° upwards, which is at a 60° inclination angle. When images of other regions are being captured, it is essential that the 10 regions are 36° apart by longitude. Consequently, the 10 positions are at 0°/360°, 36°, 72°, 108°, 144°, 180°, 216°, 252°, 288°, 324°.

When the golf ball is at 0° longitude, front top camera captures one image. At 36° longitude, another image is captured by front bottom camera. At 72° longitude, one more image is captured by front top camera, and so forth. Front top and front bottom cameras take turn to capture images every 36° until stepping motor rotates the ball once, and 10 images are captured. When the golf ball is transferred to the last stage where top and bottom cameras are in place to capture top-view and bottom-view images simultaneously, which also completes the process of capturing the total of 12 images.

Image Stitching and Fusion

The captured images are arranged based on camera locations and capture sequence. At 0° longitude when stepping motor has not started, the image captured by front top camera is numbered "1." The image captured by front bottom camera at 36° longitude is numbered "2." The image captured by front top camera at 72° longitude is numbered "3." The image captured by front bottom camera at 108° longitude is numbered "4," and so forth. The images captured by the two cameras in turn at 144°, 180°, 216°, 252°, 288°, 324° longitude are numbered "5, 6, 7, 8, 9, 10." The images captured by top and bottom cameras are numbered "11," "12," respectively. A total of 12 images are captured. After the 12 images are captured and processed, what follows is to stitch them together. The images captured at other regions have to be stitched onto their adjacent ones; the two images captured from top and bottom also have to be stitched together.

In order to improve the surroundings in which multiple images are captured, and to deal with the uneven light intensity problem, the images stitched together need fusion processing. If the value of a pixel in an image after fusion is "V"; the number of areas stitched together is "n"; the fusion weighting of the i-th subarea is "Wi." The value of the image pixel in the i-th subarea before fusion is "Vi." The arc length from an image pixel after fusion to the center in the i-th subarea is "Di." D_1, D_2, and D_3 are the arc lengths from V to the image centers C_1, C_2, C_3. The formula of image fusion is as follows:

$$\mathrm{V} = \sum_{i=1}^{n} \mathrm{W}_i \, \mathrm{V}_i \quad \text{--(2)}$$

$$\mathrm{W}_i = \frac{\frac{1}{\mathrm{D}_i}}{\sum_{j=1}^{n}\frac{1}{\mathrm{D}_j}} \quad \text{--(3)}$$

$$\mathrm{W1} + \mathrm{W2} + \mathrm{W3} = 1 \quad \text{------------------------------------(4)}$$

As shown in Fig. 6, for the value of a pixel, its weighting becomes greater as it is located closer to image center. Greater weighting means greater influence on pixel value after fusion. To facilitate image fusion for the spherical surface, this study employ plane coordinate system that expended from spherical surface. The expanded plane coordinate is a 2D coordinate system, where the horizontal axis represents the ball's azimuth ($0^o \leqq \theta \leqq 360^o$), the vertical axis represent the ball's angle of inclination ($0^o \leqq \phi \leqq 180^o$). The 0^o isoclinic line represents north pole, the 180^o isoclinic line represents south pole, the 90^o the equator. When all isoclinic lines are straightened, they are a bunch of isometric segment all parallel to the horizontal axis. The real lengths of the segment vary according to their position, so that the line gets shorter when it is closer to the north pole, and its extension ratio becomes greater, as shown in Fig. 7.

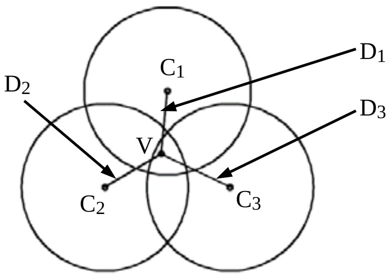


Fig.6 Diagram of image overlapping areas from 3 view angles.

