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# Angle calculation method based on Cognex binary image processing and edge tool positioning

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**Abstract.** Aiming at the problem of no suitable measurement method for the angle between a product's upper and lower cylinder axes in a specific horizontal rotation position, a calculation method based on the Cognex vision system for automatic angle measurement was proposed. This algorithm uses binary image processing technology to reduce interference in product implementation caused by variations in surface roughness and resulting inconsistencies in the reflection effect. The ability to perform robust image feature searching is thereby built upon. It utilizes edge tools to locate the points on either side of a cylindrical product and compute the axial coordinate for averaging the measured axes at these positions to determine each product element's upper and lower axial angle measurement. Simulation results show that this algorithm utilizes binary image processing to effectively filter product differences, which plays a role in capturing product image features continuously and reliably. The edge tool based on feature location can accurately locate product edges and complete target angle calculations. It has certain production field application capabilities regarding image processing effectiveness and computational logic accuracy.

**Keywords:** Machine vision, Binary image processing, Edge detection.

## 1. Introduction

### *1.1. Background*

In the end-to-end supply chain system, how to quickly, reliably, and at a relatively low cost of converting product designs into actual goods that consumers can use has become a vital issue for business.

Previously, companies relied on manual inspection and measurement to ensure that products released to the market meet established quality requirements. In order to increase output, this practice begins to consume a large amount of labor, resulting in high costs for businesses, as well as the disruption of factors such as skill proficiency and differences in cognitive abilities, leaving doubt whether the final product complies 100 % with the standard.

Since the 21st century, the continuous development of machine vision technology is changing this situation. As people continue to explore and study the field of machine vision, several mature visual development tools have emerged, encapsulating many reliable and efficient algorithms and tools. Conducting secondary development based on this software can ensure the reliable operation of the system, shorten development cycles and reduce time costs.

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### *1.2. Concept, Composition and Characteristics of Machine Vision System*

Machine vision is a comprehensive technology that integrates and organically combines image processing, computer graphics, pattern recognition, computer technology, artificial intelligence, and many other disciplines. Machine vision is the science and technology of simulating the macroscopic visual functions of biological organisms using computers or other processors, that is, using machines to replace human eyes for measurement and judgment.

The machine vision system consists of illumination part, image acquisition part, image display part, and image processing part. Generally, a CCD camera is used to capture images and convert them into digital signals, which are then processed to obtain various target image feature values required for pattern recognition, coordinate calculation, grayscale distribution diagrams, and other functions. Then, based on the results, it displays images, outputs data, sends instructions, and cooperates with the executing mechanism to complete automated processes such as position adjustment, quality screening, and data statistics [1].

There are many disciplines with research goals similar or related to machine vision, including image processing, pattern recognition or image recognition, image understanding and so on. Due to historical development or the characteristics of the field itself, these disciplines have some degree of overlap. However, machine vision has certain differences from other disciplines, which are characterized by:

Comprehensive technology: Machine vision is a comprehensive technology, including digital image processing technology, mechanical engineering technology, control technology, electric lighting technology, optical imaging technology, sensor technology, analog and digital video technology, computer software and hardware technology, human-computer interface technology, etc. These technologies are in a parallel relationship in machine vision, and they need to be applied in coordination to form a successful industrial machine vision application system.

Focusing on industrial reliability: Machine vision focus on reliability in industrial field environments, requiring adaptability to harsh industrial production environments, high fault tolerance and safety, and not damaging industrial products.

Focusing on practicality: Machine vision focus on practicality, requiring reasonable cost-effectiveness, universal industrial interfaces, and the ability to be operated by ordinary workers. It must have strong versatility and portability.

Require high speed and high precision: Due to the high speed and high accuracy requirements of machine vision, many new algorithms in digital image processing are currently difficult to apply. Therefore, the actual application speed of machine vision technology in industrial production lags far behind the development speed of image processing theory.

### *1.3. Application and Development of Machine Vision System*

Machine vision systems are highly reliable in high-speed, subtle, and repetitive manufacturing processes, and are widely used in processing and manufacturing enterprises to complete repetitive inspection tasks in high-volume production processes. The application of machine vision in quality inspection accounts for nearly 80% of the entire industrial application, with the largest application industries being: automotive, pharmaceutical, electronics and electrical, manufacturing, packaging, food, beverage, etc. Machine vision inspection is a non-contact and non-destructive inspection method that has irreplaceable advantages compared to traditional inspection methods and has been widely applied.

The development of computer vision (i.e. machine vision) in recent years is mainly manifested in the following three aspects:

One of the research goals of computer vision is to enable machines to perceive geometric information about objects in a three-dimensional environment, including their shape, position, pose, motion and so on. Since the mid-1990s, the computer vision community has systematically introduced descriptions of correspondence and projective geometry, affine geometry, and Euclidean geometry into visual computing methods, which correspond perfectly to the coarse-to-fine description of objects in the visual system. This reduces the requirement for understanding the parameters of the camera system in computer vision systems and improves the robustness of the system to noise.

