Automatic IC orientation checks

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Abstract. With the proliferation of different types of IC packages, there is a need for machine-vision-based inspection systems to be able to efficiently identify the orientation of IC packages to ensure that they are shipped to end-users in the proper orientation. The orientation of IC packages can be determined by locating special features called notches or dimples, which are molded on the IC packages. This paper presents an algorithm that automatically checks the orientation of different types of IC packages. Our algorithm incorporates several procedures to achieve a fast and robust operation. Firstly, the boundary of the IC package is detected and aligned; then regions where the notch or dimple may exist are isolated. Adaptive double thresholding is applied in the selected regions to extract the possible notches or dimples. The extracted objects are then analyzed to determine whether they represent the notch or the dimple. In these procedures, intensity-based information as well as the gradient-based information is analyzed to generate a more comprehensive description of the features of interest.

Key words: Visual inspection of IC packages – Orientation identification – Notch/dimple detection – Adaptive double thresholding algorithm

1 Introduction

In the semiconductor industry, machine vision is extensively used in various stages of the IC-device-manufacturing process (Pau 1990; Rao 1996). Significant progress in surface mount technology has been made possible with the availability of IC devices in smaller packages, resulting in the ability to produce high-density printed-circuit boards (PCBs). However, the progress of automated final visual inspection based on machine vision techniques has lagged behind that of IC packaging technology (Zhou 1998). This results in a high reliance of human involvement in the final visual inspection to ensure that the IC products are produced to a high degree of quality.
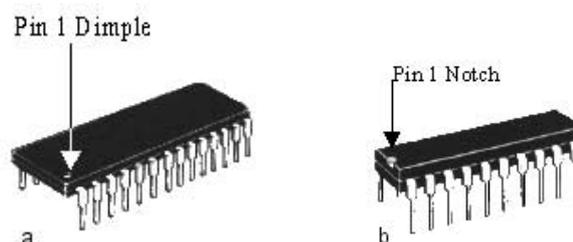
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Fig. 1. a A DIP IC package with a notch **b** A DIP IC package with a dimple

A crucial step in the final visual inspection is an orientation check of IC devices to ensure that they are shipped to end-users in the proper orientation so as to minimize problems with auto- insert machines for PCB assembly. The orientation of IC packages can be determined by locating special features called *notches* or *dimples*, which are molded on the IC packages. The notches and dimples are depressions on the IC package that indicate the device's first pin. Usually, the shape of a notch is a partial ellipse, while that of a dimple is a circle, and their sizes vary for different IC packages. Figure 1 shows two DIP (Dual Inline Package) IC packages, one with a notch and the other with a dimple. The contrast between the notch or dimple, and the rest of the IC package can be small, and varies depending on the texture and material of the IC package. This can make the notch or dimple difficult to detect using straightforward thresholding methods.

Our algorithm is capable of efficiently identifying various types of dimples and notches on IC packages. Its speed and robustness make it ideal for deployment in an industrial setting. The algorithm first detects the boundaries of the IC package before attempting to locate the notch or dimple in automatically selected regions of the package. A comprehensive description of the boundary points is derived using histogram analysis and edge detection (Jain et al. 1995). The alignment of the IC package is subsequently identified using the least squared error (LSE) fitting method or with the more robust least absolute deviation (LAD) fitting method depending on the data fitting error. To isolate the notch and dimple in selected regions of the IC package, we propose an adaptive double threshold method to account for the differ-
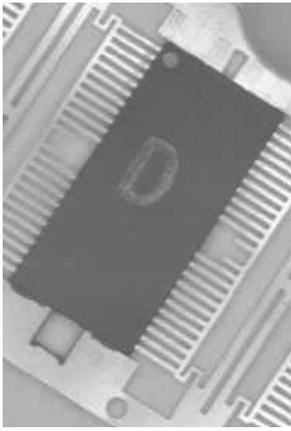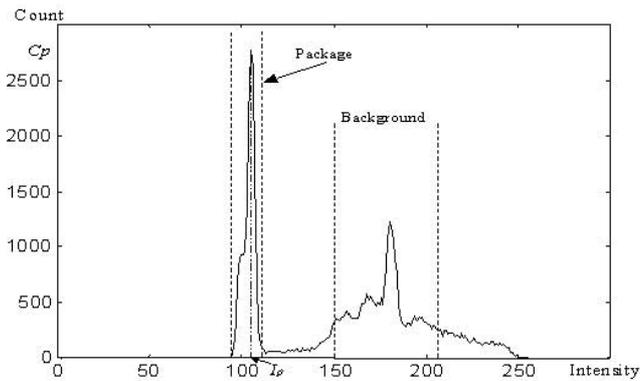
Fig. 2. An IC package with a dimple

