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Design and implementation of intelligent electronic component inspection based on PLC and vision system

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A B S T R A C T

Customer demands for product quality are increasingly complex, requiring better inspection accuracy. It is not enough if done manually because it requires high costs and varying operator accuracy. Automatic vision inspection was developed to check the product quality of terminal-type electronic components To solve this problem. Design intelligent inspection uses a conveyor driven by a stepper motor, a photosensor to calculate product distance, guides position to direct the product, a vision camera to detect product quality, cylinder ejection for product selection, and PLC as a control system. The process of detecting normal and abnormal product quality is carried out using computer logic control, then separating the abnormal product into the reject box through the ejection cylinder. The machine speed is 60 pieces/minute. The system evaluation results are carried out on three parts of the system: the success rate on the vision camera is 100%, automatic product sorting through the cylinder ejection rate success is 100%, and the success rate for product positioning is 97.5%. This research provides a useful reference for developing intelligent automatic inspection technology in electronic components.

1. INTRODUCTION

Inspection by manual method with a high level of quality will be costly, difficult, and take a long time because it involves workers with good skills [1]. Frustaci *et al*. [2] stated that inspections in the assembly area are still not carried out automatically [3], such as dimensional or geometric measurements, and this must be measured by direct physical contact with the product, resulting in a long measurement time and the potential for human measurement errors to occur. Therefore, increasing the speed and accuracy of inspection with an intelligent vision system has an important role. Machine vision technology using programmable logic control is used to identify product defects in terminals equipped with an automatic sorting process.

A growing body of literature recognizes the benefits of machine vision applications. In agriculture, machine vision is tasked with screening musk grafting seedlings with a 98% success rate with a processing speed of 1 seed in 15 minutes [4]. The multivariate analysis method was combined with machine vision for testing rice seed varieties with a success rate above 83% [5]. In the soft drink bottle industry, color classification and level checks have been successfully detected by automatic vision checks using a raspberry pi as a controller [6]. The same thing is done for bottle companies by conducting automatic visual inspections to detect defects and locations. This detection consists of Bottle bottom inspection, Bottle mouth inspection, and Bottle wall inspection, using the edge points double classifying method and least-squares fitting algorithm [7]. In the automotive industry, several researchers have documented their research, with regional consistency algorithms and cone defect gradient detection successfully detected [8], optimization of research objects can also be carried out using machine learning training methods and vision algorithms [9]. The discrete surface defects on the vehicle body can be detected well by Machine vision with an accuracy of 95.6% for dent defects and 97.1% for scratch defects, the engine speed reaches 1 vehicle per 1 minute 50 seconds [10]. The same thing was also done in research on the packaging process [11] the novelty of machine vision can detect objects in the form of columns with edge detection methods, rectangle detection, intercepts, and feature statistics in a stable, fast, and 100% efficient manner. By combining cable-based parallel robots and machine vision, it is used as a proposal for detecting rusty bolts and liner plate edge leaks in the coal bunker maintenance process [12]. With inexpensive equipment and without human intervention, the detection of color and dent defects on sandwich panel parts can be well detected by automatic visual inspection [13]. At the electronics company, machine vision was developed to increase automation and speed up the change-over product process [14]. In the steel plate industry, the automatic vision system is used to detect the quality of the cut steel plate by knowing the fracture area that is damaged and burned [15]. The combination of an electro-mechanical system is the basis for developing a fully automatic contactless inspection for testing bearings with the 608ZZ type [16]. The 3D vision system is applied in inline part inspection, and the result can significantly reduce the wastage of time and material. Researchers found that the 3D vision system can detect surface thermal maps and is accurate for detecting geometric sizes with precision with sizes below 0.03 mm [17]. However, most of the studies above focus on fairly large research objects. Identification of the inspection process speed, small defect size, and random object positions are rarely reported, and only a few reports have been made on automatic inspection technology to identify the types of terminal product defects with a fast process.

In this paper, to solve and identify the types of product defects of terminals in the inspection process, this paper analyzes and identifies the types of product defects by ignoring the product position automatically, an intelligent product inspection system developed with mechanical design, photosensors, computer programming, and PLC control. The system recognizes the type of product defect by the vision system and sends the position information of the rejected product to the programmable logic controller. The system compares the information sent by the vision system and automatically sorts rejected products without human intervention.

2. RESEARCH METHODS

2.1. Inspection object and defect taxonomy

The research is conducted on electronic component companies in Indonesia. The type of product detected is the terminal that connects lines and electrical signals to electronic equipment [18], as shown in Fig. 1. The thickness of the material is 1 mm, the dimensions of length (B) 9.5 mm, and the diameter dimension (D) 6.8 mm. Insulation material from a special Vinyl material. Small product size, precision, and the appearance of rare defects are the basis for input from the design of automatic vision inspection. Based on quality reports from the company, the defects that appear are small but can impact the failure of product use by customers.

Fig. 1. Inspection object

Maintaining the level of product quality and localizing the types of product defects to be repaired is the goal of quality control in the production department. Variations of product defects are macro-sized, easily visible, and complex using conventional inspection methods that are

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commonly used, take a long time, and are subjective [19], [20]. Detecting product imperfections and classifying the types of product imperfections is the goal of automatic visual detection [21]. The production section requires a structured and precise classification of product imperfections used as a factory database.