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Machine learning methods are receiving increasing attention. There are always two branches in all areas of pattern recognition: structure-based and statistics-based. If we say that geometric-based computer vision mainly describes the three-dimensional structure of objects and their motion through geometry, it belongs to structural methods and has been systematically studied; Statistical methods in computer vision, besides being well-suited for low-level image processing, have always been imperfect, not to mention systematic.

The application research in many specific fields is constantly deepening, and large-scale application systems are gradually moving towards commercialization. With the rapid improvement in the cost-performance ratio of current computers, the commercialization of real-time computer application systems in many specific fields has become possible. For example, using fingerprint, iris, face, voice recognition technology, behavior recognition technology, motion tracking technology, and multi-camera fusion technology to form a visual monitoring system for information security, intelligent transportation, anti-terrorism and anti-theft, identity authentication, etc.[2].

## 2. Methodology

This article uses Insight vision software for an industrial camera developed by the American company Cognex that integrates hardware systems such as task program memory, image processing memory, and sensors. This vision system software development kit integrates tool libraries for tasks such as image processing, feature localization, measurement computing, and protocol communication, allowing users to conduct secondary development on top of this foundation. Next, the software development for product perspective calculation will be conducted based on Insight Vision software and its tool library [3].

### *2.1. Vision System Hardware System*

Camera: The selected industrial camera in this experiment is Cognex In-Sight 1403 from the In-Sight Micro Vision System. The specific parameters are listed in Table 1:

**Table 1.** Specification for Camera In-Sight 1403

| Specification | | Parameter |
|---|---|---|
| **Memory** | Job/Program | 64MB non-volatile flash memory; unlimited storage via a remote network device. |
| | Image Processing | 128MB |
| **Image** | **Sensor** | **1/3-inch CCD** |
| | Sensor Properties | 5.92mm diagonal, 7.4 x 7.4µm sq. pixels |
| | Resolution (pixels) | 640 x 480 |
| | Electronic Shutter Speed | 16µs to 1000ms |
| | Acquisition | Rapid reset, progressive scan, full-frame integration. |
| | | 256 grey levels (8 bits/pixel) |
| | | Gain/Offset controlled by software. |
| | | 14 full frames per second |
| | Lens Type | CS-mount and C-mount (with 5mm extension included) |
| | CCD Alignment Variability | ±0.127mm (0.005in), (both x and y) from lens C-mount axis to the center of the image. |
| **I/O** | Trigger | 1 opto-isolated, acquisition trigger input. |

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**Table 1.** (continued).

| Specification | | Parameter |
|---|---|---|
| | | Remote software commands via Ethernet. (RS-232C is available when using the optional CIO-MICRO or CIO-MICRO-CC I/O module.) |
| | Discrete Inputs N | None. (Eight additional inputs are available using the optional CIO-MICRO, CIO-MICRO-CC or CIO-WENET (750-341) I/O module.) |
| | Discrete Outputs | 2 opto-isolated, NPN/PNP high-speed outputs. (Eight additional outputs are available when using the optional CIO-MICRO, CIO-MICRO-CC or CIO-WENET (750-341) I/O module.) |
| | Status LEDs | Network, 2 user-configurable. |
| **Communications** | Network | 1 Ethernet port, 10/100 BaseT with auto MDI/MDIX. Supports DHCP (factory default), static and link-local IP address configuration. |
| | Serial | None. (RS-232C: 1200 to 115,200 baud rates when connected to a CIO-MICRO or CIO-MICRO-CC I/O module). |

Lens: The lens selected for this time is the Fujinon high-definition lens HF12. 5HA-1B, with specific parameters listed in Table 2:

**Table 2.** Specification for Lens HF12.5HA-1B

| Specification | Parameter |
|---|---|
| Resolution | 1,500,000 |
| CCD Size | 2/3" |
| Focal Length | 12.5mm |
| Aperture Range | F1.4-F16 |

Light: The selected light source is ADVANCED ILLUMINATION BL0202-660-2 and SL-2420-660-100L, and its specific parameters are listed in Table 3:

**Table 3.** Specification for Light BL0202-660-2/SL-2420-660

| Specification | Parameter |
|---|---|
| Peak Wavelength | 660 |
| 24V Current | 0.03A per sq. inch |

Wiring diagram is designed per below Figure 1. POE power supply with 110-250 VAC is used for camera and 2 pieces of CS100 power supply with 24 VDC are used for light.

