

Automating External Visual Inspection Using Collaborative Robot

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[Summary]

Efforts are in progress to automate production at our main Anritsu Tohoku plant. One plan is to investigate automation of finished instrument external inspection now done visually by quality inspectors. This article introduces development of a prototype system combining a collaborative robot and AI image processing for this inspection and presents some examples of automated external inspection results.

1 Introduction

Anritsu main product is measuring instruments that are manufactured mostly in Japan at its Tohoku Anritsu plant. To assure the accuracy of manufactured measuring instruments, various adjustments and inspections are made. Quality assurance (QA) requires experienced skilled workers but an ageing workforce and falling population will probably be securing sufficient employees difficult in future. To support recent changing market demands, it is necessary to abandon from labor-based production systems, and promotion of DX (digital transformation) to save labor and introduce automation is becoming a key approach.

2 Automating External Visual Inspection

2.1 Target Process

Figure 1 shows the measuring instrument production process at Tohoku Anritsu.

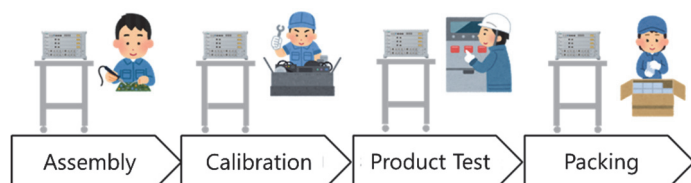


Figure 1 Measuring Instrument Production Process

Each instrument is assembled after picking the required parts. The next calibration stage makes each adjustment necessary to assure the measuring instrument function. Following calibration, the instruments are tested and inspected to confirm compliance with each specification, heat tested, and evaluated for performance. After passing all tests, they are packed and shipped.

This article explains the process of external visual inspection of finished products at the shipping inspection prior to shipment.

Since many types of measuring instruments are produced in small lots, Anritsu Tohoku uses the cell production method where each instrument moves on a cart between each process. Even the final external visual inspection of a finished product is performed on this cart (Figure 2).



Figure 2 Measuring Instrument on Cart

2.2 Inspection Contents

Table 1 lists the external visual inspection items of finished measuring instruments. Figure 3 shows an external view of a typical measuring instrument.

Table 1 Inspection Items

Item	Inspection Contents
Text Matching	Correctly printed panel and label text
Barcode Reading	Readability of barcode label
Label Position	Presence of correct label at correct position
Connector Shapes	Correct connector shapes
Damage and Dirt	Absence of damage and dirt



Figure 3 Typical Instrument External Appearance

To prevent shipment of faulty products, the same inspection is performed twice by two inspectors.

2.3 Challenges at Finished Product External Inspection

External visual inspection by workers has the following challenges. Automating this inspection would not only solve labor shortages but would also solve these challenges.

- (1) Shipment of faulty instrument due to inspection oversight

Varied small-lot production of measuring instruments make it difficult for inspectors to fully understand the reference inspection standards since there are many specifications according to the shipping destination.

Moreover, text matching requires repeated checking of text that inspectors may not understand, which increases the work burden, causing fatigue and making avoidance of careless mistakes difficult.

- (2) Visual inconsistencies between inspectors

Different testers have different personal standards regarding damage and dirt. Although the damage standard is defined using a sample, if the damage is less than the sample, the inspector may still reject the product, possibly leading to excessive quality standards.

- (3) Provision of shipping inspection evidence (images)

When responding to post-shipment warranty claims, despite having inspection evidence, this is only inspection items and results and does not prove that there was no problem at shipment. The amount of time required for inspectors to take photographic images of every item for all products manually is unrealistic.

2.4 Automation Concepts

Automating finished product external inspection was based on the following concepts as the first step in targeting future fully automated inspection.

- Rather than create a large-scale automation system, assume instruments are conveyed on the product cart.
- Focus on obtaining evidence without manual intervention. Inspection time (tact time) is not important.
- The system must be expandable for future production of various types of instruments.
- First, we aim to implement the current inspection system, which is conducted by two inspectors, with an automated system plus one inspector.

3 Prototype Development

3.1 Required Specifications

The required specifications for the prototype system performing automated external inspection of finished products are listed below.

- Must inspect all five surfaces excluding base while instrument on cart
- Must execute inspection from start to finish without manual intervention
- Must save images captured during inspection

3.2 System Configuration

Figure 4 shows the external diagram of the developed prototype and Table 2 lists the main parts.