2.2. Structure and working principle of the inspection device

The product is formed using the main machine, the speed is 60 pieces/minute, and an induction motor drives the cam. However, the inspection system on the main engine has not been able to detect classified product defects. The output of the main machine and the product's position varies depending only on the force of gravity. One by one, the products are in the conveyor system with random positions. The product position must be uniform before being captured by the vision sensor to obtain stable results. The product guide is used for uniform product positioning. Product quality inspection using vision sensors and deciding which products meet the requirements automatically enter the box poly container. Instead, the product will be ejected through the ejection cylinder. The automatic visual inspection machine is an additional machine using a conveyor integrated with the main machine. In general, the total maximum size of this machine is 870mm in length, 380mm in width, and 530 mm in height (Fig. 2). Then, the largest product size is 9.5 mm in length and 12 mm in width, so to get the best field of view, the sensor vision is placed on the conveyor at a distance of 145 mm from the object of detection. The stepper motor is connected to two sprockets and a single chain to drive the conveyor. The cam photosensor is placed parallel to the conveyor pulley. The cam photosensor calculates conveyor steps for tracking product position on-camera and rejection processes

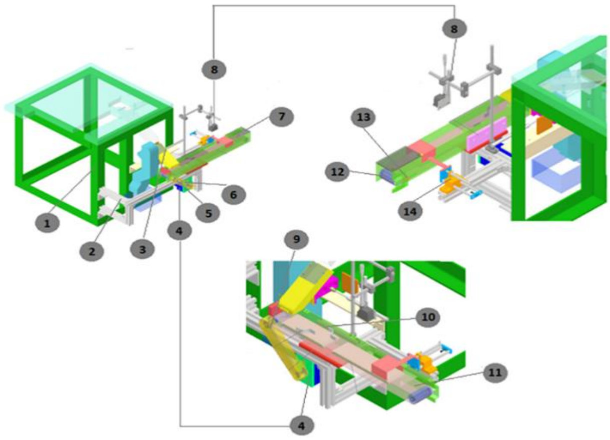


Fig. 2. Automatic vision system. (1) Main machine processes; (2) Aluminium frame automatic vision inspection; (3) Main machine shutter; (4) Stepping motor; (5) Sprocket; (6) Chain; (7) Cover conveyor; (8) Vision sensor; (9) Cover sprocket and chain; (10) Product guide; (11), Belt conveyor; (12), Pulley; (13) Slide cam; (14) Cylinder ejection

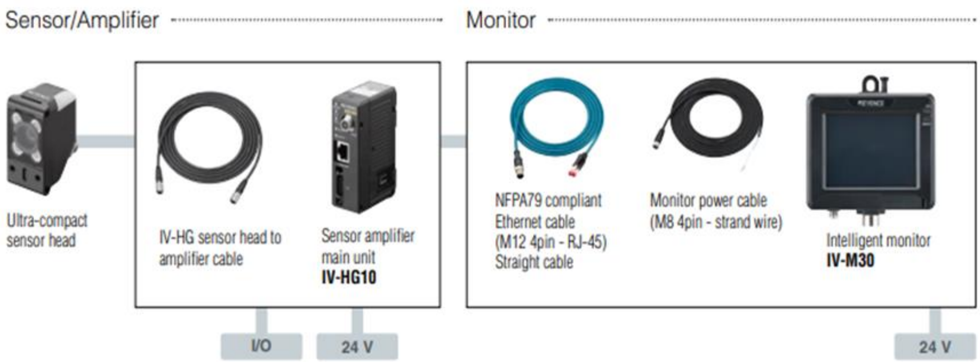
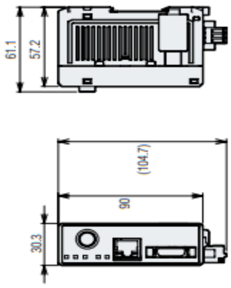
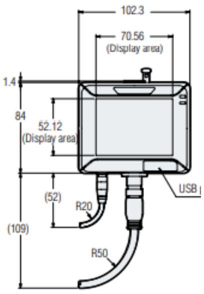


Fig. 3. Vision sensor configuration

Table 1. Vision sensor specification

Sensor					
Type	Installed distance	View	Pixel	Illumination	Weight
 IV-HG500CA	20 to 500 mm	Installed distance 20 mm: 10 (H) × 7.5 (V) mm to Installed distance 500 mm: 200 (H) × 150 (V) mm	752 (H) × 480 (V)	White LED	Approx. 75 g
Sensor Amplifier					
Type	Tools number	Rating power voltage	Input	Image history condition	Weight
 IV-HG10	Detection tools: 16 tools	24 VDC ±10% (including ripple)	For voltage input: Maximum input rating 26.4 V, ON voltage 18 V or higher, OFF current 0.2 mA or lower, ON current 2 mA (for 24 V)	NG only/All is selectable	Approx. 150 g
Monitor					
Type	Backlight method	Rating power voltage	Display	Touch panel method	Weight
 IV-M30	White LED	24 VDC ±10% (including ripple)	3.5" TFT color LCD 320 × 240 dot (QVGA)	Analog resistive	Approx. 180 g