Fig. 3. The histogram of Fig. 2

Fig. 4. Checking for the isolated edge points inside the IC package

Fig. 5. The detected boundary of the IC package in Fig. 2

ent intensity contrasts. The notch/dimple identification procedure is then performed to determine whether the isolated objects contain a notch or a dimple.

2 IC orientation-checking algorithm

Before the algorithm can be applied, suitable lighting is required to obtain a good image of the IC package (as shown in Fig. 2), which we define as follows:

– the IC package must be clearly visible, while the pin leads need not be so,
– the package must be uniformly illuminated as much as possible, and
– the chosen background must be brighter than the IC package.

A ring of LEDs was used to provide uniform illumination over the IC package. In Fig. 3, which is the histogram of the IC package in Fig. 2, the difference between the intensity range of the IC package and that of its brighter surrounding background is evident. The intensity range of the package region is basically about the peak intensity I_p in the lower half of the histogram.

2.1 IC boundary detection

The detection of the outline or boundary of the IC package is complicated by the presence of the pin leads, markings and
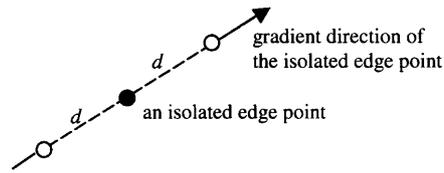
other features on the package. Ramp edge detection (Petrou and Kittler 1991) is not suitable for this case since it results in edges due to the pin leads, which should be removed by some degree of post-processing.

We use a multi-step process to identify the IC package's boundary points. The edge characteristics of boundary points are first extracted by applying a small threshold on the gradient image computed using Sobel operators (Jain et al. 1995). This ensures that all the pixels on ramp edges are included. Next, false boundary points outside the IC package are eliminated if some of their distant neighbors are not located on the IC package. This is accomplished by checking whether the intensity of the neighboring pixels lie within the intensity range of the package. Finally, an isolated edge point inside the IC package is removed if the intensity difference between two points located on its gradient at a distance d, as illustrated in Fig. 4, is not distinct enough to account for a ramp edge.

This multi-step boundary detection approach effectively detects the boundary of the IC package. The boundary of the IC package in Fig. 2 as identified by this approach is shown in Fig. 5.

2.2 IC package alignment

After the boundary of the IC package is extracted, the package is aligned with the horizontal axis using a two-step procedure. The first step involves the computation of the orientation angle θ by a line-fitting algorithm and the second step involves identifying the location of the top-left corner of the IC package.

The extracted boundary of the IC package basically consists of several linear segments on four perpendicular sides, as shown in Fig. 5. Thus, the alignment of the IC package can be determined by applying line-fitting techniques

to evaluate the orientation angle θ of the major line segment, which is the segment with the most connected pixels. Before applying the line-fitting methods, a data set consisting of pixels with similar gradient angles on the major line segment is formed and then the orientation angle θ of the segment is computed using LSE line-fitting method (Jain et al. 1995) as follows:

$$\tan \theta = \frac{a}{b+c},$$

with

$$a = 2\sum_{i=1}^{N} x_i' y_i', b = \sum_{i=1}^{N} x_i'^2 - \sum_{i=1}^{N} y_i'^2, c = \sqrt{a^2 + b^2} \qquad (1.a)$$

and

$$x_i' = x_i - \frac{1}{N}\sum_{j=1}^{N} x_j, y_i' = y_i - \frac{1}{N}\sum_{j=1}^{N} y_j, \qquad (1.b)$$

where x_i and y_i are the coordinates of the points in the data set, and N is the number of these points. In this approach, the equation of the fitted line is

$$\rho = \frac{1}{N}\sum_{j=1}^{N} y_j \cos \theta - \frac{1}{N}\sum_{j=1}^{N} x_j \sin \theta. \qquad (1.c)$$