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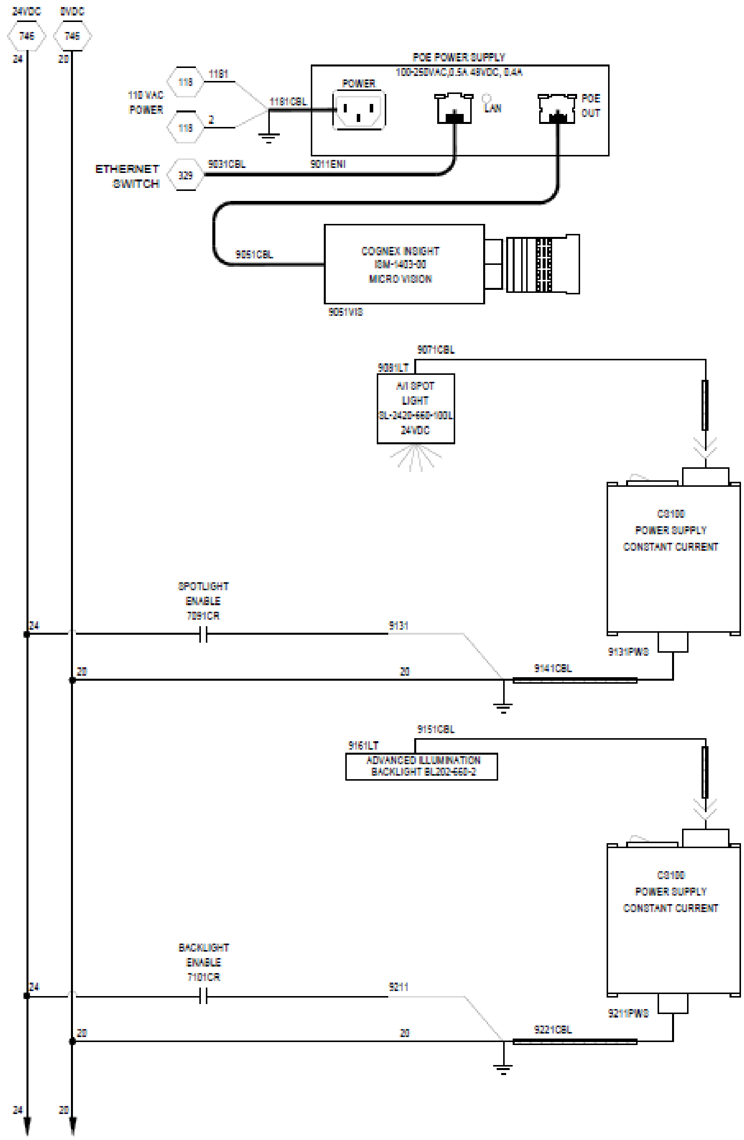


**Figure 1.** Wiring Diagram

### *2.2. Vision System Software*

This experiment adopts Cognex Insight Explorer Version 4. 9. 0 for software development.

Through the establishment of the hardware system, the product image captured is as follows (Figure 2). The upper structure of the product within the blue box and the lower structure within the green box are both cylindrical structures. During the visual inspection, the cylindrical structure rotates 360 degrees around its axis. When the product feature of the Bent Tab in the red box appears in the camera field of view, the calculated angle between the upper and lower cylinder axes is sent to the host computer [4].

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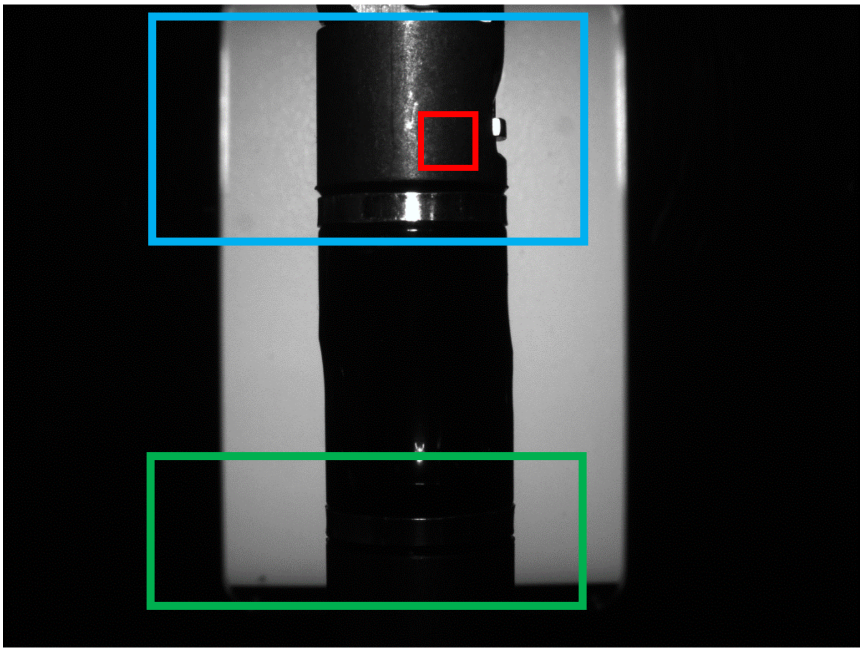

**Figure 2.** Product Image

### *2.2.1. Reference Point Location*

During the rotation, the product will continue to undergo slight movements and changes up, down, left, and right. Considering the precise positioning and calculation of subsequent edge tools, it is first necessary to analyse the image within the camera's field of view and locate the X and Y coordinates of the image reference point that moves with the product.