2.3. Requirements for detection and identification

The speed of the main machine and the product's position must be uniform, product defects must be identified, and the product entered into the poly container box must be according to specifications, a requirement for an intelligent automatic inspection system. Identification of process capabilities from beginning to end must be met, with the identification requirements as below:

a. The falling position of the product varies. It must be able to be directed so that the vision sensor can detect it properly.
b. The product is always in the middle position so as not to slip between the conveyor belt and the frame.
c. The system can register products with other types.
d. The vision sensor is easy to install, light, and small.
e. The vision sensor is easy to operate.
f. The processing speed of the vision sensor should be fast and not affect the main

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machine's speed.

g. The system should be equipped with automatic sorting without operator intervention.

Based on the information presented above, namely the type of defect, varied product sizes, ease to operate, and register of other types of products. So we need a compact vision sensor consisting of a sensor head, sensor amplifier, sensor head to amplifier cable, Ethernet cable, monitor power cable, and intelligent monitor (Fig. 3).

The minimal space is not an obstacle to installing this vision sensor. Vision sensors can be directly combined with existing systems or with the development of new systems. The master reference number of pixels is calculated in the inspection area to determine the area differences. The specified color area is graded to find out the color model. Then, the brightness of the black and white areas in the binary part is used in the monochrome model. This vision sensor is easy to operate and fast for the configuration process by using the autofocus and auto-brightness methods (Table 1).

The vision sensor capability check is done offline. The vision sensor is placed on the object at a distance of 145 mm. One thru beam type photosensor (PHS) is used to detect the presence or absence of the product. The cam photosensor is placed at the end of the conveyor and is in charge of calculating the conveyor steps as a trigger command for the vision camera to carry out product inspections (Fig. 4). Master samples are verified one by one. The master sample is placed manually on the conveyor with the same processing speed as the main machine, which is 60 pieces/minute. It must be done repeatedly to get a stable output value from the vision sensor.

2.4. Design of intelligent inspection system

The sensors on the main machine have not been able to detect product quality that the human eye can detect. The automatic vision inspection (AVI) machine is an additional machine that checks the overall product quality. The AVI machine uses an electronic pneumatic system; the air source is 0.5 Mpa to 0.6 Mpa, and the power source is 200 V to 220 V. The main machine speed is 50 pieces/min, so the design speed of the AVI machine must be greater than or equal to the main machine. By relying on the weight of the product, about 2 grams and the force of gravity, the products fall through the shutter randomly from a height of about 200 mm from the base point of the main machine. Gravitational potential energy has an impact on changing the product's shape, so it affects the quality of a product. The gravitational potential energy of the product uses the equation (1).

$$Ep = m \cdot g \cdot h \quad (1)$$

where Ep: Potential Energy (Joule); m: Mass of the object (Kg); g: Earth's gravity (meter/s2); and h: Height of the object (meters)

Therefore, to minimize the product's gravitational potential energy and momentum, the shutter design is given a 30° angle of inclination from stainless steel (SUS). The length of the conveyor is 500 mm, using a stepper motor maker Vexta Oriental Motor PK 266-02A 2 phase, DC voltage source, and a torque of 1.1 Nm. A sprocket and chain mechanism connect The stepper motor to the conveyor pulley. The cover sprocket is a safety point that must be installed because it is very close to operator activity. The stepper motor driver uses the UDK 2120 type and works on an AC voltage source of 100 V. The motor driver

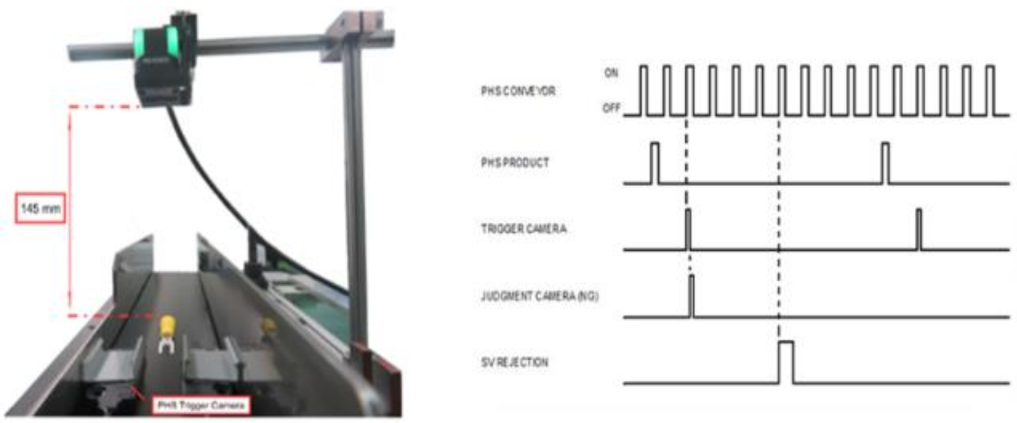

Fig. 4. Vision sensor offline trial and timing chart detection

functions as a control of the conveyor rotation position. Next, the conveyor belt is selected with an antistatic character. The AVI engine is designed to select products that match the specifications into a good box poly container. Instead, it will be separated by a cylinder by pushing products that do not meet specifications into the reject box. The timing chart of the AVI engine process is shown in Fig. 4.

