Cost-efficient Automated Visual Inspection System for small manufacturing industries based on SIFT

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Abstract

This paper presents a cost efficient Automated Visual Inspection (AVI) system for small industries' quality control system. The complex hardware and software make current AVI systems too expensive to afford for small-size manufacturing industries. Proposed approach to AVI systems is based on an ordinary PC with a medium resolution camera without any other extra hardware. The Scale Invariant Feature Transform (SIFT) is used to acquire good accuracy and make it applicable for different situations with different sample sizes, positions, and illuminations. Proposed method can detect three different defect types as well as locating and measuring defect percentage for more specialized utilization. To evaluate the performance of this system different samples with different sizes, shapes, and complexities are used and the results show that proposed system is highly applicable to different applications and is Invariant to noise, illumination changes, rotation, and transformation.

Keywords: Automated Visual Inspection, Scale Invariant Feature Transform, Quality Control, Mathematical Morphology, Computer Vision.

1 Introduction

Manufacturing industries are facing a big challenge in their production lines and quality control, which is a time consuming and costly process in product manufacturing lifecycle especially for producing small products with complicated parts. Automated Visual Inspection (AVI) systems have been successfully applied to variety of these processes and slowly improved the quality and productivity of manufacturing lines. Before these techniques being revealed, stochastic sampling by an expert at the final stage of production line was the common product quality control solution that is both slow and not cost efficient.

There are many applications for AVI systems such as automobile manufacturing [1], Size Measurement [2], Fabric Inspection [3], defect detection in textured materials [4][5][6], evaluation of structure damage [7], inspection of printed circuit boards [8], quality inspection of food products [9], Space Platforms Inspections[10] and other large industry demands for quality control of their products. The advantages of AVI Systems are mostly accuracy and speed as well as reducing quality control cost in most single product large manufacturing industries.

In some small and medium size industries, the only efficient and comfortable solution is still human-based inspection. In spite of low speed and accuracy of these methods, they are cheaper in some cases. The major disadvantages of Computer Vision based inspection systems are high setup cost, as well as hardware and software costs, which makes them not feasible for most small industries. In addition, current inspection systems are custom-designed for specific tasks and it is often very difficult to change them for new applications. Therefore, they are not advisable for small and most medium-size industries that produce different types of products.

It should not be forgotten that human based inspections are poor, requiring too much redundancy of inspectors, and increasing cost and inspection time. Therefore, a cheaper AVI system may be more economic and accessible, especially toward small and medium size industries.

Recently, Garcia and Villalobos introduced a reconfigurable framework for AVI Systems [11]. Although it is good to design a reconfigurable system, it is still costly to implement, especially for small industries.

In this paper an AVI system that is designed and implemented on simple machine vision techniques is introduced. The advantage of this system is its accuracy and cost-efficiency. The System is highly reconfigurable to be used in different applications, requiring small or even no changes. This system is designed similar to human visual inspection that makes it simple, accurate, and applicable for most small and medium size industries. The system detects visually detectable defects of products and

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quantitatively computes various types of defects. Scale Invariant Feature Transform is used for detecting keypoints that make the method invariant to size, shape, direction, and position of the sample. The technique is also invariant to small illumination changes.

The rest of this paper is organized as follows. In Section 2 a brief introduction of some related techniques used in proposed method, is given. Section 3 describes proposed method and the experimental results are reported in Section 4. Finally Section 5 concludes the paper and proposes future works on this topic.

2 Related techniques

2.1 Scale Invariant Feature Transform

Feature extraction is the most important part of the inspection system. Because samples may have minor distance differences from camera and they may not be at the same direction of original sample, these features should not depend on the size and direction. Although the system is self-illuminated, but there may be a slight illumination disruption. Thus, a technique that is not depended on illumination changes is more appropriate.

Scale Invariant Feature Transform (SIFT) developed by David G. Lowe [12] is a popular feature extraction technique. It is a method to extract distinctive invariant features from images originally designed for object recognition: features detected in a sample image are matched to a large database of previously extracted features from various objects at different viewpoints. Because these features have been proved to be invariant to image rotation, scaling, translation, partial illumination changes, and projective transformations, they are good candidates for using as registration control points.