X-axis coordinate: Find the vertical line on the bottom left side of the product and take the X coordinate value of the vertical line as the reference point X coordinate [5]. Refer to Figure 3.

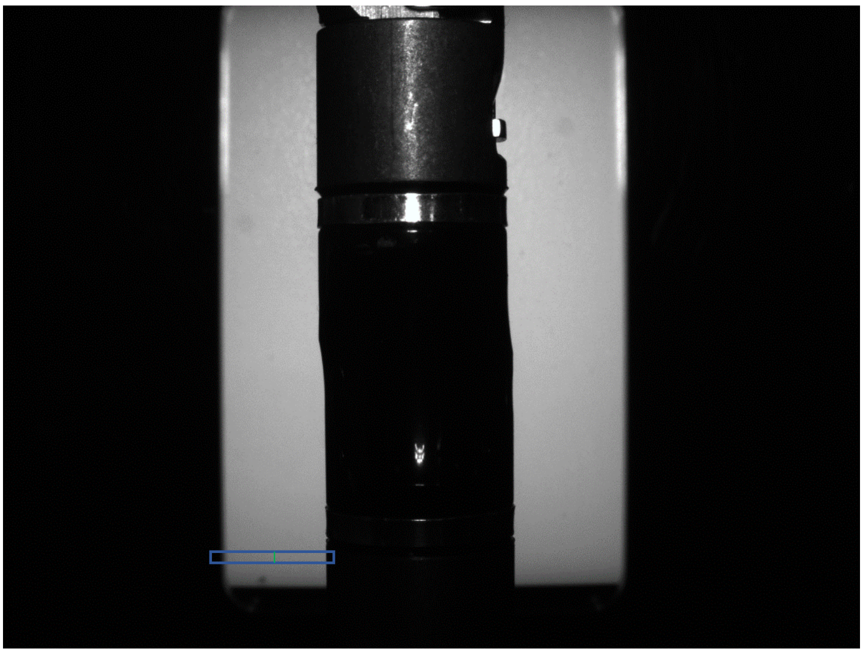

**Figure 3.** X-axis coordinate

Y-axis coordinate: Find the horizontal line below the metal ring on the product and take the Y coordinate value of the horizontal line as the reference point Y coordinate.

During the experiment, it was noticed that the surface roughness of the metal ring differed, resulting in inconsistent reflection effects of light sources on its surface, with the reflective area not having sharp edges and significant fluctuations in the Y-axis coordinates. Therefore, binary processing was applied to the image [6].

Image binarization refers to a common method for studying grayscale images using grayscale transformation, which sets a threshold value to divide the pixels of a grayscale image into two groups: pixels that are larger than the threshold value and pixels that are smaller than the threshold value [7]. For example, if the input grayscale image function is f (x, y) and the output binary image function is g (x, y), then

$$g(x, y) = \begin{cases} 0 & f(x, y) < \text{Threshold} \\ 255 & f(x, y) \geq \text{Threshold} \end{cases}$$

Threshold is a ruler that separates objects from backgrounds. Choosing an appropriate threshold is to preserve image information as much as possible while minimizing the interference of backgrounds and noise, which is the principle of choosing a threshold. The binary processing of an image is to set the grayscale of the points on the image to 0 or 255 [8], which results in a clear black-and-white image across the image. That is, a binary image that still reflects the overall and local characteristics of the image is obtained by selecting an appropriate threshold value for 256 grayscale images with varying intensity levels [9].

In this experiment, the threshold value was set to 20. As can be seen from the following image (Figure 4), the edge of the reflective area is displayed clearly through binarization. This helps the edge tool perform a more accessible and more accurate search of the underlying edge's horizontal lines [10].