2.4.1. *Product positioning*

One by one, the product exits the machine through the shutter to a conveyor with a height of 200 mm from the base point of the main machine. The shutter design is tilted at an angle of 30 degrees and resembles a pyramid to minimize the product's gravitational potential energy and momentum (Fig. 5 (1)). The final correction uses two positioning guides placed on the left and right sides of the inside of the conveyor. Guide positioning directs the product so that the product is always facing up. The distance of the positioning guides to each other is adjusted to correct the movement of the product when in contact. The guide positioning design is made at an angle of 30° so that the product and guide positioning when in contact are smooth (Fig.5 (2)). The guide positioning can be adjusted so that the gap between the guide positioning and the conveyor belt is smaller than the thickness of the conductor material. It must be noted that if the gap between the guide positioning and the conveyor belt is greater than or equal to the thickness of the material, it will impact changes in product quality, and the conveyor belt will be damaged quickly. Stainless steel material was chosen for this study because it is difficult to deform and stable against elastic loads [22]–[25].

2.4.2. *Vision inspection process*

An industrial machine vision system is made up of several vital components. It must be chosen carefully, considering the required resolution, how many frames per second should be recorded, and whether grayscale or color images are required. The camera must have an objective with the required focal length and magnification distance [26]. Illumination has an important role, and the light source must be installed to ensure that the sample is illuminated with a uniform light distribution [27]. Therefore, the camera resolution is determined from the beginning of the design, taking into account the field of view (FoV) and the size of the defect to be detected [28], with the following equation (2).

$$Rc=(FoV\,.ND)/DS \quad (2)$$

where Rc: Resolution camera (Pixel); FoV: Field of view (millimetre); ND: Number of pixels for smallest defect (Pixel); and DS: Smallest defect size (millimeter).

Illumination and lighting techniques have been integrated with the camera, making it easier for researchers to conduct experiments quickly. The camera is installed at a distance of 145 mm from the object to be detected. The size of the detected object is 25 mm, and the system will be installed on the machine at a speed regulated by the pneumatic system. The camera acquisition configuration system uses an integrated camera with an LED light with a size of 0.5 Megapixels. The objects detected by the visual system are structural quality (incomplete parts) and dimensional quality (following standard requirements). As shown in Table 1, the resolution of the vision sensor is 752 pixels horizontally and 480 pixels vertically. To obtain optimal focus, the field of

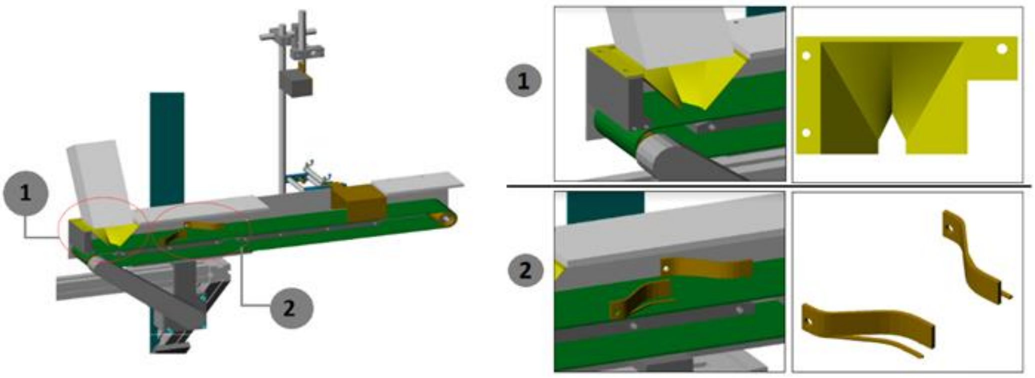

Fig. 5. Product positioning design. (1) Idle shutter; (2) Guide positioning

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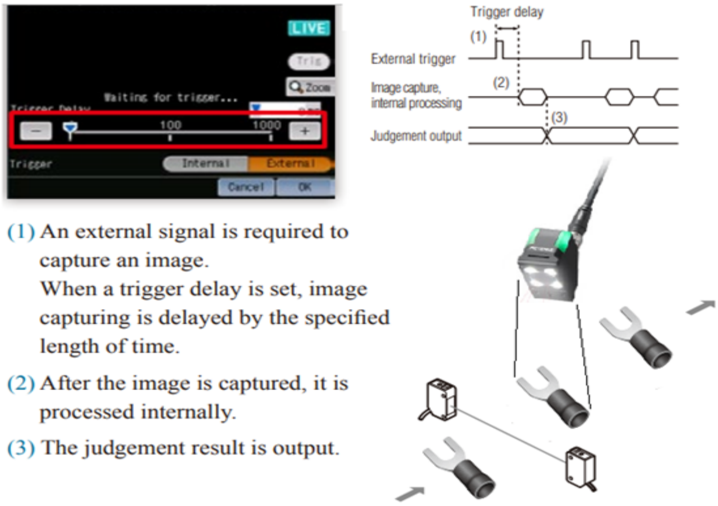