The computed angle θ will be accurate when the number of boundary points in the data set is large and there are no outliers (i.e., points far from the fitted line) in the data set. Outliers produce much error in the evaluation of the alignment angle θ. In such instances, a more robust fitting method using LAD criterion (William et al. 1992) is applied to iteratively evaluate a and b in $y = a + bx$ as follows:

$$a = median\{y_i - bx_i\} \text{ and } 0 = \sum_i x_i \text{sgn}(y_i - a - bx_i), \quad (2)$$

in which sgn(0) is interpreted as zero. Then the orientation angle $\theta = arctg(b)$. Once the alignment angle θ is found, the boundary image (as in Fig. 5) is aligned to the horizontal axis by rotating it anti-clockwise by θ. Next, the horizontal and vertical projection profiles of the rotated boundary image are computed, and the position corresponding to the upper left corner of the IC package is obtained by locating the first maximums along the vertical and horizontal projection profiles.

2.3 Notch and dimple detection

The first pin of every IC device is indicated either by a notch or a dimple. Although IC packages come in different sizes, notches and dimples are located in specific regions on the packages. As illustrated in Fig. 6, notches are normally located in the middle of one side (usually the shorter side) of the IC package while dimples are located at one of corners. Once the boundary of the IC package is identified and the alignment correction is made, the notch or dimple detection can be performed in the specific regions on the IC package, i.e., areas of interest (AOIs), as shown in Fig. 6.

The square-shaped AOIs should be large enough to include all possible sizes of notches and dimples. For rectangular IC packages, one third of the length of the shorter side
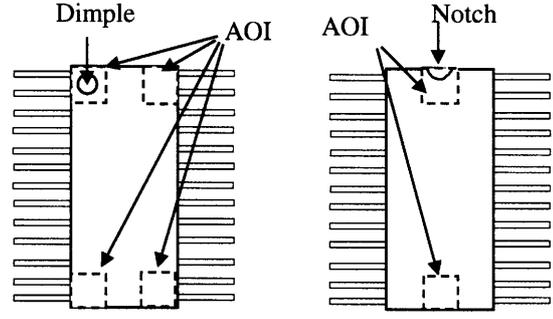

Fig. 6. The top view of notches, dimples and the AOIs on IC packages

of the package was found to be a suitable size for the AOI, while for square IC packages, one quarter of the package length was found to be suitable. The intensity and the gradient information in these AOIs come from the corresponding parts of the intensity and the gradient image of the IC package, obtained during the boundary detection procedure.

2.3.1 Image segmentation in the AOIs

In the AOIs of the IC package, edge-based segmentation is used to extract features of interest, i.e., those representing the notch/dimple. To achieve a fast operation, a thresholding scheme is applied on the edge image. However, as the intensity contrast between the dimple/notch and the rest of the IC package may be significantly different for different types of IC packages and different lighting set-ups, the issue of threshold selection becomes very crucial for successful segmentation. We used the adaptive double thresholding method (Jain et al. 1995) on the edge image of the AOI to segment/isolate the notches/dimples in the AOI. The double thresholding scheme involves

i. selecting two thresholds T_1 and T_2;
ii. partitioning the AOI into three regions: R_1 containing all pixels with gradient magnitude below T_2; R_2 containing all the pixels with gradient magnitudes between T_1 and T_2 (inclusive); and R_3 containing all pixels with gradient magnitudes above T_1;
iii. visiting each pixel assigned to region R_3 and if the pixel is the end of a contour and has a neighbor in region R_2, then the neighbor is assigned to R_3; and
iv. repeating step (iii) until no pixels are reassigned.

The values of intensity thresholds T_1 and T_2 are derived using the *P-Tile* method (Jain et al. 1995). The P-Tile method uses an estimate of the size of the desired features based on a percentile P_n to determine the intensity threshold T_n using the following equation:

$$\sum_{x=T_n,255} h(x) = \frac{P_n}{100} \cdot \sum_{x=0,255} h(x), \qquad (3)$$