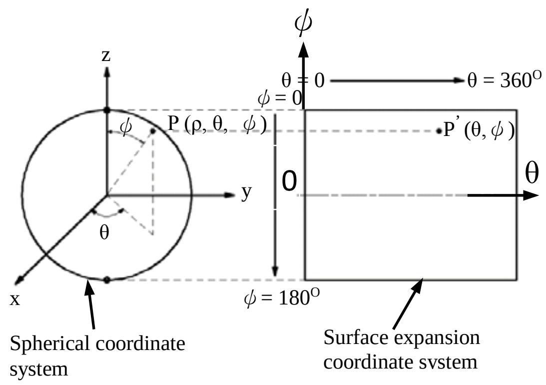


Fig.7 Spherical coordinate and the expanded coordinate.

EXPERIMENTAL RESULTS AND DISCUSSION

Experiment Equipment

A real machine for golf ball surface inspection is designed, fabricated, and assembled, as shown in Fig. 8. PLC and LabVIEW are used for automatic control. The electric control box and wiring also need to be designed and fabricated. A general-purpose computer is in charge of image processing and capture, and overall machine operation.

The automatic control circuit consists of pneumatic cylinders, stepping motor, and CCD cameras. User interface is a button panel implemented with LabVIEW, and is operated on a computer. “Manual” and “Auto/Manual” are the two modes designed for this machine. When all parameters are correctly set under manual mode, it may be switched to automatic mode.

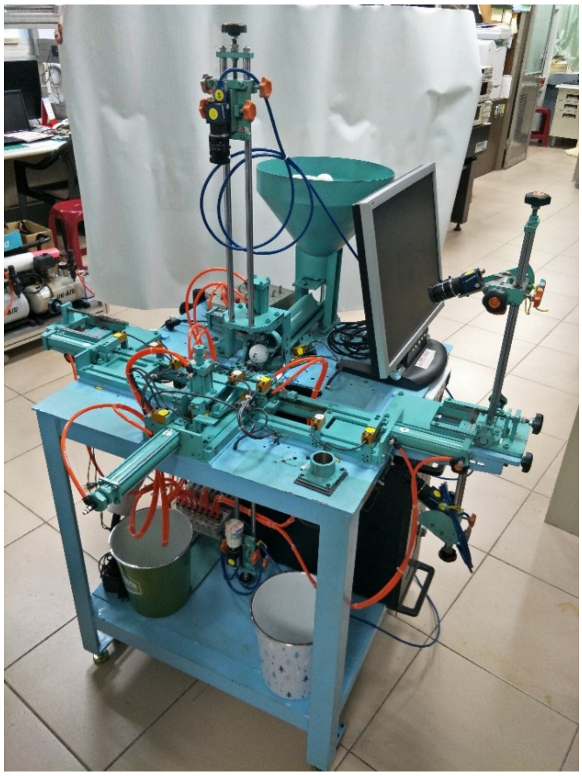


Fig.8 The overall drawing of the whole machine.

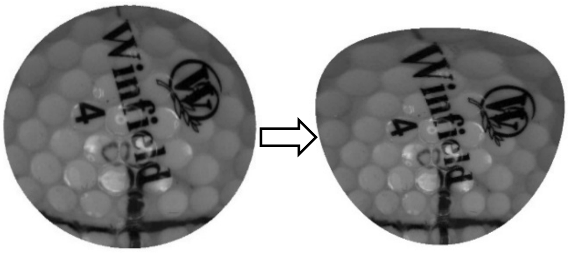
Experimental Procedure

Fill the hopper with golf balls and follow the following steps to do the experiment: (1) Open hopper gate and let balls fall to inspection track until balls reach track gate. (2) Open track gate and let ball fall to the positioning spot of stage 1. (3) Clamp the ball securely. (4) Capture images at stage 1. (5) Transfer the ball from stage 1 to stage 2. (6) Capture images at stage 2. (7) computer processing.

Experimental results

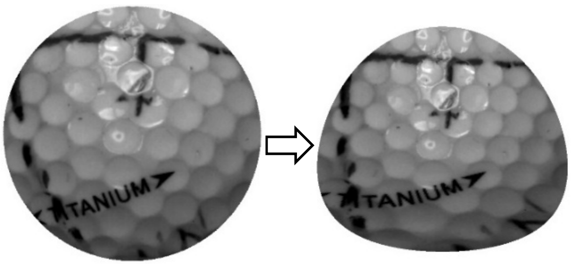
The 4 CCD digital color cameras used in this study have the resolution of 640x480. They are fitted with 35mm lenses. The working distance is 450mm. It connects computer through a USB3.0 cable, offering H40xV30 field of view images. Under this field of view and owing to the depth of view limitation, image quality off the center circle becomes out of focus. We have the brief information about image stitching and fusion in the following paragraphs:

The image in Fig.9 (a) is a partial circular clear image captured from view angle 1. The image in Fig.9 (b) is the expanded image corresponding to its ball surface. Fig.10 (a)/Fig.10 (b) and Fig.11 (a)/Fig.11 (b) are the expanded images captured from view angle 2 and 11. Expand the mages captured from different view angles may produce different contours. As mentioned earlier, when an isoclinic lines is closer to the north pole, its extension ratio becomes greater. That is to say, when image is expanded, the part closer to the north pole has greater deformation. In Fig.9 (a), the upper part of the image captured from view angle 1 is closer to the north pole. When this part is expanded, greater curvature in the image can be seen (close to a straight line). The lower part is closer to ball center, therefore the curvature is little when it is expanded. In Fig.10 (a), the upper part of the image captured from view angle 2 is closer to ball center; the lower part is close to the south pole. When it is expanded, the characteristic is just opposite to that from view angle 1. The image in Fig.11 (a) is captured from view angle 11, which is directly above the north pole. When it is expanded the lines at top and bottom are straight. The image looks a rectangle.



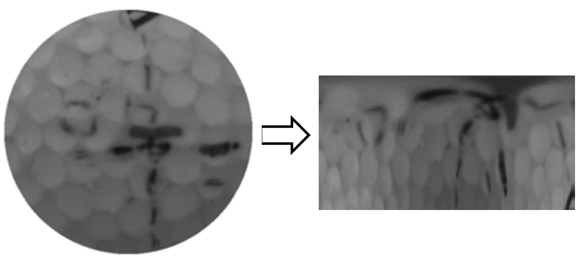
(a) View angle 1 (b) Expansion image of view angle 1

Fig.9 Image captured from view angle 1, and its expanded image.



(a) View angle 2 (b) Expansion image of view angle 2

Fig.10 Image captured from view angle 2, and its expanded image.



(a) View angle 11 (b) Expansion image of view angle 11

Fig.11 Image captured from view angle 11, and its expanded image.

After the images captured from view angle 1 and 2 are expanded to rectangular coordinate system, they are stitched together, as shown in Fig.12. Light intensity on different images will vary with different view angle. When they are stitched together, unreal image boundary on stitched area becomes visible due to light intensity difference. The unreal image boundary can be eliminated by using the fusion equation (2)-(4) introduced in this research. Image of real ball surface can then be obtained after that. The image in Fig.13 is the fusion of images expanded from view angle 1 and 2. The image in Fig.14 is the fusion of images expanded from view angle 1 and 3. The fusion equation introduced in this study can be applied to multiple images fusion. What we see in Fig.15 is the fusion of the 3 images expanded from the 3 different view angles. To obtain the image of the whole ball surface, 12 images from different view angles have to be processed with image fusion. The image in Fig.16 is the result of image fusion done on the images expanded from 12 view angles. The image after fusion is presented in 3D spherical format, as shown in Fig.17. They are presented from 4 different viewpoints. Adding lines with hand on ball surface to check the perfect stitch can confirm the quality of fusion result. The lines can be used to confirm perfect image alignment. They can also be used to highlight the errors between machine calibration and original design on view angles and positioning. Calibration needs to be done only once. After that the following cases are free to run. A number of cases are done in this study, only one case is shown in Fig.17.