Fig. 6. External trigger mode selected

view (FoV) size on the vision sensor is 60 mm on the horizontal axis (X-axis) and 45 mm on the vertical axis (Y-axis). By comparison, it is obtained that the size of each pixel on the X axis is 0.08 mm/pixel, on the Y axis is 0.095 mm/pixel, and the most optimal defect size on the product is 0.38 mm. The shooting product image experiment was carried out several times to measure the stability of the process (Fig. 6). The detection steps with the vision sensor include:

1. Set image optimization for clear target imaging. Adjust the image to determine the difference between high and low-quality targets. The object contrast is clear and done in standard setting conditions with an exposure time of 0.1 ms. Set the trigger options and adjust the brightness and focus of the imaging, as shown in Figure 6, and the external trigger timing chart is selected.
2. Start the imaging by inserting the trigger at a variable time. When the trigger delay interval is set, the imaging start time will be delayed for a specified period.
3. Perform internal processing after imaging.
4. Displays status results.
5. Register the master image high-quality target image and register the master image for evaluation reference.
6. Set the tools (edge width and diameter geometric), set the tool to evaluate the target, set the tool to dominate the image, and set the threshold for scoring. Based on the tools, the time required for image analysis is 50 ms or the same as the program time.
7. Output assignment: assign the function to output to each output line.

2.4.3. *Automatic ejection process*

The AVI machine is equipped with automatic ejection, which separates non-standard products into the reject box. The ejection movement uses a pen-type cylinder, bushing, and shaft as supports to make translational movement more precise. Cylinder stroke specifications are 80 mm and cylinder diameter 12 mm. The effective force released by the cylinder uses the equation (3).

$$F = A\,.P \tag{3}$$

where F: Effective force of cylinder piston (Newton); A: Piston cylinder surface area (meter2); and P: Pneumatic working pressure (Newton/meter2)

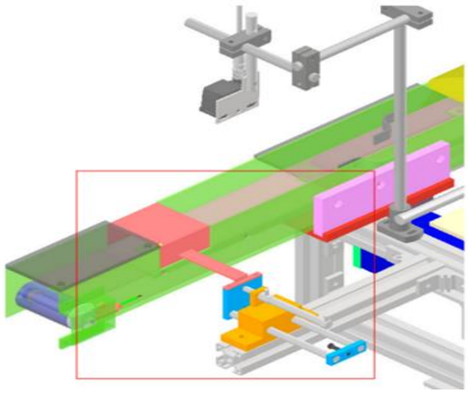

Fig. 7. Ejection stage

The effective force of the cylindrical piston is 67.8 Newtons, or the equivalent of 6.7 Kg. The working load of the cylinder piston is the sum of the mass of the stainless-steel plate supporting the cylinder and the product's weight. The total cylinder workload is around 1 Kg or less than the theoretical workload. The ejection system design uses a U shape that surrounds the conveyor (Fig. 7). When the AVI machine detects a product that does not meet specifications, the sequential system is that the ejection cylinder solenoid valve will be active, then the cylinder moves to release the product into the reject box, followed by the machine stops.

2.5. *Control system design*

The control hardware design comprises two Panasonic photo sensors (PHS) type EX-15E and PM-T45 (Table 2). First, PHS 1 functions to detect the position of the product on the conveyor. Second, PHS 2 functions to detect product displacement from PHS 1 to the position of the vision camera as a trigger. PLC gets an input signal, which is then calculated and compared to instruct the ejection cylinder to work if it detects that the product is not according to specifications. Stepper motors are connected to sprockets and pulleys to drive the belt conveyor. The vision sensor (camera) is mounted at 145 mm from the object, with the stand being easily adjusted for optimal FoV. PLC adapted to the system input, output, and operating budget needs. PLC with type OMRON CP1HX40DT was chosen because it has the number of inputs and outputs that suit the needs. The processing speed of basic and special instructions is under 0.16 microseconds, 20,000 steps of program capacity, and has an NPN transistor-type output. The overall design of the control system (Fig. 8) and the hardware specifications needed are based on production operational needs (Table 3). The hardware is connected and installed according to the electrical wiring diagram and the internal structure of the PLC electrical cabinet that has been completed (Fig. 9).