The major stages of computation of SIFT features are as follow:

Scale-space extrema detection: The first stage is to compute the Gaussian pyramid of input image and difference-of-Gaussian (DoG) pyramids. The construction is shown in figure 1 left. To detect the local maxima and minima, each sample point is compared to its eight neighbours in the current image and nine neighbours in the scale above and below, as shown in figure 1 right. The point is selected if it is larger than or smaller than all of its neighbours. Thus, potential interest points which are invariant to scale and orientation are identified.

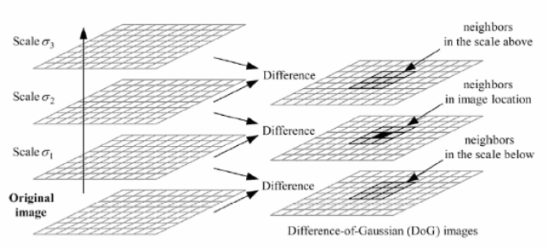


Figure 1: The SIFT pyramids: (left) Gaussian pyramids, (right) DoG pyramids.

Keypoint localization: There are some candidates chosen by last stage. This stage is to perform a detailed fit to the nearby data for location scale, and ratio of principal curvatures. The points which have low contrast or are edge-like, detected by Harris edge detector, are rejected.

Orientation assignment: to determine the keypoint orientation, a gradient orientation histogram is computed in the neighbourhood of the keypoint. The contribution of each neighbour pixel is weighted by the gradient magnitude as in equation (1) and a Gaussian-weighted circular window. Peaks in the histogram correspond to dominant orientations (equation (2)), thus one or more orientations are assigned to the keypoint according to the direction corresponding to histogram values within 80% of the maximum histogram value.

$$M_{ij} = \sqrt{(A_{ij} - A_{i+1,j})^2 + (A_{ij} - A_{i,j+1})^2} \qquad (1)$$

$$R_{ij} = \text{atan2}(A_{ij} - A_{i+1,j}, A_{i,j+1} - A_{ij}) \qquad (2)$$

In the above equation, A is the smoothed image, M is the magnitude of contribution and R is the orientation.

Keypoint descriptor: The descriptors are formed from a vector containing the values of all the orientation histograms entries. Histograms contain 8 bins each, and each descriptor contains a 4 × 4 array of 16 histograms around the keypoint. This vector is normalized to enhance invariance to change in illumination.

As shown in Figure 2 there are too many keypoints detected in the original sample image and a distort sample, which as seen most of them are of a good match in two image. Matched keypoints are emphasized by stars with the same colours.

2.2 Image Registration

Image Registration is a technique to align two image of the same scene or two identical or semi-identical images. This method is based on the use of control points or tie points, which are a subset of pixels whose location in two images is identical. There are various types of special transformation to the control points [13] and in this paper affine transformation is used as the registration method. It is a combination of scaling, rotating, shearing, and translation.

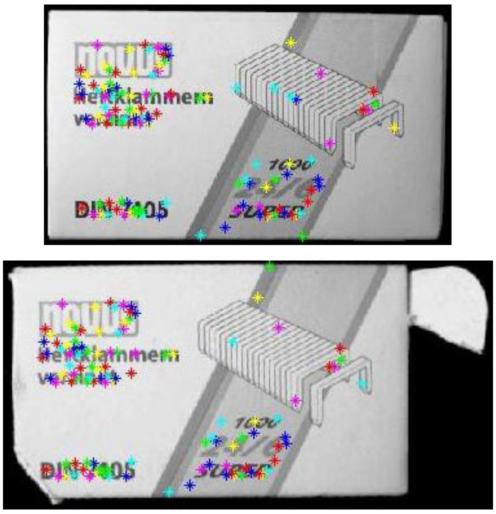


Figure 2: SIFT keypoints for an original sample and a distort one. keypoints are almost completely matched in two images.