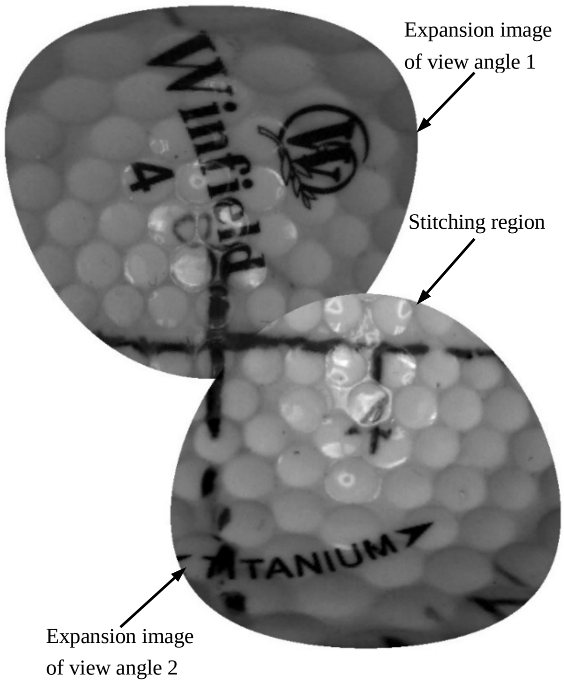


Fig.12 The Expanded and stitched image from view angles 1& 2.

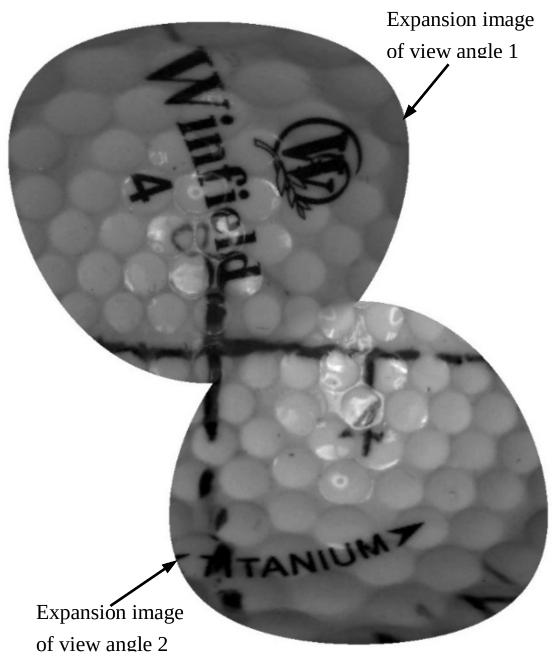


Fig.13 The fusion image of expanded images from view angles 1& 2.

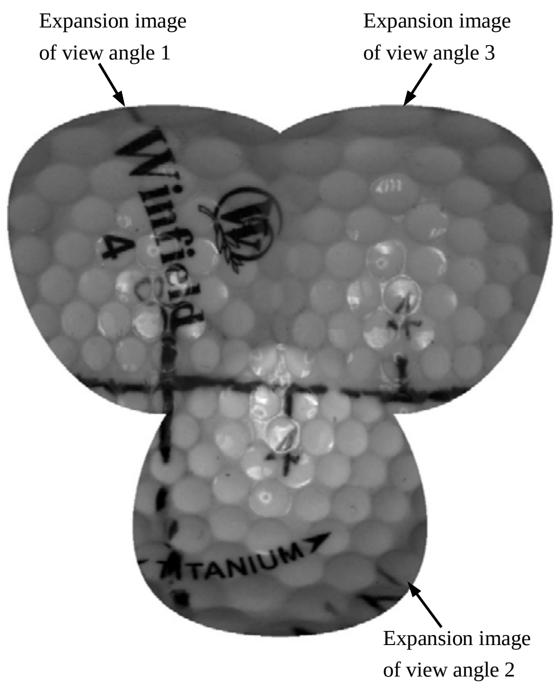


Fig.15 The fusion image of expanded images from view angles 1 & 2 & 3.

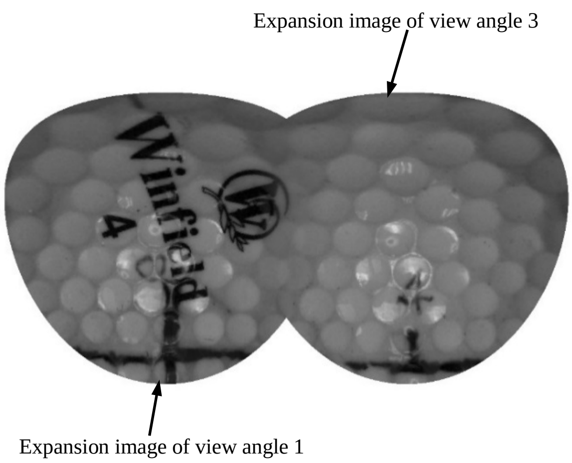


Fig.14 The fusion image of expanded images from view angles 1& 3.