A camera unit mounted on the end of the robot arm captures images from every angle of an instrument on the cart.

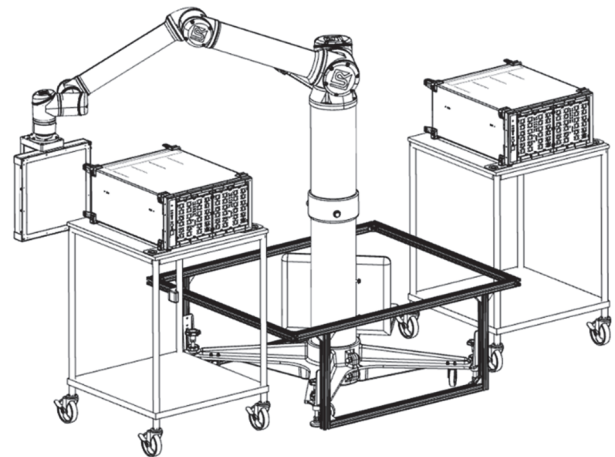


Figure 4 Prototype External Inspection Diagram

Table 2 Main Structural Parts

No	Component	Qty	Remark
1	Camera Unit	1	Flat dome lighting + camera
2	Robot System	1	Robot arm + control box
3	Robot trestle	1	Cast aluminum frame + positioner
4	PC Controller	1	Windows PC running inspection software
5	Operation Panel	1	Touch panel
6	Monitor	1	Inspection screen display

3.3 Details of Each Structural Element

The details of the prototype system parts are listed below.

- (1) Camera Unit

The structure of the camera unit is shown in Figure 5 and Table 3 lists the parts. The system is composed of lighting, camera, and lens for shooting the required

images at inspection. There are two different optical cameras to shoot the images with pulling and close up.

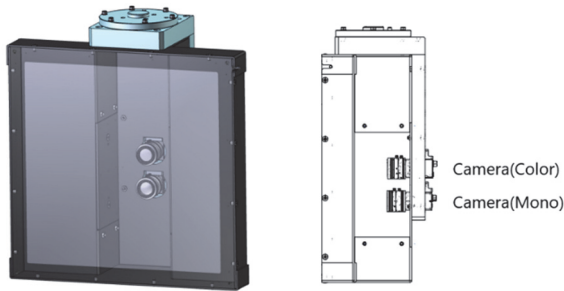


Figure 5 Camera Unit

Table 3 Camera Unit Parts

No	Part	Qty	Main Specification
1	Camera (color)	1	5 million pixels CCD camera + 12 mm lens For wide-angle images
2	Camera (monochrome)	1	5 million pixels CCD camera + 25 mm lens For damage/shape inspection
3	Flat Dome Light	1	Light size 30 cm × 30 cm
4	Camera Unit Handler	1	Camera and light base w/ attachment to robot arm

(2) Robot System

Table 4 lists the robot system specifications.

When choosing the robot system, key points were the ability to handle the camera unit weight and an arm length permitting imaging of all five surfaces of the inspected instrument.

We selected the collaborative robot from Universal Robot (hereafter UR). Since general-purpose production robots require work space and inspectors, it was necessary to secure a wide space. In a production plant mainly using cell-style production, it was thought a collaborative robot was advantageous from the layout efficiency perspective.

Table 4 Robot System Specifications

Item	Specification	Explanation
Carriage Weight	10 kg	Camera unit weight approx. 5 kg
Arm Length	1300 mm	—

(3) Inspection Software

Figure 6 shows the prototype system software structure.

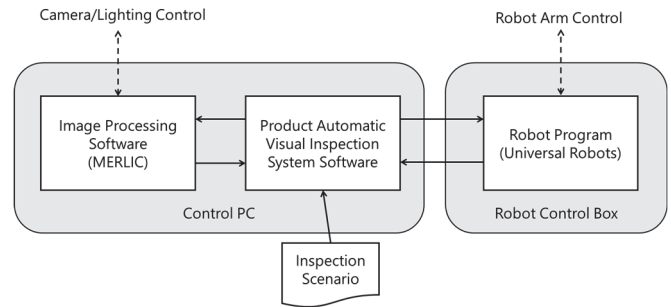


Figure 6 Prototype Software Blocks

Inspection using this system uses operation software running according to inspection scenarios on the PC controller.