2.3 Morphological Operations

Mathematical Morphology [13] is a technique for analysis and processing of geometrical structures based on set theory. There are two main operation in this technique namely dilation and erosion. Dilation is an operation that grows or thickens objects with a structuring element. Erosion on the other hand shrinks or thins objects. These two operators as well as opening and closing operators are used in the proposed method.

3 Proposed Automated Visual Inspection System

3.1 Hardware setup

Proposed AVI system has two main parts, Hardware architecture that consists of a simple PC with a CCD camera and image processing software that processes the images and detects various types of defects based on an image from the original sample. Because of using simple hardware and also using fast image processing algorithms the system is highly cost-efficient and applicable for small factories. Hardware setup of the system is shown in figure 3. To increase accuracy of the system, Camera has been stabilized at the top of sampling box. Although proposed algorithm has pre-processing stage to overcome illumination disturbance, the box light is stabilized by an illuminator so that the detection and measurements could be more accurate.

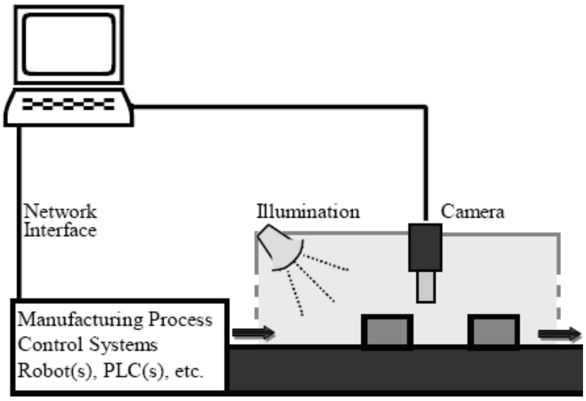


Figure 3: Hardware setup of proposed AVI system.

3.2 Proposed algorithm

For detecting and measuring defects, the algorithm consists of pre-processing, feature extraction, feature matching, image registration and fine tuning. Figure 4 shows the algorithm using block diagram. Each step's description is as follows:

Pre-processing: In this step, captured image's illumination and contrast is adjusted to prepare image for next steps. These adjustments will increase the accuracy and detection rate of the algorithm. For fast and less accurate applications, this step can be omitted.

Background elimination: Samples are captured in a controlled environment but there is some noise in the background that abates speed and accuracy of the algorithm. Background of the image was eliminated by detecting sample using Edge detection. A fast Canny edge detection detect the edges of the sample. Then image is dilated with a plus-like structural element. This morphological operator fills the sample area and next erosion operator with a diamond like structural element will remove extra spaces at the edge of the sample. After the sample pixels are identified, all other pixels of the image will be set to zero and will not be taken into account in next steps resulting in a speed up and increase in accuracy for next steps.

Compute SIFT: As described before, SIFT is used to compute keypoints and select them as control points for registration on some criteria described in next step. Figure 2 shows the result of SIFT on a sample image and its original sample image. The number of detected keypoints is noticeable and is numerous for registration. This will make the process of registration vey slow but accurate. To have a good trade-off between speed and accuracy, only some of these key points will be selected for registration.

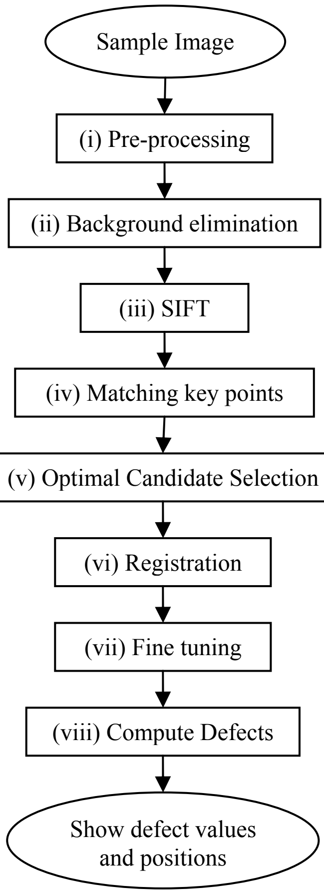


Figure 4: Proposed algorithm's block diagram.