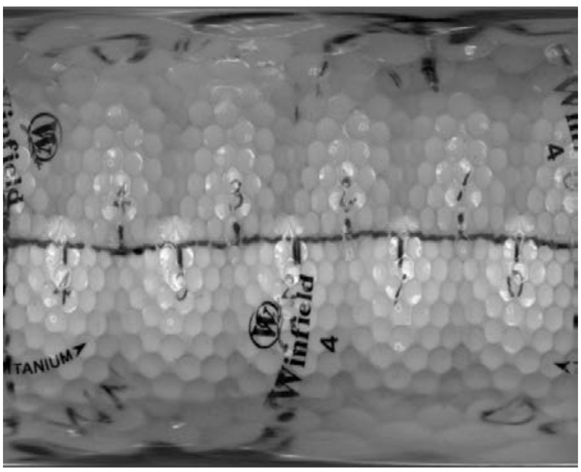


Fig.16 A complete ball fusion image from multiple expanded ones.

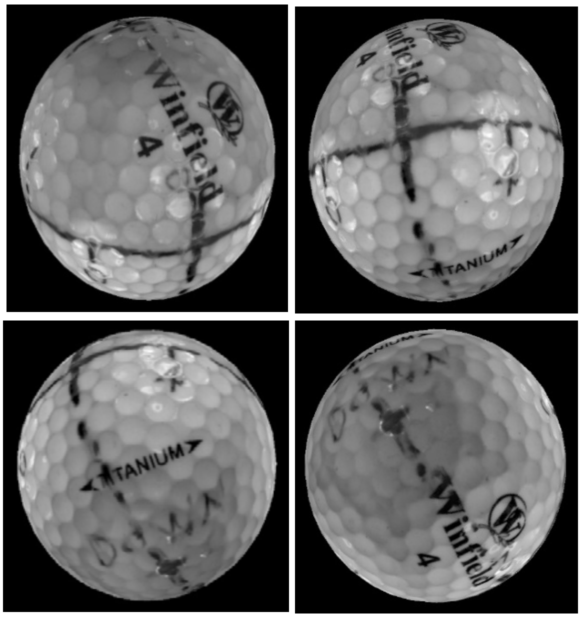


Fig.17 The fusion image of a complete ball from four viewpoints.

Discussion

1. It is difficult for vision technology to do 3D non-contact detection because the complete spherical surface image cannot be captured in one shot. This study uses a multi-view image capture and image fusion machine to do quality inspection.

2. Capturing overlapping images is easy for 2D object. However, capturing image of spherical object is a 3D issue, which is subject to depth of field limitation on cameras. To obtain complete image of a whole ball, the images captured will overlap. The design of image overlapping is the primary mission of this research. The stitched images need image fusion to improve the different surroundings where images are captured, and solve the problem of uneven light intensity. The images to be processed by image fusion are captured with multiple identical cameras. Images from different view angles are processed with image fusion according to pixel weighting average. For the value of a pixel, its weighting becomes greater as it is located closer to image center. Greater weighting means greater influence on pixel value after fusion. To facilitate image fusion for the spherical surface, this study employ plane coordinate system that expended from spherical surface. The expanded coordinate system is a 2D coordinate system.

3. Inspection of spherical objects is not a hot topic in previous literature. It is time-consuming in most cases. Machine accuracy is another issue that makes it less successful. Given the shortcomings in previous literature, we intend to improve it by employing accurate positioning and fusion technology in this research.

4. The systems designed in this study include 2-stage positioning for golf ball, CCD camera installation, 2-stage image capture and fusion, computer analysis, and product packaging. Two sets of ball positioning fixture, and front top, front bottom CCD cameras positioning and calibration fixture are also important to this research.

5. Under normal lighting, most ball surface will cause light to produce concentration effect. Given that dimples scatter throughout the surface, which is also covered with varnish layer, brightness noise will reflect off the surface under lighting. As a result, the captured images could be unable or hard to process. To resolve this problem, we design two sets of lighting sources with adjustable lighting and shade. There are two positioning stages for golf ball, and four cameras at four different places to capture images. For this reason the light intensity on every image could be uneven, and these are the things we can further improve.

