ORIGINAL PAPER

IMAGE PROCESSING METHOD BASED QUALITY TEST ON A SMART FLEXIBLE ASSEMBLY MECHATRONIC SYSTEM WITH COMPONENT RECOVERY

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Manuscript received: 16.05.2020; Accepted paper: 21.10.2020;
Published online: 30.12.2020.

Abstract. *The article presents a new approach for image processing algorithms based on image processing techniques: edge detection, normal cross correlation (NCC) and M-estimator Sample Consensus (MASC). The new algorithm is integrated into the station dedicated to the quality test (QT) on a SMART flexible assembly mechatronic system with component recovery. As a result of the QT analysis, the manufacturing flow can continue with either the following operations: disassembly and recovery of components or transport and storage of good products. It is obvious the importance of implementing a high accuracy analysis function for products quality. The new algorithm increases the performance of the detection function both in terms of identification but also in the speed of QT execution. The results obtained in this article will be used in future research for the development of a machine vision system adapted to modern Industry 4.0 technologies, in which it will have the control structure specific to an integrated IoT sensor.*

Keywords: *A/DML; quality test system; NCC; MASC; Gaussian filter.*

1. INTRODUCTION

In recent decades, modern production systems are being developed on complex manufacturing platforms, with successive or parallel production flows. At the same time, these systems perform product quality testing based on quality tests with high performance. The research presented in this article considers the process of assembly / disassembly of a flexible manufacturing line (A/DML) with an advanced quality analysis system. The A/DML production system is able to deliver products with different typologies, by implementing real-time control coordinated with flexible manufacturing planning.

During production, two interconnected parallel flows can be differentiated. In order to produce a type of parts, it is necessary to pass the workpiece through production stations [2]. The system in which the assembly is performed in the interconnected stations has the characteristics of a flexible manufacturing process [3]. Within these systems, due to a large number of possibilities for the succession of the stations, the requirements for the performance of the product quality assurance system increases.

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For the implementation of a high-performance quality analysis system, specific to systems with flexible manufacturing, the following requirements are needed: integration of a quality system that does not significantly change the duration of the total manufacturing cycle for each type of part, rapid adaptation to different product typologies and minimizing contact during the execution of the quality test. These considerations require the design and control of a complex quality analysis system with the specific structure of a Machine Vision (MV).

MV systems are mainly used for: automatic image acquisition and processing, robot guidance or for industrial process control. The MV system has multiple applications such as quality control, sorting, component assembly inspection and image distance measurement [4].

The main objective of this article is to presents the results obtained after implementation of the algorithm for detecting the defective part in the quality system. The result of the quality test has a decisive role in the real-time control of the production flow. This system decides whether the part must be disassembled or stored. That is why a fairly good detection accuracy must be obtained.

The A/DML structure and the positioning of the Quality Test (QT) station, as an integral part of the production process control structure, are highlighted, as well as, the algorithm used for performing the quality test. This algorithm uses three main image processing techniques: edge detection performed by successive comparison, M-sample estimator and normalized cross correlation (NCC). The results obtained after the implementation of the proposed detection algorithm of quality system sustain the conclusions.

2. MATERIALS AND METHODS

2.1. QUALITY TEST SYSTEM INTEGRATED IN A/DML

A/DML is a precision production system consisting of seven stations served by a mobile robot and a SCARA robot with mobility on three Cartesian axes [5]. A/DML has been designed to follow the principles of flexible production: the principle of integrated quality, the principle of adequacy, the principle of dynamic conception and the principle of adaptability [6].

Flexible manufacturing for A/DML involves the following specific aspects: different types of parts obtained by reconfiguring the same components and the flexibility of the line configuration. Thus A/DML will have two parallel workflows: the flow of successive operations of the interconnected stations of the line and the flow generated by the order of execution of operations controlled by the SCARA robot (Fig.1). Furthermore, the flexibility of the part type is given also by the presence of the flexible cell equipped with ABB IRB 120 manipulator. The cell is able to produce parts of a different type than the basic production of A/DML.

The hypothesis in this approach is considered that the A/DML system will produce only two types of parts: a type of part obtained by manufacturing in the flow of connecting the stations and a type of part delivered by the ABB flexible cell.