Matching key points: keypoints matching algorithm uses Euclidean Distance between descriptor's vectors and a distance ratio, ratio of closest neighbour distance to that of second closest one, which was checked against a threshold to discard false matches. In fact each keypoint matches to a corresponding keypoint in the original sample image that has the smallest Euclidean distance and keypoints with a distance ratio larger than a predefined threshold will be omitted. Results show that this step will remove all false detected keypoints.

Candidate Selection: SIFT algorithm is originally designed for object recognition [14] and thus the number of key points detected by it is too much. Image Registration can be done by only three control points and with experiments show appropriate results with 7 to 20 control points. To speed up the process of registration, these keypoints were limited to at least 7 and at most 20 keypoints. Key points with Euclidean Distance to original sample keypoints less than a small predefined threshold value are selected as control points for registration. If the number of control points is less that 7 or more than 20, this threshold will increase or decrease appropriately until the control point number lies between 7 to 20 points. Figure 5 shows the result of these selections on the sample image. Matched keypoints are emphasising by stars with the same colours.

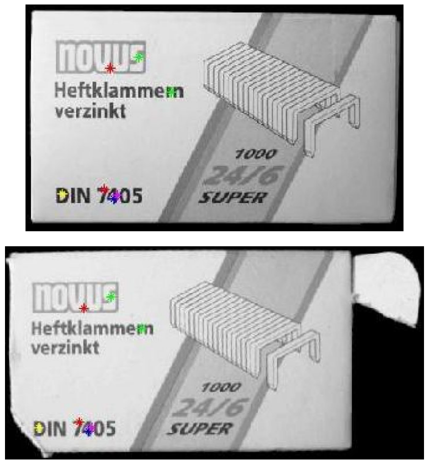


Figure 5: Selected control points for registration.

There is also another restriction on the control points selected for registration. Control points should be distributed on the sample to get better results, thus keypoints that are further far from each other have more chance of selection. This restriction is not working on all samples as you can see there is no good control point to be selected at the right side of figure 5.

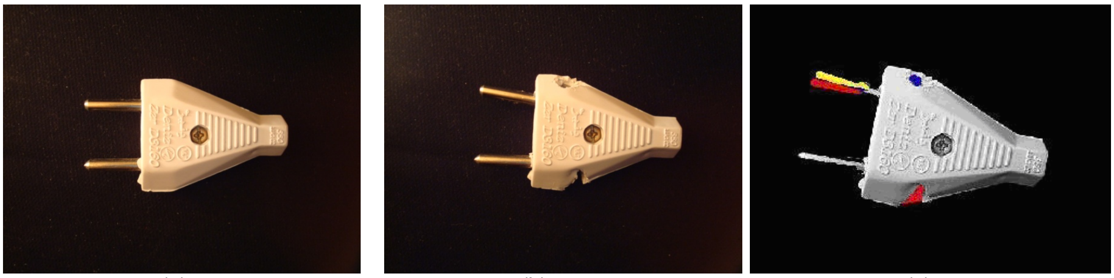
Image Registration: By using SIFT keypoints as control points for image registration in affine mode, the sample image is registered onto the base image to detect defects.

Fine Tuning: Registration has a blurring effect on the image because of pixel interpolation. Thus, as a tuning step; the image has been enhanced with a Laplacian filter to remove the blur effect. In addition, results show that even after a good registration there is a slight difference between the original sample and the current sample images even if they are the same. Thus a fine tuning algorithm is used to detect only real differences based on Least Squares method. The sample image is rotated in both direction and sum of deviations squared is computed and best angle that minimize this value is selected. Then the same step will detect the base place by transforming image in each of four directions and repeating the Least Square method. Experiments show that without this step, the algorithm accuracy will decrease about one percent.