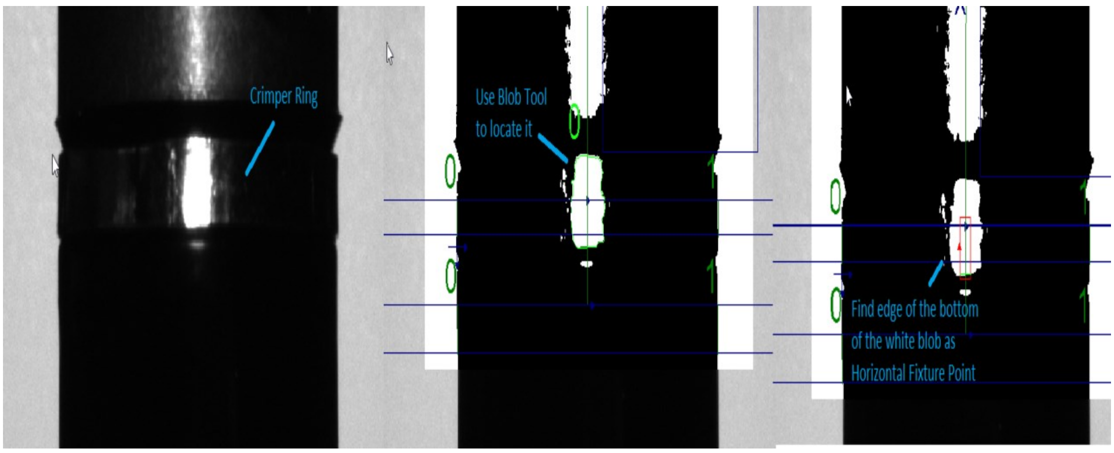


**Figure 4.** Image Binarization for Product

The X and Y coordinates of the final reference point can serve as a reference point for tools during the angle calculation process, making the positioning of tools more accurate and efficient.

*2.2.2. Angle Calculation*

The experiment uses the Find Pattern tool to detect Bent tabs. Rotate the product to the location in the figure below and train the Model Region in the Find Pattern tool to match scores greater than or equal to 80. To ensure that the calculated angle is valid and transferred back to the host computer only when the matching score is greater than or equal to 80 during actual operation [11]. Refer to Figure 5 for reference.

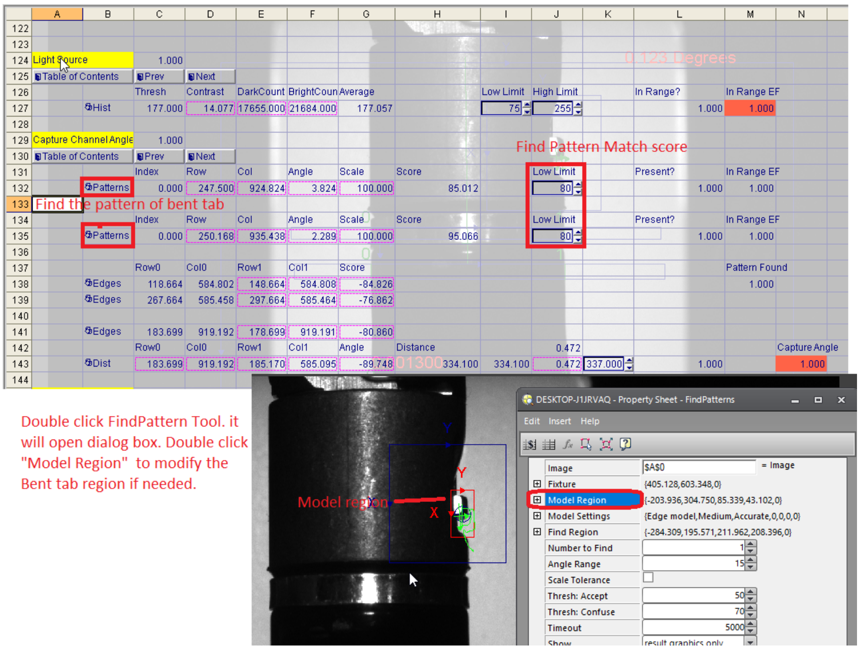


**Figure 5.** Bent Tab Detection

Next, use the edge tool to search the edges of the product on both sides of the upper cylinder and obtain four coordinate points: A (Xa, Ya), B (Xb, Yb), C (Xc, Yc), and D (Xd, Yd).

So the coordinates of two points E and F on the axis are respectively

$$Xe=(Xa + Xb)/2; \ Ye=(Ya + Yb)/2$$

$$Xf=(Xc + Xd/2); \ Yf=(Yc + Yd)/2$$

The straight line formed by these two points is the axis of the upper cylinder. Refer to Figure 6 for reference.

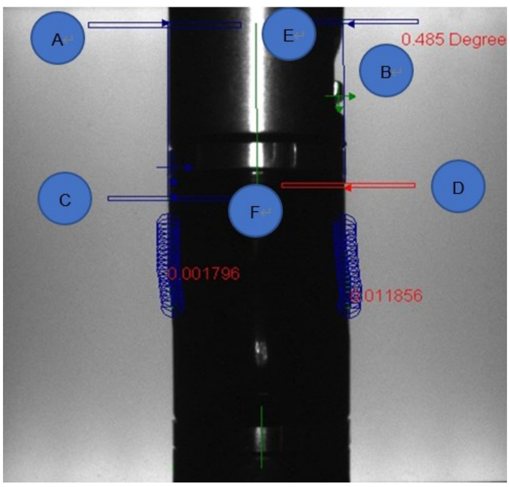


**Figure 6.** Upper Cylinder Axis Calculation

Use the angle calculation tool PointToPointAngle (Xe, Ye, Xf, Yf) to obtain the angle **Angle1** of the upper cylinder axis. Refer to Figure 7 for reference.