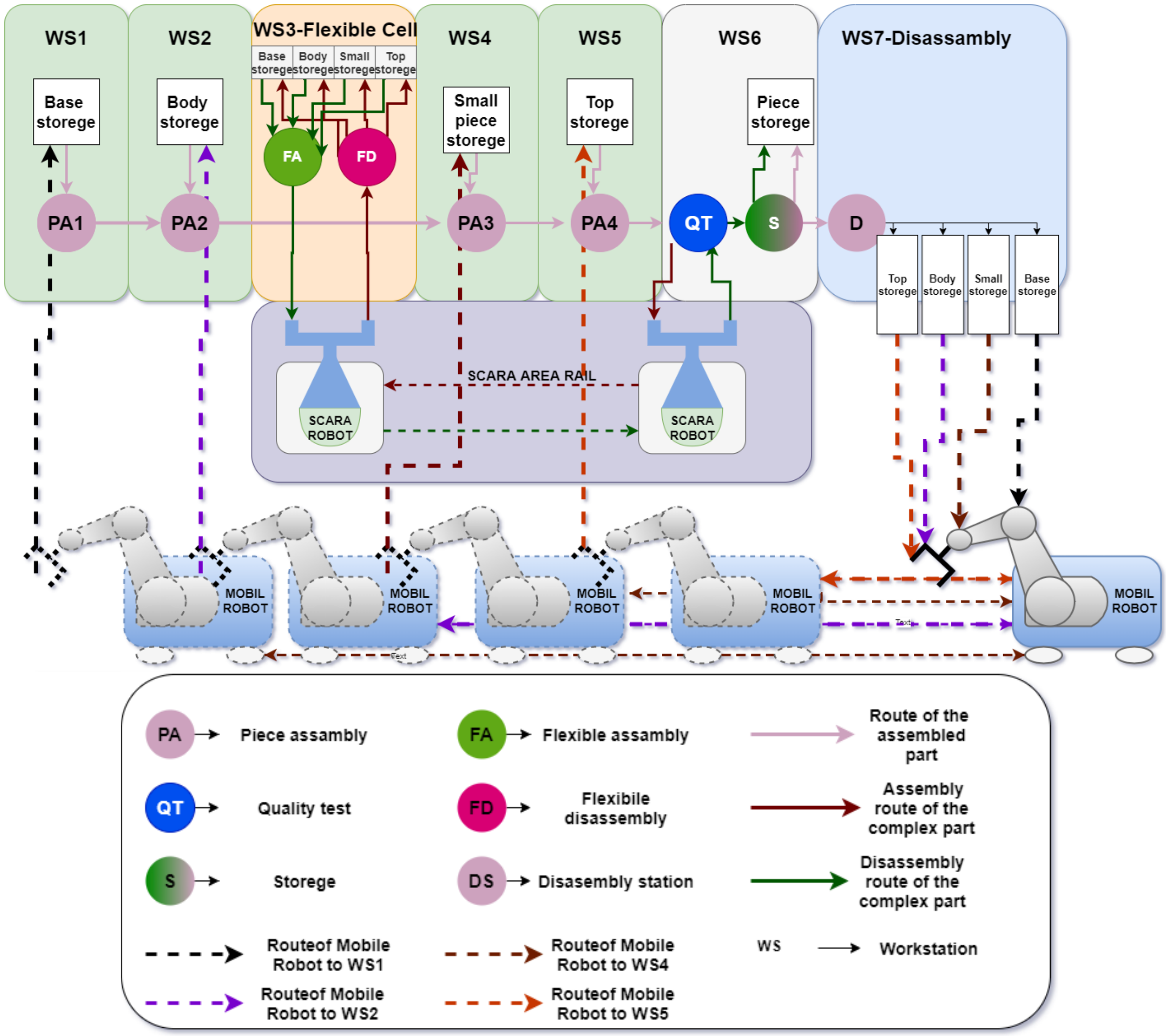


Figure 1. A/DML served by wheeled mobile robot and a SCARA robot.

The ability to make a very large number of configurations of assembled parts is given by the integration in the production process of robotic manipulators (RM). Both the Fanuc LR Mate 200ID 4S robot located in Workstation 3 (WS3) and ABB IRB 120 located in Workstation 3 (WS3) can assemble the two types of products in a wide variety of configurations depending on the production needs.

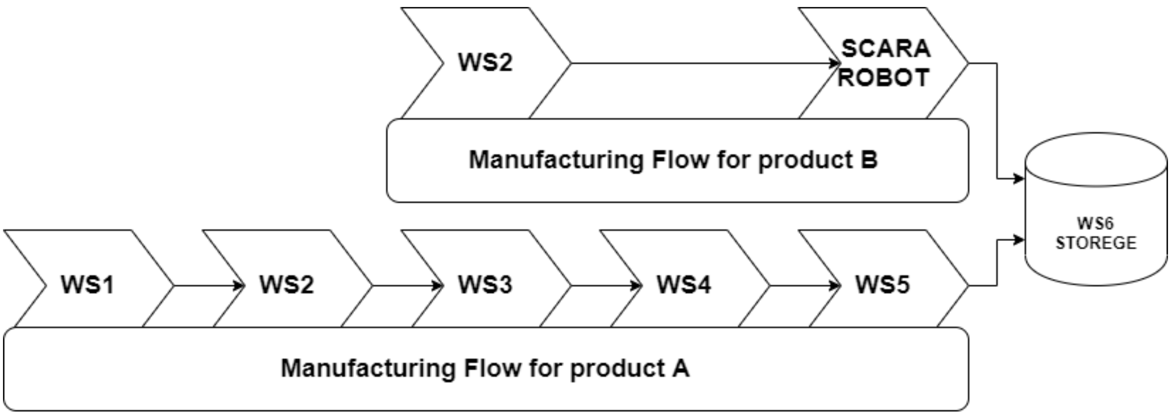
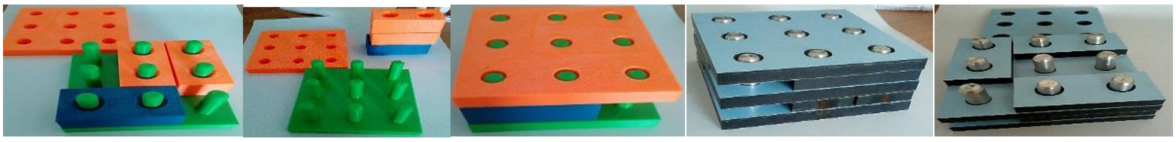


Figure 2. A/DML production flows.