Compute Defects: Finally in this step defects are computed and a decision on defect type is made. First the difference between the resulted image from the previous steps and the original sample image is computed. Each pixel in this difference is a candidate for defect with a probability proportional to the absolute value of the difference. To get rid of noise and result in better defect regions a repeated Opening operation is performed on the result with a Disk-like structural element. The radius of disk starts from 2 and is increased by one in each step. Each opening operation performs on the result of the previous step until the disk radius reaches 5. Each pixel is selected

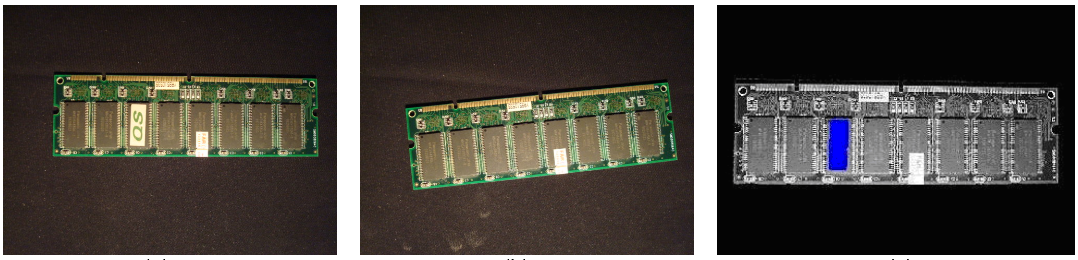
(a) (b) (c)

Figure 6: Result for a box. (a) Original sample, (b) damaged sample, (c) highlighted defects.



(a) (b) (c)

Figure 7: Result for a plug. (a) Original sample, (b) damaged sample, (c) highlighted defects.



(a) (b) (c)

Figure 8: Result for a RAM Module. (a) Original sample, (b) damaged sample, (c) highlighted defects.

as defect if its absolute value is larger than 0.4 of the maximum value.

At this point, all defect points are found. To decide on their types and compute percentage of defect, the result of background elimination step is used. Sample region detected in that step were considered as a base for computing the percentages and type of defects. All defect pixels that lie on the sample region and do not exist in original image are marked as *extra defects*. These pixels should not form a thin single pixel line, otherwise they will be eliminated from the result. *Missed defects* are detected in a reverse process and all other defects are treated as *surface defects*. With counting the number of pixels of all types, percentage of each defect and overall defect percentage were computed.

4 Results

To show that proposed method is applicable in different applications, different samples from different classes were used and damaged. The results are shown in figures 6 to 8. Table 1 summarize quantitative results for all three samples.

First sample is a box that was damaged by cutting some parts of it and ripping its door. Out method successfully detects defects and shows missed and extra parts (marked with red and yellow colour respectively). There was no surface defect in this sample and the surface defect value for this sample was near zero, as expected.

Second Sample is a plug with damaged pins, cut body and a hole within its body. All three types of defects can be seen in this sample and the algorithm precisely locates and calculates them.

Last sample tested the accuracy of the algorithm on detecting a missed label on a RAM module. The exact missed label position is located and highlighted in the third picture. This can be useful in detecting labels and lack of them on the productions.

Table 1: Defects of samples in percent.

	Missed	Extra	Surface	Overall
Box	0.722206	5.554717	0.019739	6.296662
Plug	3.551609	1.672290	0.450706	5.674605
RAM	0.000000	0.000000	2.858414	2.858414

5 Conclusion and future works

In this paper const-efficient Automated Visual Inspection system is proposed. This system is efficient for using in small and medium size manufacturing industries in both supervised and unsupervised environments. Results show that the proposed method has good abilities in detecting different types of defects. Samples used to test this system have surface, extra, and missed defects that system detects and identifies them correctly. Moreover, experiments with this system show that it is invariant to affine distortions as well as size and location of the samples in the image. The system output is both visually and quantitatively useful for detecting, measuring, and fixing defects. In addition, the system is cost-efficient in comparison to existing AVI systems, which makes it a good candidate for small manufacturing industries.

In its current form, however, the system should be optimized and tested in real manufacturing environments to show how much it is applicable.

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