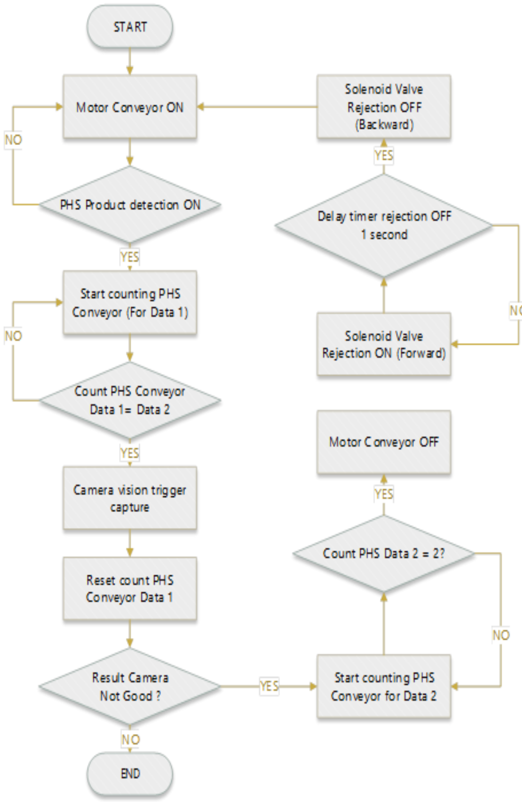

Fig. 8. AVI flow program chart

Table 2. Hardware acquisition

No	Item name	Type	Maker	Quantity (unit)
1	Voltage Source	AC 200 V	-	-
2	Noise Filter	RSEN-2010	TDK Lambda	1
3	Power Supply	S8VS-12024	Omron	1
4	PLC Unit	CP1HX40DT-D	Omron	1
5	Driver Motor Stepper	UDK-2120	Oriental Motor	1
6	Stepper Motor	PK266-02A	Oriental Motor	1
7	Vision Camera	IV-HG500CA	Keyence	1
8	Amplifier Camera	IV-HG10	Keyence	1
9	Monitor Camera	IV-M30	Keyence	1
10	Human Machine Interface	GP-2301-LG41	Proface	1
11	Photo sensor	EX-15E	Panasonic	1
12	Photo sensor	PM-T45	Panasonic	1
13	Push Button switch	A165L-AGM-24D-2	Omron	1
14	Push Button switch	A165L-ARM-24D-2	Omron	1
15	Push Button switch	A165L-AYM-24D-2	Omron	1

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Table 3. Input and output addresses

No	Channel	Input	Channel	Output
1	0.00	Driver Motor stepper error	100.00	Signal CW Stepper
2	0.01	Start button	100.01	Signal CCW Stepper
3	0.02	Stop button	100.02	Motor Stepper Off
4	0.03	Reset button	100.03	Trigger Camera vision
5	0.04	Output camera vision	100.04	Solenoid Valve rejection
6	0.05	Camera vision Run		
7	0.06	Camera vision Busy		
8	0.07	Camera vision Error		
9	0.08	Sensor PHS Product		
10	0.09	Sensor PHS Conveyor		