The production of A/DML results in two types of products: the type A product and the type B product (Fig. 3). These products are structurally different. To obtain the type A product, the following manufacturing flow must be followed: WS1, WS2, WS3, WS4 and WS5. This product consists of three structural components: base, small parts and top, transported with a tray. The type B product is assembled in the flexible cell in the configuration preset by an operator.

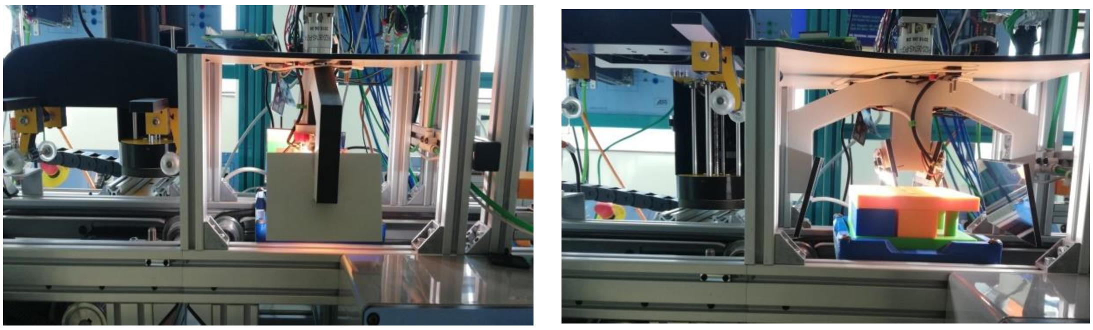
This type of product consists of the following semi-products assembled in successive order: *body piece*, *small piece*, *top piece*, *body piece*, and *top piece*.



a) b)

Figure 3. A/DML product types: a) product A; b) product B

In order to obtain products with the highest possible quality, an MV system must be designed and built. The MV system is designed in order to be constructively and functionally adapted to the A/DML production flow. In the WS6, the dimensional constraint is higher because in this station is located the product warehouse and it also has the workspace of the SCARA robot (Fig. 4).



a) b)

Figure 4. Machine Vision for QT station: a) front-back view; b) left-right view.

The location of the MV system in WS6 aims to test both types of products for all configurations in which they can be assembled. MV system's decision determines the subsequent behavior of the entire production process. There are three possible scenarios that may arise following the decision of the MV system: the first - product type A or product type B declared "good" in terms of quality, where the products are stored in WS6; second - product type A declared "failed" with the required quality standards, in which case the product is sent to WS7 for disassembly; three - product type B declared "failed" with the imposed quality standards, in this case, the product is transported by the SCARA robot to WS2, where it is disassembled by the ABB IRB 120 robot.

The developed MV system has a software component compatible with the specific hardware structure. The hardware structure is composed of light equalization system, motion insurance system, two cameras and a processing unit. The software component has the following tasks: control of the entire hardware support to obtain a sample image; implementation/execution of the image analysis algorithm by processing the acquired images: implementation/execution of the decision algorithm by delivery of the QT results; send all the data to the database.

The quality assurance system has two components in the developed software: a real-time local control component of the production process by defect detection and a long-term control component by the possibility of data processing to determine the cause of defects. Based on the data saved in the database, the production optimization algorithm can be adapted according to customer requirements to achieve a balance between production times and production cost.

The quality test involves the following steps: stopping the part in the defined position of the MV system; obtaining two images from the front and back view; rotating the system at a 90° angle; obtaining two images from the left side view and the right side view and rotating the system by -90° to its original position.

Motion control, image acquisition, image processing, decision making and its transmission to the programmable controller that drives the station is performed using the Raspberry Pi 3 B+ microcontroller (Fig. 5).