6. When images are stitched together, unreal image boundary on stitched area becomes visible due to uneven light intensity. The unreal image boundary can be eliminated by using the fusion equation (2)-(4) introduced in this research. The image quality after fusion can be confirmed by checking the lines drawn on ball by hand. The perfect match between the lines from Fig.12 to Fig.16 is the answer. The lines drawn by hand can also be used to check the results of machine calibration and view angles positioning errors.

7. In one motion cycle of this machine, CCD cameras capture 12 images. After the process of image stitching and fusion, the following steps of image positioning and template matching can help identify good and defective products. They are sorted into different packages. The goal of fast and automatic quality inspection is achieved.

REFERENCES

Boby, R.A., Sonakar, P.S., Singaperumal, M., and Ramamoorthy B., Identification of defects on highly reflective ring components and analysis using machine vision. Int J Adv Manuf Technol 52:217–233 (2010).

Chen, J., Yang, D., Zhou, H., and Backley, S. “Avoiding Spurious Reflections from shiny Surfaces on a 3D Real-time Machine Vision Inspection System,” IEEE Instrumentation and Measurement Technology Conference, St. Paul, Minnesota, USA 18-21 May (1998).

Chung, S.M., “On the positioning the orientation of a golfball using image servoing control,” a master’s thesis, Kun Shan University, Tainan, Taiwan (2005).

Dong, J., Zhuang, D., Huang, Y., and Fu J., “Advances in Multi-Sensor Data Fusion: Algorithms and Applications,” Sensors, 9, 7771-7784 (2009).

Killing, J., Surgenor, B.W., and Mechefske, C.K., “A machine vision system for the detection of missing fasteners on steel stampings," Int. J. Adv. Manuf. Technol. 41:808–819 (2009).

Krishnamoorthy, S., Soman, K.P., "Imple-mentation and Comparative Study of Image Fusion Algorithms," International Journal of Computer Applications (0975 – 8887) Volume 9– No.2, November (2010).

Lin, K.C., Chang, M.F., "Drawing, Letter, Logo, and image contour matching on Golf Ball Surface," the proceedings of the 20th mechanical engineering conference, National Taiwan University, Taipei, Taiwan (2003).

Malviya, A., Bhirud, S.G., "Image Fusion of Digital Images," International Journal of Recent Trends in Engineering, Vol 2, No. 3, November (2009).

Qiang, G., Shanshan, Z., Yang, Z., and Mao, C., "Detection method of PCB component based on automatic optical stitching algorithm," Circuit World, Vol. 41 Issue: 4, pp.133-136 (2015).

Rani, K., Sharma, R., "Study of Different Image fusion Algorithm," International Journal of Emerging Technology and Advanced Engineering, Volume 3, Issue 5, May (2013).

Rosati G., Boschetti G., Biondi A., and Rossi A., "Real-time defect detection on highly reflective curved surfaces," Optics Lasers Eng. 47, 379–384 (2009).

Sonka, M., Hlavac, V., and Boyle, R., Image Pro cessing, Analysis, and Machine Vision, Thomson Learning, Toronto, Canada, 3th ed. (2008).

Zhu, S., Gao, Y., "Noncontact 3-D coordinate measurement of cross-cutting feature points on the surface of a large-scale workpiece based on the machine vision method," IEEE Trans. Instrum. Meas., vol. 59, no. 7, pp. 1874-1887, July (2010).

高爾夫球表面多視角影像擷取機台設計及擷取影像融合處理

林穀欽 胡福文

崑山科技大學 機械與能源工程研究所

摘要

視覺應用於三維球形物體檢測之困難處在於影像擷取以及融合後處理等技術。本研究設計多視角影像擷取之一自動化機台，本機台包括：一檢測球儲備裝置，兩組球定位控制機構，一組球旋轉機構，四台 CCD 攝影機視角可調機構以及照明裝置等。本機台採 PLC+PC 可程式化控制全機的操作及影像擷取時序，透過 LabVIEW 軟體實施數位化影像擷取、座標轉換分析及影像融合技術應用，可獲得高爾夫球之完整的全球影像，以利後續之球品檢測。本研究技術可應用於高爾夫球、壘球及各類球體之自動化球表面檢測。