The camera unit is moved via the robot program to required inspection locations according to inspection scenarios for each instrument type. The cameras and lighting are controlled to capture images that are then image-processed by software for inspection.

The captured image processing uses commercial software (MERLIC) which has rich image processing libraries such as OCR and barcode reading.

3.4 Inspection Items and Flow

The prototype system inspection flow is described below.

- (1) Positioning on Product Cart
 - Inspector positions instrument at specified position on cart using guide.
- (2) Inspection Start
 - Inspector starts inspection using operation panel.
 - Monitor displays inspection progress status.

Table 5 lists the inspection items executed by this system.

Table 5 Prototype Inspection Items

Inspection Item	Inspection Target
Text Matching	Front panel printed text
	Front panel label text
	Back panel label text
Barcode Reading	Back panel S/N
Label Position	Top panel Eco label
Connector Shape	Front panel N-connector center axis opening
Damage and Dirt	Top panel damage and dirt

(3) Inspection End

- System generates inspection results report (OK/NG evaluation result and photo images)
- Inspector moves cart with inspected instrument

3.5 Design Points

The following section describes the important design points when developing the prototype.

(1) Robot System Choice

When choosing the robot system, we used 3D simulation (Figure 7) to confirm whether candidate systems could capture images of all five instrument surfaces without problems.

3D data from each robot system vendor was used to evaluate the positional relationship between the robot and instrument and whether the instrument surface furthest from the robot could be imaged by the camera unit.

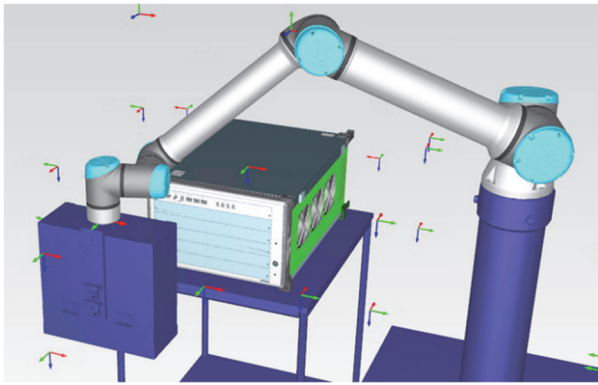


Figure 7 3D Simulation

(2) Lighting Choice

The lighting choice for external visual inspection of the instrument was most difficult. The main product panels are vertical metal sheets with satin-like finish that reflects light when illuminated by light from a ring or bar lamp using for ordinal visual inspection and prevents image processing at some angles. The best solution to this reflection issue was a dome light that illuminates the target equally from the 90° to surface direction. However, a large dome light could be hit by the robot arm and the camera opening in the dome tended to be a little darker, which was unsuitable for wide-area inspection.

Comparing the results of inspections using various light sources led to use of a flat dome light source, which gives the same equal illumination as a dome light but does not require a camera opening. Additionally, the LCD panel shape can be carried by the robot arm (Figure 8).

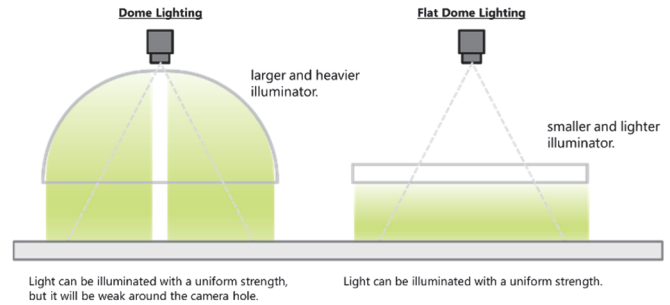


Figure 8 Dome and Flat Dome Lighting

(3) Instrument Position Detection

Although the instrument cart used for inspection is put in position using a guide, there can be somehow differences in the position of the instrument on the cart. Performing inspection requires an accurate understanding of the instrument position.

Generally, specific markers are attached to a target and the distance and angles between these markers are calculated by image processing. However, the target in this inspection is a product to which markers cannot be attached.

Therefore, we devised a method to detect the instrument corners by image processing (Figure 9).