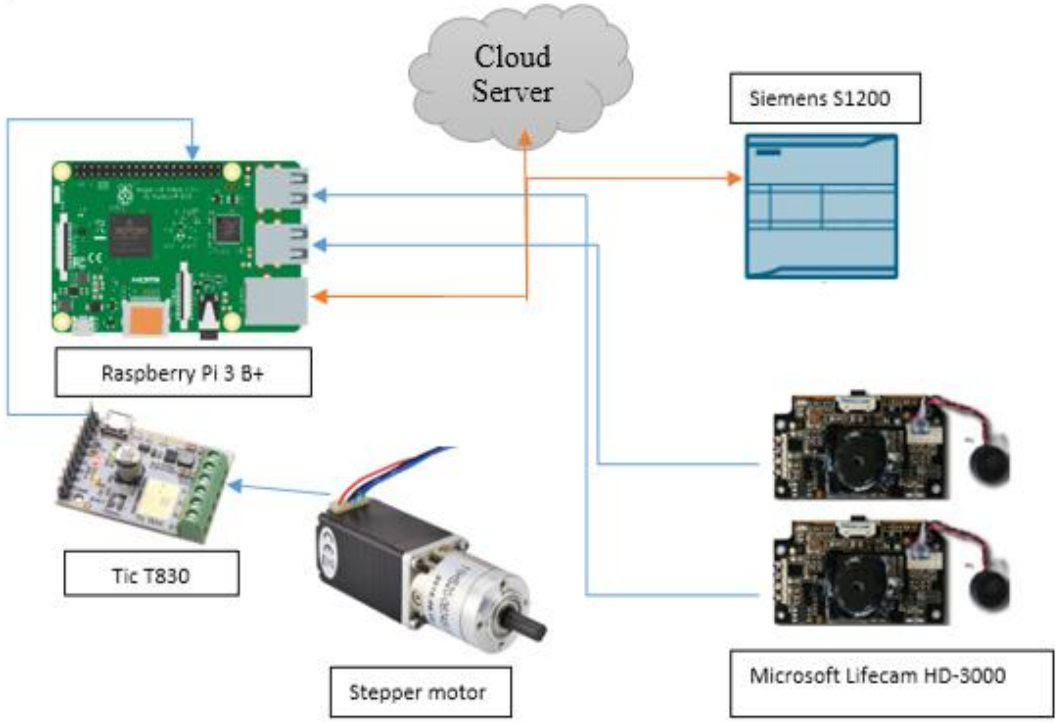


Figure 5. The components of MV system

2.2. THE DEFECT DETECTION ALGORITH

The algorithm used for image processing implemented in the MV control structure is based on the following analysis techniques: edge by successive comparison (SCA), normalized cross-correlation (NCC) and M-estimator Sample Consensus (MASC).

The proposed algorithm goes through the following stages: upload the template image and the image in which the template is searched; reduce image size; applying the SCA algorithm to both images; align the resulting images using MASC; applying the NCC algorithm; marking the area where the NCC index is at its maximum and displaying the image in which the template image was identified.

The proposed approach for edge detection is done by the pixel-level analysis of intensity differences. This approach proposes a series of comparisons between the value of the intensity function in the points with x, y coordinates and the value of the same function in the coordinates of the 8 neighbors sifted with a comparison index. In this function, *x* and *y* are the coordinates representing the position of the pixel and the value of the function representing the image intensity.

The successive comparison algorithm (SCA) maybe reads the pixels belonging to the edge in successive stages, so that after each iteration, edge pixels are added. Pixels that don't belong to the edge are removed. To compensate, pixels with an intensity of 255, representing the color white, are added instead.

The result obtained after applying the SCA algorithm on a sample image is saved in a pixel array. The values saved at position (x, y) in the matrix range from 0 to 255. The value 0 represents a strong edge and the value 255 indicates the absence of the edge. After applying this algorithm, a large number of pixels are obtained. To decrease their number and increase the pixel detection accuracy, it is necessary to compare the pixel amplitude with the amplitude of the neighboring pixels to which an index is added. The pixels identified for a high value of the added index belong to the strong edges.

The calculation of the comparison index is done using the following formula:

$$c = \sum_{x=1}^{n-1} \left(\sum_{y=1}^{m-1} \frac{\sqrt{\left| f(x,y) - \bar{f}(x,y) \right|}}{6} \right) \tag{1}$$

In this formula: $\bar{f}(x,y)$ represent the average value of intensity and $f(x,y)$ represents the value of the current pixel.

The quality testing algorithm for A/DML considers the deviations of transport and positioning of the parts, determined by the conveyors. Thus, it is unlikely that the tested product will be "ideally" positioned, so to identically match the position of the template. The proposed solution to eliminate the effects of product positioning and scale mismatching is to apply the MASC algorithm. The MASC algorithm approximates the scaling and image rotation parameters [7]. The matrices present in Table 1 are used to approximate these parameters.

Table 1. Image transforming matrices.

Matrix operation	Transformation matrix	Characteristics
Translation	$\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ T_x & T_y & 1 \end{pmatrix}$	T_x - moving after X T_y - moving after Y
Scale	$\begin{pmatrix} S_x & 0 & 0 \\ 0 & S_x & 0 \\ 0 & 0 & 1 \end{pmatrix}$	S_x - scale after X S_y - scale after Y
Shear	$\begin{pmatrix} 1 & SH_y & 0 \\ SH_x & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$	SH_x - shear element after x SH_y - shear element after y
Rotation	$\begin{pmatrix} cos(\alpha) & sin(\alpha) & 0 \\ -sin(\alpha) & cos(\alpha) & 0 \\ 0 & 0 & 1 \end{pmatrix}$	α - rotation angle

The NCC algorithm identifies a template in an image based on statistical data obtained by applying the NCC formula. During this step, both the template image and the sample image are two-dimensional functions. A requirement of the NCC algorithm is that the template image to be smaller than the sample image. After applying the NCC algorithm, a matrix of the correlation coefficients will be obtained [8]. The maximum value of the cross-correlation coefficient indicates the position of the template image in the sample image. [9]

The formula for calculating the normalized cross-correlation index is [10]:

$$N(u,v) = \sum_{x,y} \left[f(x,y) - \bar{f}(u,v) \right] \cdot \left[t(x_u, y_u) - \bar{t}(x_u, y_u) \right] \quad (2)$$

$$D(u,v) = \sqrt{ \left(\sum_{x,y} \left[f(x,y) - \bar{f}(u,v) \right] \right)^2 \cdot \left(\sum_{x,y} \left[t(x_u, y_u) - \bar{t}(x_u, y_u) \right]^2 \right)^2 } \quad (3)$$

$$\gamma(u,v) = N(u,v) / D(u,v) \quad (4)$$

where the value of $\bar{f}(u, v)$, represents the average value of the sample image moved to the coordinates (u, v), and can be calculated using the following equation:

$$\bar{f}(u,v) = \frac{1}{T_i \cdot T_j} \sum_{i=u}^{u+T_i} \left(\sum_{j=v}^{u+T_j-1} f(x,y) \right) \quad (5)$$