where $h(x)$ is the histogram value at intensity x. The segmented region produced by the double thresholding method based on thresholds T_1 and T_2, is analyzed to determine whether it corresponds to either a dimple or a notch (this procedure is discussed in Sect. 2.3.2). If it is found to be
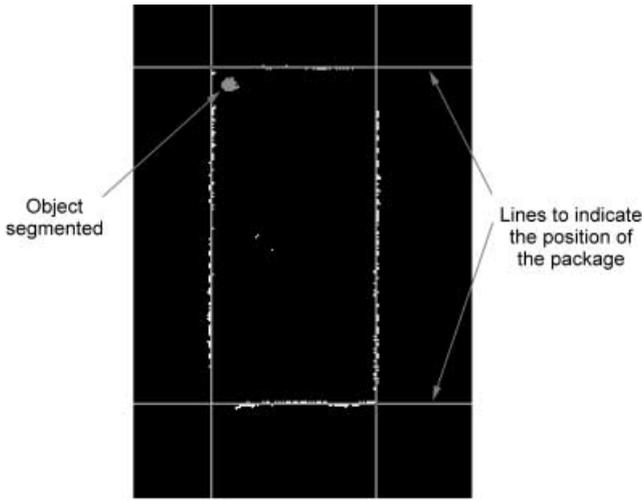
Fig. 7. The segmentation result of Fig. 2

2.3.2 Notch/dimple identification

For the each object segmented using the double thresholding scheme in the AOIs, we need to determine whether it is a notch or a dimple. If the dimple or notch is not found, the threshold pair (T_1, T_2) will be updated and segmentation based on double thresholding will be performed again. The shape of the circular dimples or elliptical notches is not easily identified because their boundaries vary substantially due to the limited resolution and lighting effects. Instead, region-based analysis (Sonka et al. 1993) is used in the identification process to achieve a fast and robust identification of notches and dimples.

The descriptors used in the region-based analysis include the region area and the region position. By checking such properties, the noise spots will be excluded. To distinguish the notch/dimple and other features on an IC package, such as mold marks and character markings, descriptors based on projection profiles are used. These descriptors include the maximum position, width and length along the vertical and horizontal projection profiles. There are also additional criteria to distinguish between dimples and notches as the dimple is circle- shaped and the notch is part of ellipse-shaped (Zhou 1999).

2.4 Algorithm description

The complete algorithm for checking the orientation of IC packages can be summarized as follows.

i. The boundary of the IC package is extracted using histogram analysis and gradient image analysis.
ii. The alignment of the IC package is identified by grouping the connected boundary points of similar gradient direction, and evaluating the package orientation using the LSE or LAD fitting method.
iii. The boundary image is aligned to the horizontal axis.
iv. Package position within the image is determined using projection profile analysis.
v. Notch/dimple detection is then performed by
    a. selecting the AOIs where notches or dimples may exist,
    b. initializing the thresholds of the double thresholding method,
    c. segmenting the gradient image of each AOI to extract the regions of interest using the double thresholding scheme,
    d. for each segmented object, region-based analysis is performed to ascertain whether it is a notch or a dimple,
    e. if there is no notch or dimple in the AOI, the thresholds are updated using Eqs. 3 and 4, and the procedure continues from **step c**. If the updated threshold reaches its lower bound, then the procedure continues from **step f**.
    f. the intensity image is segmented using the double thresholding method.
vi. If the notch or dimple is detected, the position of the notch/dimple will be evaluated.

neither a dimple nor a notch, the double thresholding procedure is repeated with revised thresholds based on adaptively updated percentile values. The procedure to update the percentile values is based on the fact that images formed at lower percentile values (i.e., higher intensity thresholds) will contain more "gaps" (i.e., unconnected border segments) but fewer "noise spots". We associated the updating procedure with the number of pixels and gaps in region R_3 as follows:

$$P_1^{k+1} = P_1^k + \tau \frac{N_{k-1}}{N_k}; P_2^{k+1} = P_2^k + \tau \frac{N_{k-1}}{N_k} \left(1 + \frac{N_p^k}{N_C}\right);$$
$$k = 1, 2, ., \text{ and } N_0 = N_1, \qquad (4)$$

where τ is the fixed updating step size, N_k and N_{k-1} are the number of pixels in region R_3 formed with thresholds based on percentile pairs (P_1^k, P_2^k) and (P_1^{k-1}, P_2^{k-1}), respectively, N_p is the gap number in region R_3, N_C is a fixed number to control N_p and (P_1^1, P_2^1), is set as (3%, 10%). The segmented object (points in R_3) becomes more and more complete as the thresholds are updated. Percentile P_1 is updated by smaller amounts when the number of points in R_3 increases substantially, and vice versa. The updating of percentile P_2 is also controlled by the gap number N_p so as to obtain more complete features.