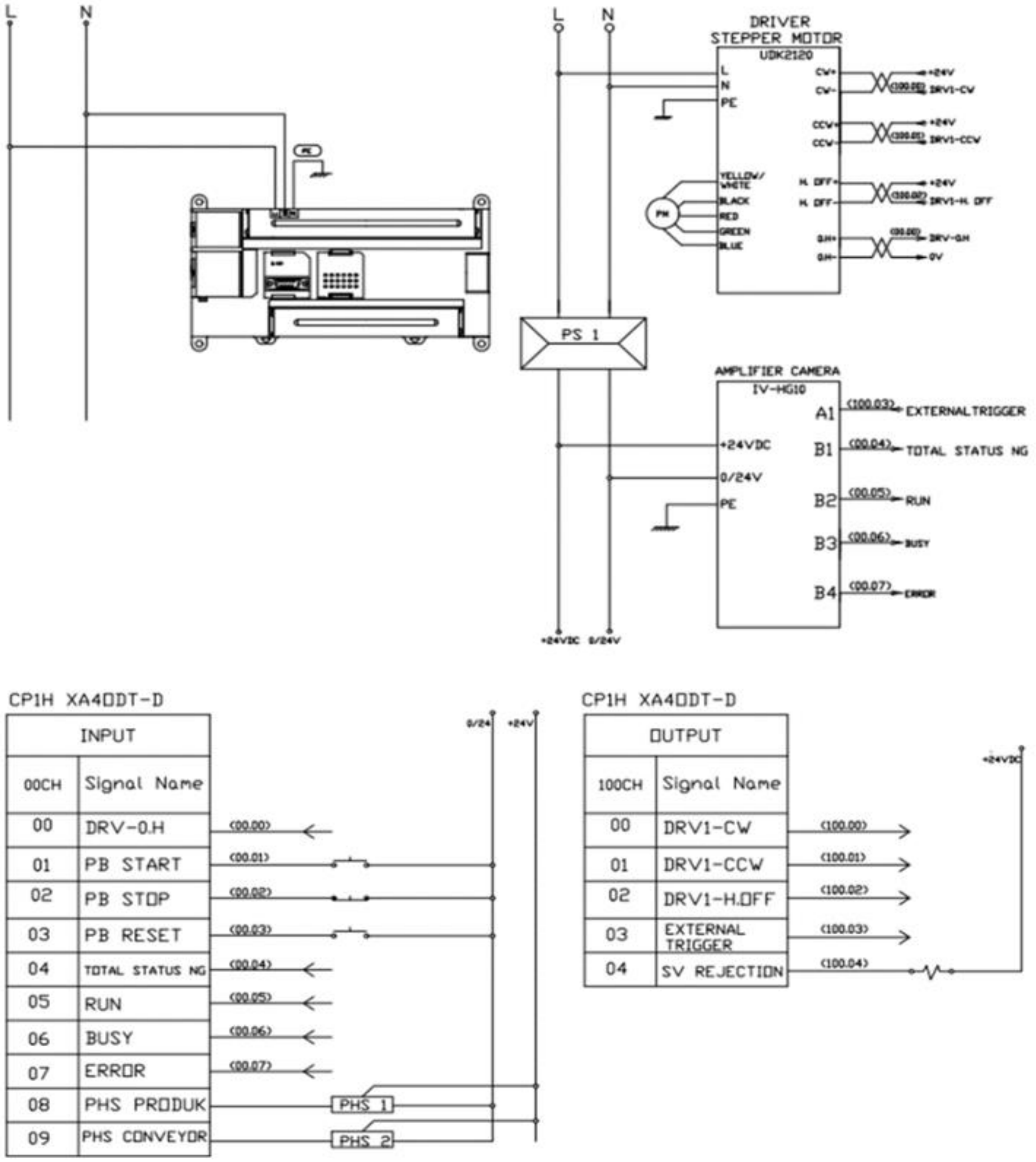

Fig. 9. Wiring design

3. RESULTS AND DISCUSSION

Experiments were carried out in the manufacturing area offline. As explained above, the first is to collect product data as the initial master data. In line with previous research, getting optimal image results does not take a long time (a single minute) because the sensor setup is facilitated by autofocus and auto-brightness, without some experimenting with distance settings and lighting settings [28]. With the ease of setting the vision camera, it can provide added value to the company so that the product change-over process will be faster and more efficient [29], [30]. Initialization of the product according to the specifications is done by observing a vision camera to get the optimum threshold value. The output of normal and abnormal products can be visualized by a vision camera through a color monitor TFT camera with a size of 3.5" (Fig. 10). Master products that have been collected are checked using camera vision. To determine the stability of the data from the master product, five times the data was collected using camera vision. The value of the master product that does not meet the specifications is compared to the threshold value determined from the initial use of the normal product.

3.1. Ejection and product positioning experiment

The following experiment is to evaluate the guide positioning product and cylinder ejection. First, two positioning guides made of SUS 320 material are installed crosswise to correct the product position. The consistency of the product position in the middle and facing up is a requirement for optimal data retrieval on camera vision. Second, evaluate the PLC output's response to the solenoid valve's ability to drive the cylinder ejection, which functions as a separator of normal and abnormal products.

The experimental results show that there are 80 trials to determine the process capability of product positioning, Vision sensors, and cylinder dispensing (Fig. 11). Experiments were carried out in real-time at 60 pieces/minute speed. It can be seen that the accuracy of the vision sensor to capture product defects and the ability of the ejection cylinder to respond if a problem occurs is 100%. However, in product positioning, the accuracy is 97.5%, and the overall accuracy of the AVI machine is 99.2%