The value of $\bar{t}(u, v)$ represents the mean values of the intensity function of the template, and it is calculated according to the formula:

$$\bar{t}(u,v) = \sum_{i=u}^{T_i-1} \left(\sum_{j=v}^{T_j-1} t(x,y) \right) \quad (6)$$

Applying the NCC algorithm on the samples on which the SCA algorithms and the MASC algorithm were initially applied has the following advantages: it diminishes the effect of the pixels that are not the object of the quality test, thus improving the accuracy of the test which increases the safety of the quality test.

3. RESULTS AND DISCUSSIONS

Before implementing the algorithm in the MV system, performance tests must be applied. The results of tests performed aim at the following aspects: the accuracy of the edge detection algorithm must be as high as possible and the value of the quality index of the NCC should be close to the maximum value.

Within the SCA algorithm, the value of the comparison index has decisive implications for the number of pixels belonging to the edge (Fig. 6.). Experiments performed on a series of images show that the comparison index directly influences the accuracy of edge detection. In the SCA algorithm as the index is bigger edge detection accuracy increases yielding strong edges. In the case of small values of the comparison index, noise is obtained near the edges. This aspect is not advantageous, as the purpose is to identify the edge differences in the products determined by the noise values that influence the value of the NCC index.

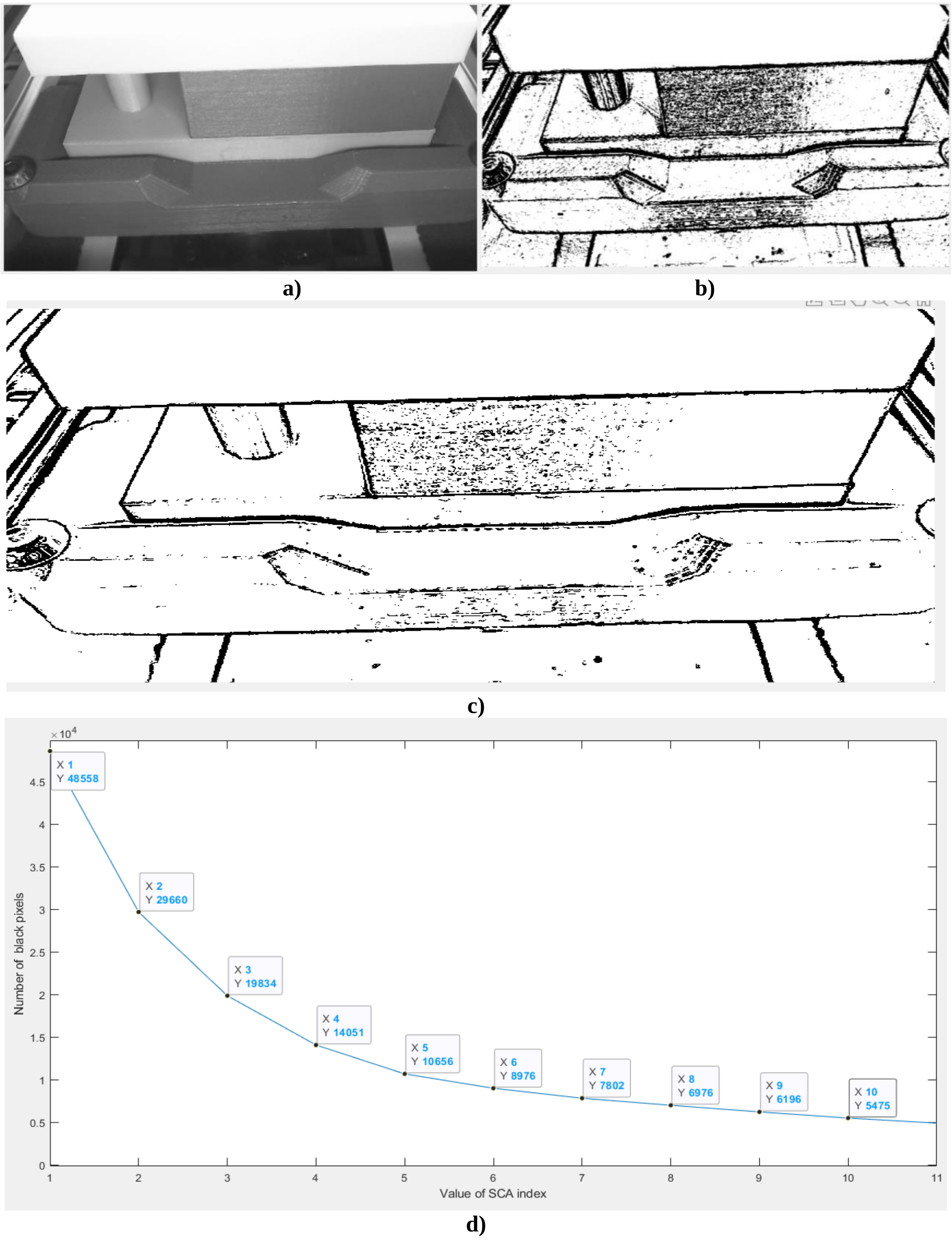
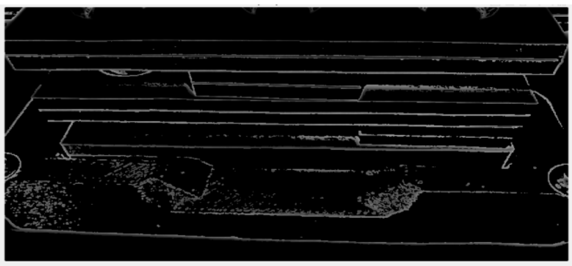