The notch or dimple in the AOIs is extracted using the adaptive double thresholding method with fewer steps of threshold updating when the features have good contrast with respect to the background. Figure 7 shows the segmented object (located at the top-left corner on the package), and the parameter settings used in the threshold updating are: $\tau = 3$ and $N_c = 5$. The dimple in Fig. 2 has good contrast with respect to its background and the thresholds were updated three times to obtain the result.

When there is much intensity variation inside the dimple/notch area due to the uneven characteristics of the depression area, segmentation based on edge characteristics does not work and the adaptive double threshold procedure is performed on the intensity magnitude of the AOIs to segment the features.
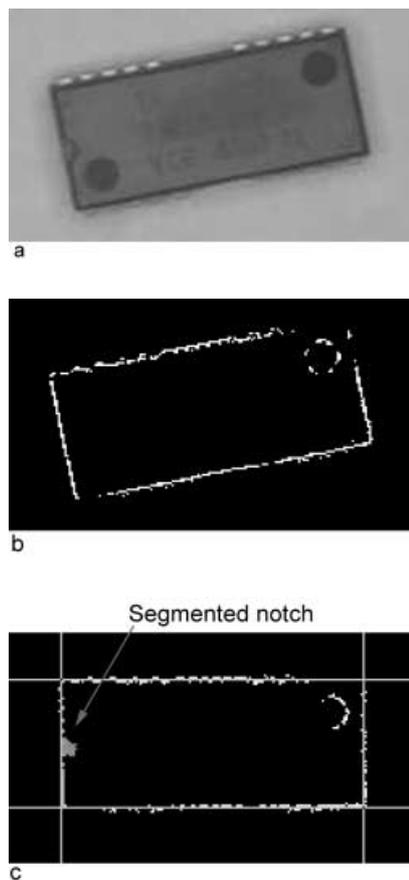
Fig. 8. Notch Detection Example **a** IC package Image; **b** Boundary of the IC package; **c** The detection result superimposed on the aligned package

3 Experiments

The effectiveness of our algorithm was tested using different types of DIP and small-outline (SOP) IC packages. Images of the IC packages were captured at a resolution of 4.5 mils/pixel using a ring LED lighting set-up. At lower resolutions, the resulting features were too small for the notch/dimple detection process. The images of the IC packages (as in Figs. 2 and 8a) were similar to that captured by industry-standard IC package inspection set-ups ensuring real-world applicability.

The algorithm was tested with images of 100 DIP and 100 SOP IC devices that were placed at different orientations (from 0° to 180°). The algorithm was able to correctly detect the notch or dimple in all images, irrespective of the orientation of the package. Dimple detection is illustrated in Figs. 2, 5, and 7, while Fig. 8 illustrates the detection of a notch. Figure 8a is the original image of an IC package, while the detected boundary of the package is shown in Fig. 8b. Part of the IC package is undetected because the illumination by the LED ring lighting set-up is not entirely uniform. However, the process is not impaired and the boundary image is correctly aligned and the notch is detected successfully, as illustrated in Fig. 8b and 8c. The shape of the notch detected in the AOI of Fig. 8c is not exactly part of an ellipse because of limited resolution and the shadow effects of the notch. Threshold updating is performed twice

in this example, as there are strong edge characteristics on the border of the notch in the image.

On a Pentium 166 PC, the average running time of the algorithm was about 200 ms for a 200 by 150 image of an IC package. The exact computation time for a specific case depends on the alignment of the IC package and the intensity contrast between the notch/dimple and the surrounding region in the AOI on the IC package.

4 Concluding remarks

In this paper, we propose a fast and robust algorithm to automatically check the IC orientation by locating the notch or dimple on the IC package. The algorithm proceeds by first deriving a comprehensive description of the IC boundary and then realigning the IC package image with the horizontal axis. Next, the adaptive double thresholding method is used to extract the features of interest in the automatically selected areas. Experiments conducted in controlled lighting environments, similar to that used in industry-standard IC inspection equipment, clearly show that our algorithm is able to correctly and rapidly detect notches and dimples at appropriate resolutions on different types of ICs.

Similar techniques can be used to analyze other molded features on IC packages and can also be adopted for inspection processes in the automatic assembly of other small electronic components (You et al. 1990).

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