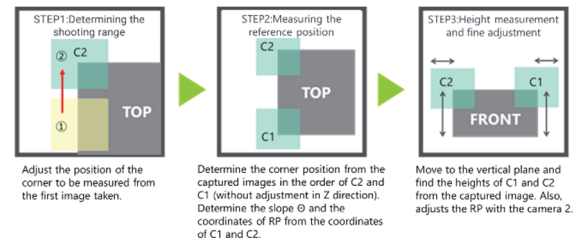


Figure 9 Instrument Position Detection

The procedure is as follows:

1. Detect corner (C2) of front panel by taking picture of product top surface
2. Detect corner (C1) of front panel by taking picture of product top surface
→ Top panel surface angle adjustment
3. Detect corner (C2) of front panel by taking picture of product top surface
4. Detect corner (C1) of front panel by taking picture of product top surface
→ Top panel height adjustment

The product position is calculated from the detected cabinet angle coordinates.

(4) Using AI (Deep Learning)

When detecting labels (presence/absence and position) by image processing, conventional pattern matching processing tends to be poor at the peripheral edges although the image center detection is good. This is thought to be due to breaks in the shape caused by lens distortion. Consequently, we used AI (Deep Learning) for the image processing software.

We used a learning model with 100 images and data on label types and annotations were appended to the evaluation to improve label recognition rates (Figures 10 and 11).



Figure 10 Deep Learning Function (Learning Screen Examples)



Figure 11 Using Deep Learning Function (Label Detection)

(5) Expandability

Assuming the range of target instrument types will expand in future, we constructed a software platform using scenario control.

Every software scenario can select the instrument inspection surface and move the camera unit, supporting many instrument types without requiring corrections to the robot program.

Additionally, image processing of each captured image is handled by loading the required module from the scenario, so just the image processing can be adjusted without changing the scenario.

4 Evaluations

4.1 Possible Inspections

We evaluated the prototype to discover issues about the accuracy of inspection results using image processing and

installing the automated system into the manufacturing line. Table 6 lists current inspection contents and Figure 12 shows a possible prototype inspection setup.

Table 6 Possible Prototype Inspection Contents

Inspection Item	Normal Test Sample Count	Abnormal Test Sample Count
Text Matching	20	20
Barcode Reading	20	20
Label Position	20	20
Connector Shape	20	1
Damage and Dirt	20	1



Figure 12 Possible Prototype Inspection Setup

4.2 Evaluating Inspection Accuracy

The inspection accuracy evaluation is shown below.

(1) Text matching Inspection

Table 7 lists the inspection accuracy evaluation results and Figure 13 shows an example of an inspection result image.

There are no problems with reading the text itself and an error in the product serial number (SN) on the seal attached to the instrument could be detected, which was the target purpose. The text matching accuracy achieved a satisfactory usage level.

Table 7 Inspection Accuracy Evaluation Results (Text Matching)

Text Matching Confusion Matrix		Evaluation with Prototype	
		OK	NG
Actual Result	OK	20	0
	NG	0	20

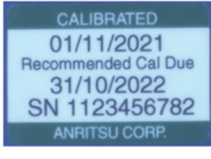
Verdict	OK	NG
Criteria	1123456781	
Detected	1123456781	1123456782
Image		

Figure 13 Example of Inspection Results Image (Text Matching)

(2) Barcode Reading Inspection

Table 8 lists the inspection accuracy evaluation results. Figure 14 shows an example of an inspection result image.

Similar to text matching, there was no problem reading the barcode itself and it was possible to detect a mis-attached barcode label. The barcode reading accuracy achieved a satisfactory usage level.

Since multiple barcodes can be verified as a batch, this function is expected to reduce inspectors' workloads.

Table 8 Inspection Accuracy Evaluation Results (Barcode Reading)

Barcode Reading Inspection Confusion Matrix		Evaluation with Prototype	
		OK	NG
Actual Result	OK	20	0
	NG	0	20

Verdict	OK	NG
Criteria	Printed characters and barcode must match	
Detected	#1 OK : TXT 9876543216 CODE 9876543216 #2 OK : TXT 9876543217 CODE 9876543217 #3 OK : TXT 9876543218 CODE 9876543218 #4 OK : TXT 9876543219 CODE 9876543219 #5 OK : TXT 9876543220 CODE 9876543220 #6 OK : TXT 9876543221 CODE 9876543221	#1 OK : TXT 9876543216 CODE 9876543216 #2 OK : TXT 9876543217 CODE 9876543217 #3 OK : TXT 9876543218 CODE 9876543218 #4 OK : TXT 9876543219 CODE 9876543219 #5 OK : TXT 9876543220 CODE 9876543220 #6 NG : TXT 9876543221 CODE 9876543222
Image		

Figure 14 Example of Inspection Results Image (Barcode Reading)

(3) Label Inspection

Table 9 lists the label accuracy evaluation results and Figure 15 shows an example of the evaluation results image.