Figure 6. QT results: a) Test image in grayscale; b) The resulting image after applying an SCA algorithm with an index value equal to 1; c) The resulting image after applying an SCA algorithm with an index value equal to 4; d) The number of pixels obtained for different values of the SCA index

Edge detection performance analysis of the developed algorithm involves comparing the results obtained with the SCA algorithm with the results of the established algorithms used for edge detection: Canny, Sobel, Prewitt and zero-cross. In order to assess this, a visual inspection of the results is made. The overlapping of the resulting images (Fig. 7b-f) with the test image (Fig. 7a) highlights that the SCA algorithm identifies a small number of false edges compared to classical algorithms. This feature is due to the algorithm's lack of sensitivity to brightness differences [11, 12].

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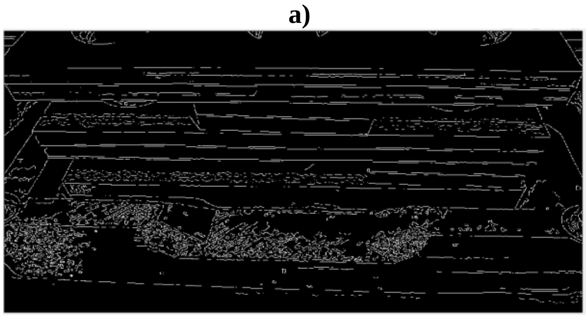
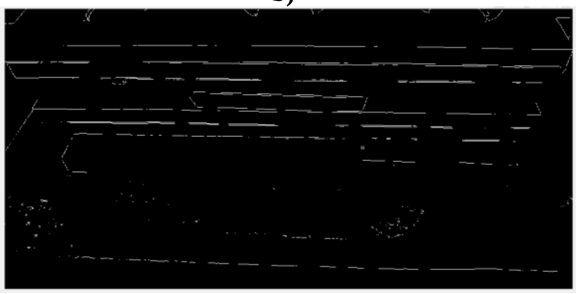
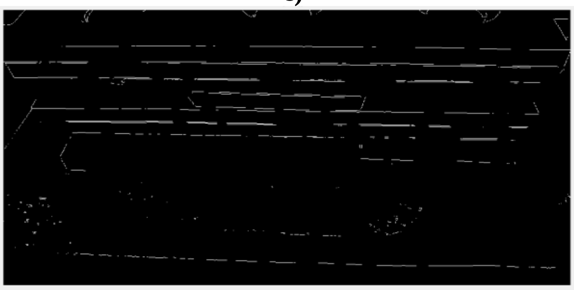
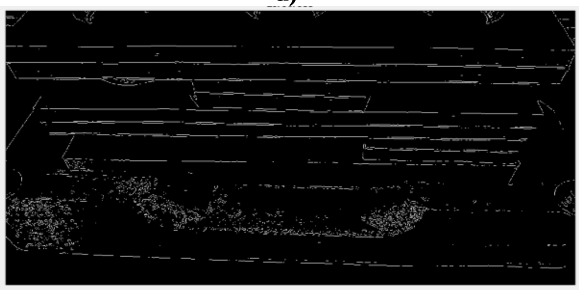
 

c) d)

e) f)

Figure 7. Edge detection algorithms: a) Sample image; b) Image obtained using the SCA; c) Image obtained by Canny algorithm; d) Image obtained by Sobel operator; e) Image obtained by Prewitt operator; f) Image obtained by zero-cross operator.

Another aspect that must be analyzed for the study of SCA performance is the execution time. To highlight the results, a comparative analysis of the execution times of the commonly used algorithms was performed (Table 2). The workstation used to obtain time values has an Intel-i3-4000M processor that allows running the Matlab programming environment.

Table 2. Execution times associated with the algorithms for edge detection in MATLAB.

Algorithm	Execution time [s]
SCA	0.057693
Canny	0.077192
Sobel	0.026097
Prewitt	0.023918
Zerocross	0.269493

The study on SCA performance shows that from the perspective of edge detection quality and execution time, this algorithm can be used for real-time edge detection. It can be used for edge detection both in real time and in videos with a rate of 17 frames per second. When studying the performance of the SCA as part of the defect detection algorithm, the influence of SCA on the NCC index must be discussed. To study the effects of the algorithm on the NCC index, two images are considered: a test image and a small template image obtained from the test image. The SCA algorithm with a comparison index of 8 was applied to these images. Applying the NCC algorithm to the two images should indicate a 100% match percentage but the tests indicate a 98.5% (Fig. 8).