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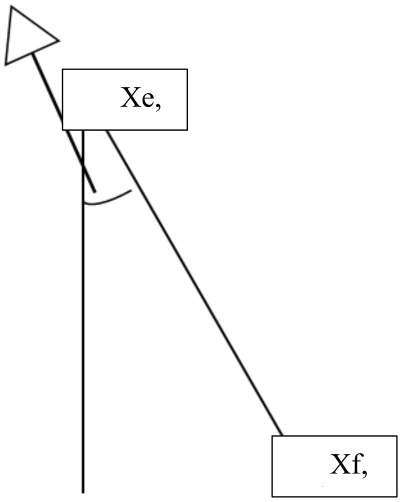


**Figure 7.** Upper Cylinder Axis Angle Calculation

Similarly, using the Edge Tool on both sides of the lower cylinder to find the product edges, four coordinate points are obtained: G (Xg, Yg), I (Xi, Yi), J (Xj, Yj), and K (Xk, Yk).

Therefore, the coordinates of the two points M and N on the axis are

$$Xm=(Xg + Xi)/2;\ Ym=(Yg + Yi)/2$$

$$Xn=(Xj + Xk/2);\ Yf=(Yj + Yk)/2$$

The line formed by the two points is the axis of the lower cylinder. Refer to Figure 8 for reference.

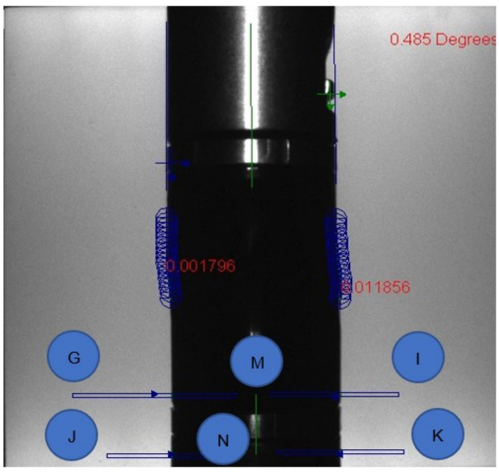


**Figure 8.** Lower Cylinder Axis Calculation

Use the angle calculation tool PointToPointAngle (Xm, Ym, Xn, Yn) to obtain the angle **Angle2** of the lower cylinder axis [12] [13]. Refer to Figure 9 for reference.

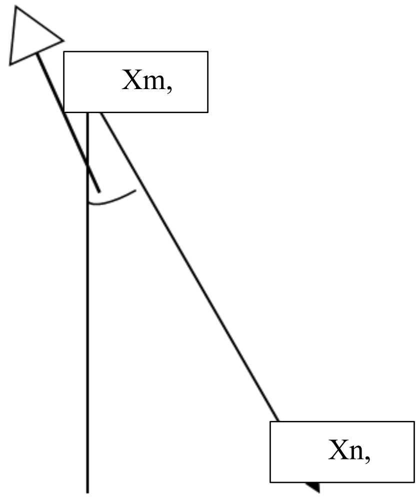


**Figure 9.** Lower Cylinder Axis Angle Calculation

**Angle3** is the angle between the two axes, **Angle3**=Abs (**Angle1** - **Angle2**).

## 3. Result

### *3.1. GRR Analysis*

In order to ensure this angle calculation method by using Cognex vision system with serval vision tools is suitable for its intended purpose, normally gauge repeatability and reproducibility study will be performed in determining this measurement system uncertainty and to specify requirements for qualification of gauging systems used to make quality decisions.

The GRR strategy is defined per Table 4 as below for this angle calculation method.

**Table 4.** GRR Strategy Summary

| GRR Category | Appraisers | Design | Trials | Samples per Trial | Total Test | Sample type |
|---|---|---|---|---|---|---|
| Variable Non-destructive | 3 | Blinded/ Randomized | 2 | 10 | 60 | 10 randomized sub-assembly picked from RM batch. |

Non-destructive GR&R study must be acceptable per criteria for success for variable data under evaluation (see Table below) [14] [15].