There was no problem with label position detection and it was possible to detect whether the attachment

angle was within the reference standard. Label detection reading accuracy achieved a satisfactory usage accuracy level.

Table 9 Inspection Accuracy Evaluation Results (Label)

Label Detection Confusion Matrix		Evaluation with Prototype	
		OK	NG
Actual Result	OK	20	0
	NG	0	20

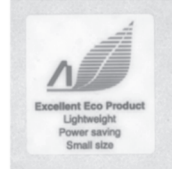
Verdict	OK	NG
Criteria	X direction: within ± 2 mm, Y direction: within ± 2 mm Angle: within $\pm 2^\circ$	
Detected	X direction: -0.61mm Y direction: -1.28mm Angle: 0.16°	X direction: -0.1mm Y direction: 0.6mm Angle: 2.1°
Image		

Figure 15 Example of Inspection Results Image (Label)

(4) Connector Shape Inspection

Table 10 lists the inspection accuracy evaluation results and Figure 16 shows the inspection results image.

The connector shape inspection accuracy achieved a satisfactory usage level. Moreover, this inspection has no criteria about opening angle of the central axis and the OK/NG verdict at conventional inspection has dependency to a vary inspector, therefore this robot inspection system must be much effective to improve such fluctuation as well.

Table 10 Inspection Accuracy Evaluation Results (Connector Shape)

Connector Shape Inspection Confusion Matrix		Evaluation with Prototype	
		OK	NG
Actual Result	OK	20	0
	NG	0	1

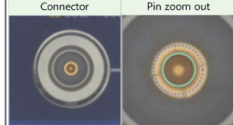
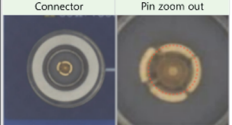
Verdict	OK	NG
Criteria	$r=0.8\pm0.2$ mm, quality ≥ 0.7	
Detected	$r=0.839$ mm Quality=0.860	$r=N/A$ Quality=N/A
Image		

Figure 16 Example of Inspection Results Image (Connector Shape)

(5) Damage and Dirt Inspection

Table 11 lists the inspection accuracy evaluation results and Figure 17 shows an example of an inspection results image.

There was no problem detecting deliberately inflicted damage but there some NG evaluations for OK instruments. The main cause was that dust and dirt that was present when the image was captured was evaluated as damage. We think the solution will require adjusting the image-capture environment and image processing.

Table 11 Inspection Accuracy Evaluation Results
(Damage and Dirt)

Damage and Dirt Confusion Matrix		Evaluation with Prototype	
		OK	NG
Actual Result	OK	12	8
	NG	0	1

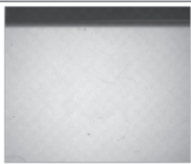
Verdict	OK	NG
Criteria	Scratch : 0, Stain : 0	
Detected	Scratch : 0, Stain : 0	Scratch : 0, Stain : 1
Image		

Figure 17 Example of Inspection Results Image (Damage and Dirt)

4.3 Discovered Automated System Challenges

(1) Improving Inspection System Accuracy

A satisfactory accuracy was achieved for practical inspection of text matching, barcode reading, and label and connector shape inspection.

On the other hand, currently, the damage and dirt inspection misreported the presence of faults. We shall try to improve the image-processing detection accuracy necessary for an automated system assuming operation in collaboration with inspection personnel.

(2) Automation Inspection Work

This prototype system was able to completely automate inspection without manual intervention by inspection staff from after the candidate instrument (on its cart) had been correctly positioned. In particular, automated capture and storage of images as inspection evidence linked to inspection OK/NG evaluation results will probably have a large impact on production quality management.

Implementing future fully automated inspection without staff intervention still faces challenges in designing equipment for automated transport, positioning, and handling of inspected instruments.

5 Conclusions

We combined a collaborative robot and AI image processing to automate external visual inspections of finished instruments previously performed by quality inspectors.

In addition to solving remaining challenge, we are targeting rapid introduction based on this system to our production lines to fully automate manual inspections now using other human senses.

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