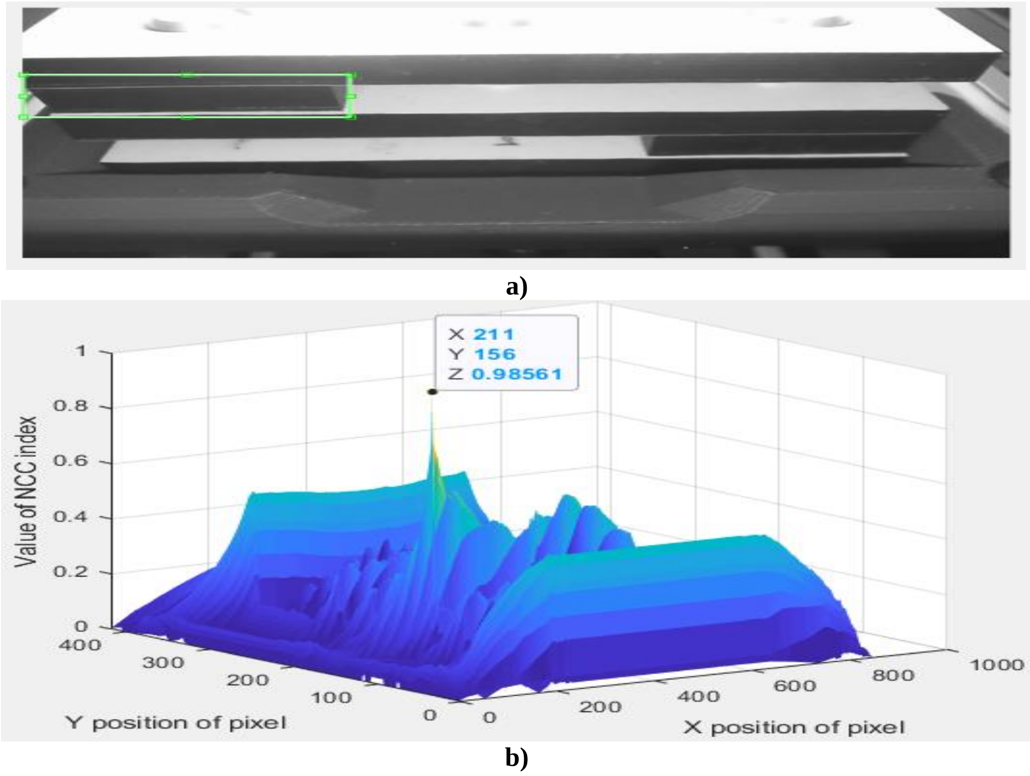


Figure 8. Results analysis: a) The template image identification; b) Three-dimensional graph of the image.

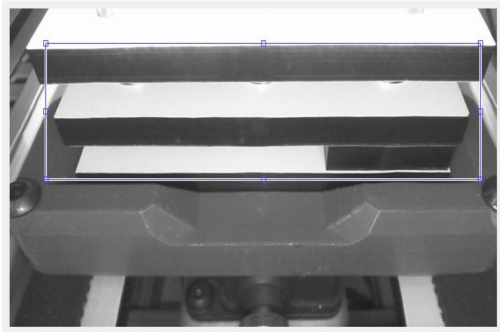
The SCA algorithm in the proposed approach has two important roles in removing colors and preserving the edges of images. Once the edge images have been obtained, the conformity test performed with the NCC algorithm is applied to them. This algorithm allows the comparison of the image taken from the line with the standard compliance image. Ideally, this approach would be normal. In practice, there is a major problem with the presence of tolerance limits. For example for the assembly of product A, there are tolerance limits imposed by conveyor and assembly in the manufacturing cells.

Tolerance limits are a major problem because they can induce changes in the position of the part. The NCC algorithm is sensitive to changes in position and rotation of images (products in the image), for this reason, the proposed and implemented solution was the MASC algorithm.

Table 3. Execution times associated of MASC algorithm in MATLAB

Resolution	Execution time [s]
1787x2056	0.816371
720x1028	0.237683
360x640	0.075508
180x320	0.061068

In order to establish the size that brings the most efficient image quality ratio - execution time, experiments with the image resolution were performed. According to Table 3, it can be seen that the resolution influences the execution time. Due to these results, the image quality will be maximum at the maximum execution time. In the experiments performed, the resolution of 720x1028 was used because it has the most reasonable quality-execution time ratio.