In terms of this GRR study, the blinded and randomized approach will be used. Every physical sample will be placed in Tray and the parts will be place in order from “01” to “10”. Before sample measurement, an individual associate will take the sample out and give it to inspector. After measurement, the individual associate will put the sample back to the tray,and measurement result will be recorded. This can ensure that inspector will be blinded with the sample order. 3 appraisers will measure 10 parts with 2 times and this sampling plan provides enough degrees of freedom to consider the reliability of the study of repeatability and reproducibility.

### *3.2. GRR Acceptance Criteria*

Non-destructive GR&R study must be acceptable per criteria for success per Table 5 below for variable data.

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**Table 5.** GRR Acceptance Criteria

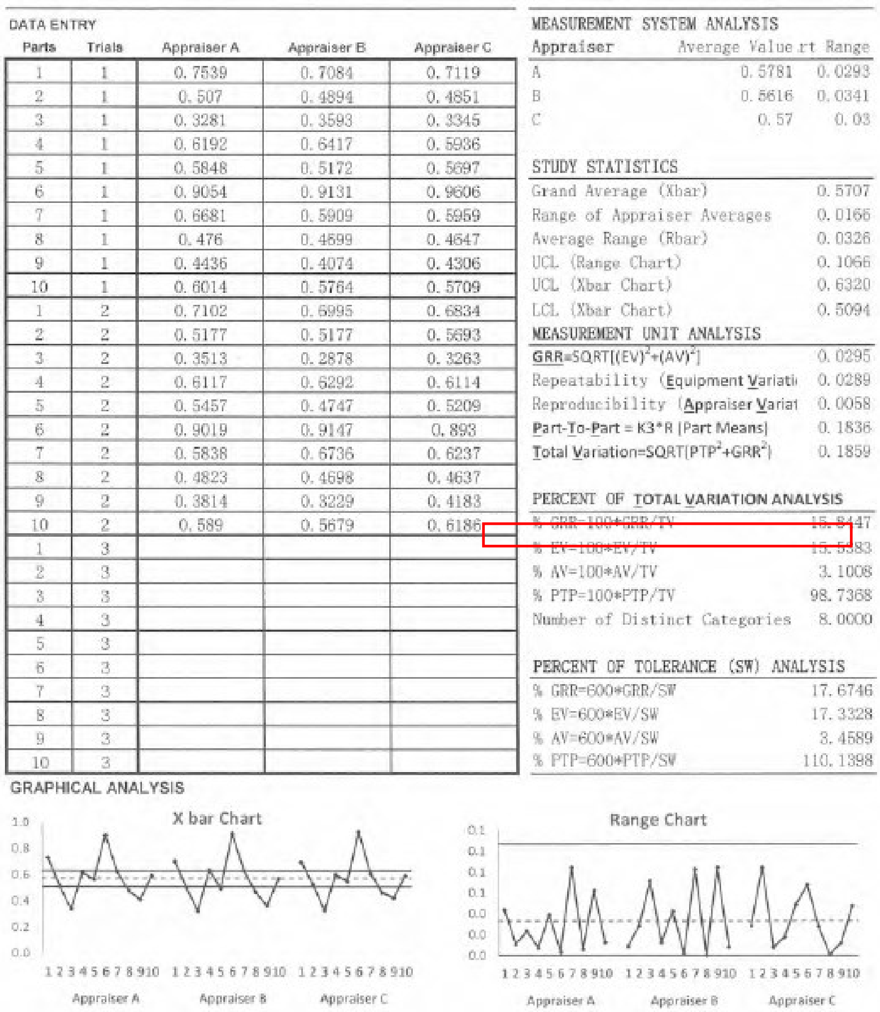
| | |
|---|---|
| Percent R&R / % Study Var is < 10% | This measurement system is acceptable |
| Percent R&R / % Study Var is ≤ 30% | The measurement system may be acceptable based upon the importance of the application, cost of the gauge, repair cost, or other factors as determined and documented by the responsible function. As lower as better, identify additional opportunities for improvement. |
| Percent R&R / % Study Var is > 30% | The measurement system is unacceptable, and corrective action is required. |

[a] The number of distinct categories 【1.41(PV/R&R0)】 shall be 5 or more.

[b] Note: The acceptance percentage for R%R is based on 6 standard deviations of the gauging system. If 5.15 standard deviations are used in the numerator, then the acceptable R&R is 25%

### *3.3. GRR result*

The actual test result is as follows, see Figure 10 for GRR execution summary.