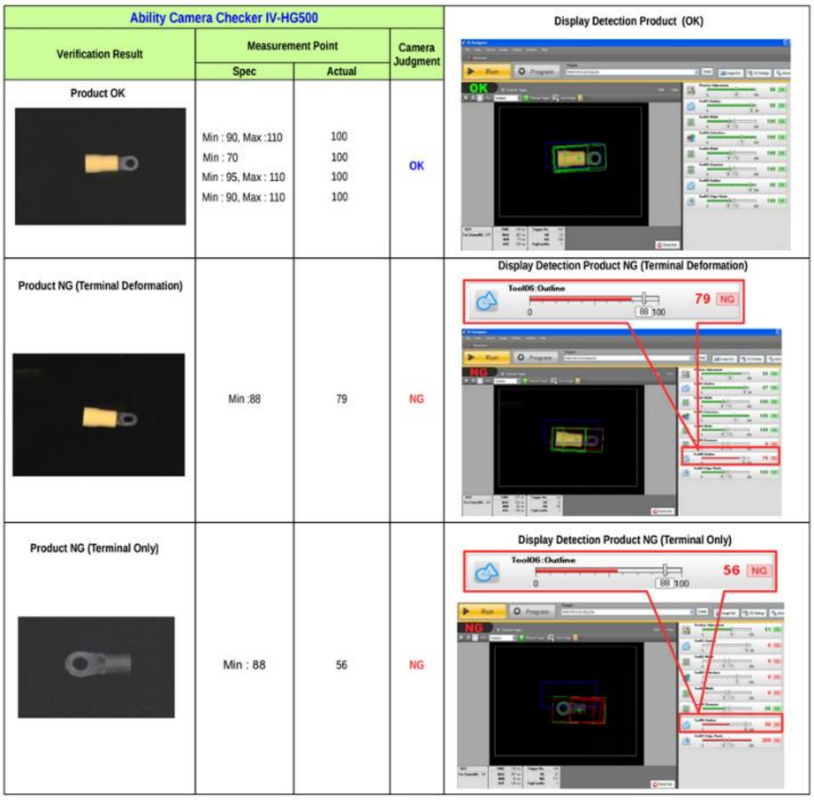

Fig. 10. Sample normal product and defect product result verification

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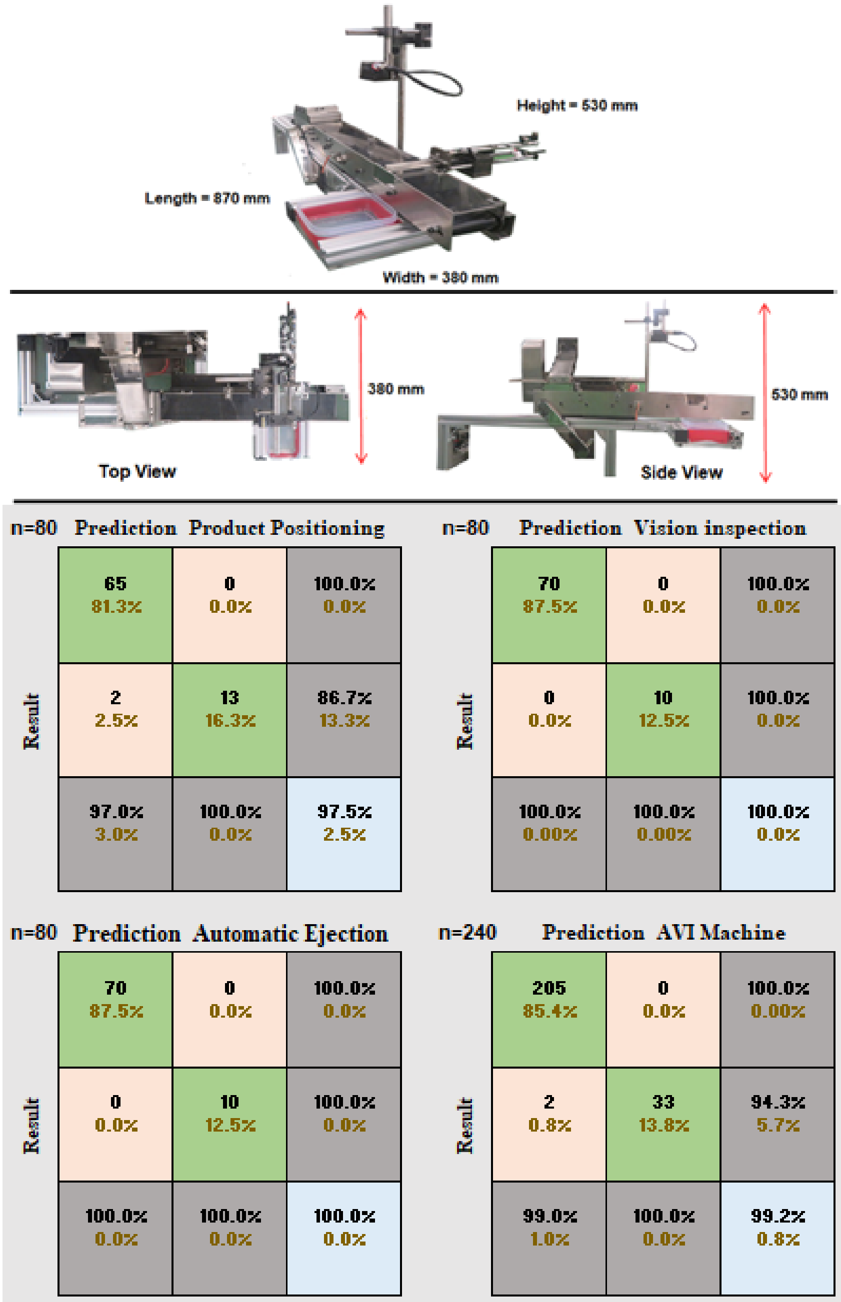

Fig. 11. Real-time experiment and AVI machine confusion matrix

3.2. Comparative analysis

Based on the data, one operator is required to perform the product selection process, done manually using magnifying. The operator's salary is assumed to be IDR 72,000,000 per year. Not only that, automation can be done 100% because there is no need for manual product selection. If this innovation has not been done, the company's annual cost based on salary is IDR 72,000,000 per year. To calculate the payback period (PBP) using equations (4), electricity and maintenance costs are ignored for machine innovation investment.

$$PBP = Cost\ of\ innovation / Yearly\ profit \qquad (4)$$

$$PBP = 100{,}000{,}000 / 72{,}000{,}000 = 1.4 \text{ Years}$$

4. CONCLUSION

This research focuses on checking the quality of terminal products at electronic component companies by designing and developing automatic vision inspection machines. This automatic vision inspection machine consists of a photo sensor, a stepper motor, a stepper motor driver, a vision camera, and a PLC as a control system. The product randomly falls onto the conveyor, and then the correction function is carried out by the positioning guide so that the product position becomes uniform. Normal and abnormal products have been identified by the vision sensor and as feedback to the PLC control system. They were sorting normal and abnormal products through cylinder ejection. The experimental results found that First, the ability of the vision sensor process and the sorting process was 100%. Second, when the processing speed is 60 pieces/minute, the success rate of product positioning is 97.5%. Third, The overall accuracy of the AVI machine is 99.2%. Fourth, the speed of automatic vision inspection is equal to that of the main machine. Future research in this area could focus on finding other manufacturing defects, with product sizes and shapes varying on the sides and bottom. The robot arm will add flexibility to designing a comprehensive automated visual inspection system for electronic component production lines

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