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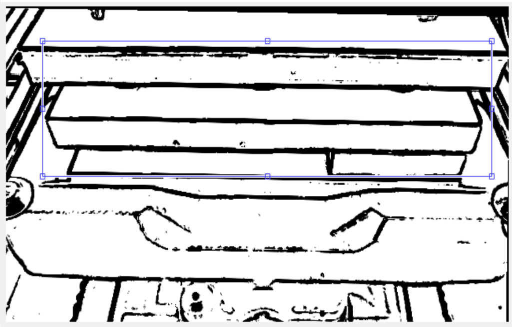

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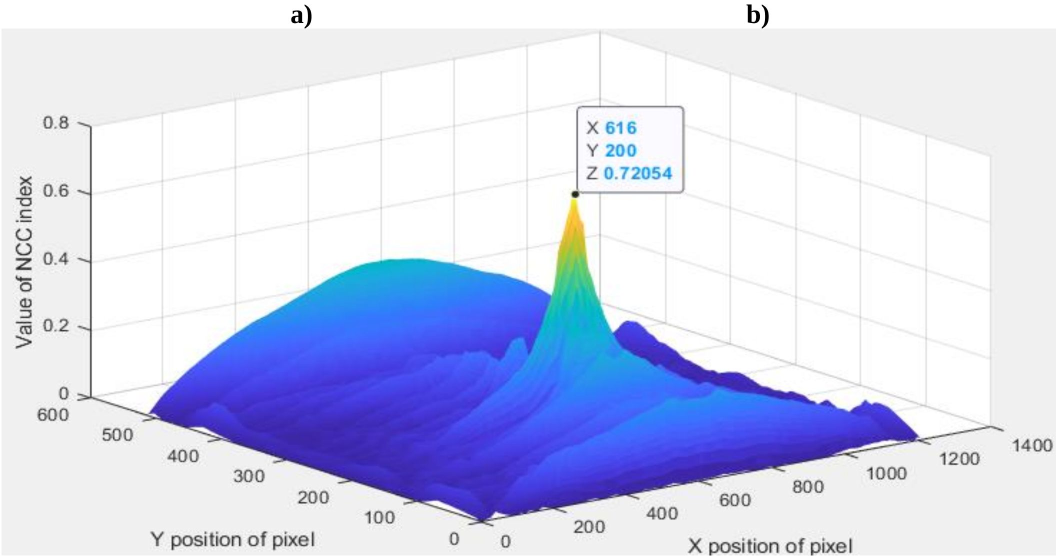

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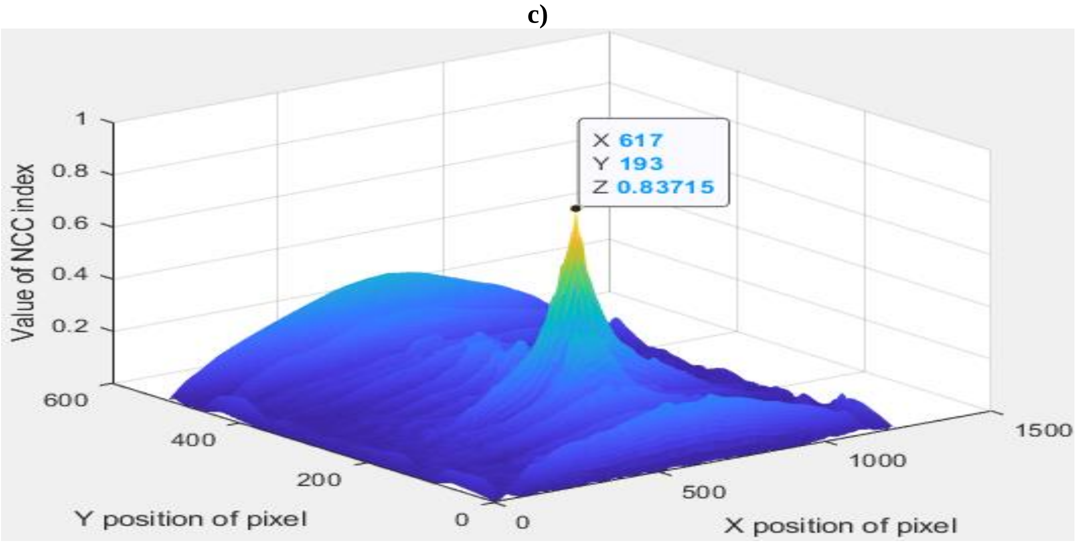

d)

Figure 9. The accuracy of results for different scenario: a) The product image has 17° related to the coordinate system; b) The product image is aligned with the template image; c) The three-dimensional graph of the cross-correlation values of unaligned image; d) The three-dimensional graph representing the cross-correlation values of aligned images.

The MASC algorithm applied before the NCC algorithm brings significant improvements to the NCC index. For 11-degree rotation, the experiments showed an increase in the NCC index of 11 percentage points (Fig. 9). The MASC algorithm by applying geometric transforms achieves the angular fit of the images so that the detection accuracy is greatly improved.

4. CONCLUSIONS

The research results show that the proposed algorithm for fault detection can be implemented in an MV system. An essential feature of this algorithm is the stability over time. The analysis of the results shows that there is a certain influence on the value of the normalized correlation coefficient caused by the SCA algorithm. This influence is considered to be insignificant due to it being caused by the intensity of the pixels, directly altered by the external light. The MV system is designed considering the hypothesis that the working light for sampling is uniform and any disturbances are caused by variations in ambient light. An advantage of implementing the algorithm is that it doesn't have scaling or positioning sensitivities. The MASC algorithm aligns the parts in the image so as to obtain advanced detection performance.

The results obtained in this article will be used in future research for the development of an MV system adapted to modern Industry 4.0 technologies. All information acquired in the A/DML process will be stored in the Cloud server to be processed by specific applications for remote monitoring and real-time control. Thus, the MV system will have a functional and control structure similar to an integrated IoT sensor. This will allow increasing the performance of analysis and decision algorithms in the quality analysis process.

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