DATA ENTRY

| Parts | Trials | Appraiser A | Appraiser B | Appraiser C |
|---|---|---|---|---|
| 1 | 1 | 0.7539 | 0.7084 | 0.7119 |
| 2 | 1 | 0.507 | 0.4894 | 0.4851 |
| 3 | 1 | 0.3281 | 0.3593 | 0.3345 |
| 4 | 1 | 0.6192 | 0.6417 | 0.5936 |
| 5 | 1 | 0.5848 | 0.5172 | 0.5697 |
| 6 | 1 | 0.9054 | 0.9131 | 0.9606 |
| 7 | 1 | 0.6681 | 0.5909 | 0.5959 |
| 8 | 1 | 0.476 | 0.4699 | 0.4647 |
| 9 | 1 | 0.4436 | 0.4074 | 0.4306 |
| 10 | 1 | 0.6014 | 0.5764 | 0.5709 |
| 1 | 2 | 0.7102 | 0.6995 | 0.6834 |
| 2 | 2 | 0.5177 | 0.5177 | 0.5693 |
| 3 | 2 | 0.3513 | 0.2878 | 0.3263 |
| 4 | 2 | 0.6117 | 0.6292 | 0.6114 |
| 5 | 2 | 0.5457 | 0.4747 | 0.5209 |
| 6 | 2 | 0.9019 | 0.9147 | 0.893 |
| 7 | 2 | 0.5838 | 0.6736 | 0.6237 |
| 8 | 2 | 0.4823 | 0.4698 | 0.4637 |
| 9 | 2 | 0.3814 | 0.3229 | 0.4183 |
| 10 | 2 | 0.589 | 0.5679 | 0.6186 |
| 1 | 3 | | | |
| 2 | 3 | | | |
| 3 | 3 | | | |
| 4 | 3 | | | |
| 5 | 3 | | | |
| 6 | 3 | | | |
| 7 | 3 | | | |
| 8 | 3 | | | |
| 9 | 3 | | | |
| 10 | 3 | | | |

MEASUREMENT SYSTEM ANALYSIS

| Appraiser | Average Value | rt Range |
|---|---|---|
| A | 0.5781 | 0.0293 |
| B | 0.5616 | 0.0341 |
| C | 0.57 | 0.03 |

STUDY STATISTICS

| | |
|---|---|
| Grand Average (Xbar) | 0.5707 |
| Range of Appraiser Averages | 0.0166 |
| Average Range (Rbar) | 0.0326 |
| UCL (Range Chart) | 0.1066 |
| UCL (Xbar Chart) | 0.6320 |
| LCL (Xbar Chart) | 0.5094 |

MEASUREMENT UNIT ANALYSIS

| | |
|---|---|
| GRR=SQRT[(EV)²+(AV)²] | 0.0295 |
| Repeatability (Equipment Variati | 0.0289 |
| Reproducibility (Appraiser Variat | 0.0058 |
| Part-To-Part = K3*R [Part Means] | 0.1836 |
| Total Variation=SQRT[PTP²+GRR²] | 0.1859 |

PERCENT OF TOTAL VARIATION ANALYSIS

| | |
|---|---|
| % GRR=100*GRR/TV | 15.8447 |
| % EV=100*EV/TV | 15.5583 |
| % AV=100*AV/TV | 3.1006 |
| % PTP=100*PTP/TV | 98.7368 |
| Number of Distinct Categories | 8.0000 |

PERCENT OF TOLERANCE (SW) ANALYSIS

| | |
|---|---|
| % GRR=600*GRR/SW | 17.6746 |
| % EV=600*EV/SW | 17.3328 |
| % AV=600*AV/SW | 3.4589 |
| % PTP=600*PTP/SW | 110.1398 |



**Figure 10.** GRR Execution Summary

As it can be seen from the above graph, the GRR value is 15.8447%, which is lower than the required 30 % which is defined in Table 5. Based on the fact that the deviation in angle in the process was classified as a non-critical defect, this measurement system can be considered acceptable.

## 4. Conclusion

This article designs a measurement method for product angles in the production process based on the Cognex vision system, mainly focusing on the calculation of angles at specific rotational positions of the product. This method includes the selection of components for the vision system and the construction of the hardware architecture. It introduces the design process of the method and its qualification, and mainly completes the following items.

A brief introduction to the background, concept, composition, and characteristics of vision systems in industrial applications, describing their application and practical value in real-world fields, as well as their current development status and future directions.

List the parameters of each component of the hardware system in detail and the wiring diagram for this measurement system.

Detailed introduction of the angle measurement method for the product. First, the image is binarized to determine the reference point. Then, search for the features of the product. Finally, the angle with the specific rotation position of the product is calculated by using edge tools and angle calculation method.

Perform analysis on the repeatability and reproducibility of this angle measurement method. Result shows the method is stable and reliable through a designed test plan with test acceptance criteria. Overall, this measurement system achieves the initial design requirements.

The measurement system uses the Cognex vision system, which is currently common in the industrial field. Secondary development is conducted based on its underlying algorithm. It applies image binarization, edge detection, and other tools to complete the development of product angle measurement methods. It helps enterprises achieve high-speed and stable product automation testing, greatly reducing daily operating costs due to personnel input and product scrap, meanwhile it also reduces the possibility of defective products entering the end market and the resulting of reputation loss.

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