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Research on Seal Ring Defects Inspection Algorithm Based on Clustering Analysis

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Abstract: In order to detect the defects of the seal, a seal ring defects inspection algorithm based on clustering analysis was proposed. Firstly, template matching was used to update inspection coordinate system of the collected image and extract the seal ring. Secondly, the image was processed with methods such as median filter and automatic thresholding operation and the edge points were found by edge detection, stray points were removed by mathematical morphology. Thirdly, an advanced circle fitting method based on Least Square Principle (CBL) was proposed to get a fitting circle of the seal ring and inspect the defects with clustering analysis while the fitting circle was set as one class like all the edge points set as one. After defects inspection samples include 500 seal rings, the algorithm proposed with an inspection accuracy rate of 95.2% which proved that an effective defects inspection algorithm to the seal was found.

Key words: Seal ring, defects inspection, automatic thresholding operation, advanced CBL, clustering analysis

INTRODUCTION

Seal is a common industrial product and plays an important role in industrial production. But the production influenced by various uncertain factors in the productive process easily which lead the seal appearing defects such as deformation, scratch and pollution which badly influence the quality of the seal products, degrade the seal performance, trigger all kinds of potential safety hazard, so defects inspection in the production of seal is necessary. For manufacturing process reason, deformation defects mainly exist in the seal inner ring, as shown in Fig. 1. For seal defects inspection, the traditional artificial visual inspection method is susceptible to missing inspection and false inspection, also the large seal production enhance the need of an efficient and automated inspection system. This article proposed the method of machine vision inspection for seal defects which is accurate and automated.

According to the features of seal inner ring, deformation defects inspection with machine vision ultimately come down to circle defects inspection. Traditional circle defects inspection methods mainly are Hough transform and Least squares method (Zhang, 2010) and other relevant fitting methods, although the fitting accuracy of these methods is high which are susceptible to the noise and stray points and outliers, leading to the fitting circle departing the ideal circle widely and causing the circle defects inspection rate is not high. Clustering analysis finds the similarity of samples by the distance between the samples for defects classification (Qiao *et al*., 2009), widely used in defects inspection, but the defects class number is affected by the spacing value between classes which leads to defects inspection inaccurate. This paper proposed that the fitting circle set as a class while each edge point set as a class, then simple clustering analysis the classes to inspecting defects. To inspecting defects accurately, the circle fitting accuracy is essential, therefore, the study proposed an advanced least square circle fitting which adopt the normal least square fitting method to get a fitting circle firstly and then calculate the weighted values of each edge point by the distance of each edge point to the fitting circle and get the fitting circle again with the edge points by the weighted value.

The proposed seal ring defects inspection algorithm based on clustering analysis which sets a new inspection coordinate system of the collected images with template matching and then extracts the seal image according to the coordinate system and then adopts the median filtering and automatic thresholding operation and mathematical morphology to preprocessing the extracted seal. Process the preprocessed seal image with edge detection and get the edge points, fit circle of the seal inner ring with the advanced CBL and then inspect the defects with clustering analysis while the fitting circle set as one class like all the edge points.

PROPOSED METHOD

Problem description: Seal inner ring defects are shown in Fig. 1, As for the principal reason of manufacturing process, the inner ring appears concave deformation

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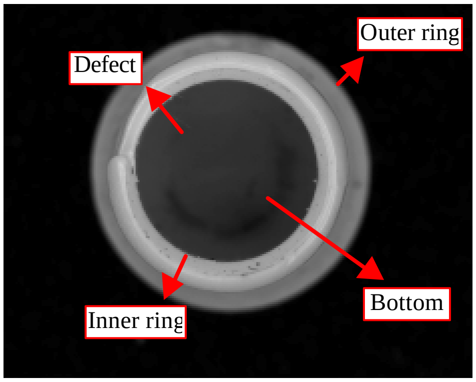

Fig. 1: Defective seal

defects commonly which not only influence the product appearance and quality, but also produce safety hazard for the distorted seal get stuck in the automatic loader and unloader easily. There disadvantages lead the seal production not conducive to automatic production. Human inspection is a traditional way to remove defective bearings which is instable and time consuming. So a high accuracy and automatic inspection system for defects in seal is especially needed.

Inspection algorithms: Aiming at the problems above, we develop a machine vision system for seal defects inspection and propose a kind of seal ring defects inspection algorithm based on clustering analysis. As shown in Fig. 1, seal defects mainly on the surface of the inner ring, the camera needs to focus on the inner ring when collecting defects images. The collected image will be able to eliminate the outer ring and the bottom when the inner ring and the defects can be remained after automatic thresholding operation and then the inner ring defects can be detected by the seal ring defects inspection algorithm, the ring defects inspection algorithm flow chart is shown in Fig. 2.

The image collected by image acquisition system may contain material guide rail or other seals, etc. which affect the seal defects inspection, so the seal should be extracted from the image collected first; The image template matching is adopted to establish a new coordinate system of the collected image and then extract the seal from the collected image in accordance with the new coordinate system; Adopt the median filtering and automatic thresholding operation and mathematical morphology to preprocessing the extracted seal; Edge detection the preprocessed seal image and get the edge points, fit circle of the seal inner ring with the advanced CBL and then inspect the defects with

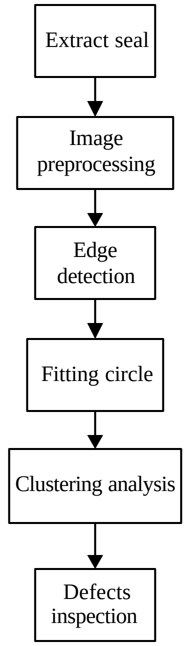

Fig. 2: Flow chart of proposed algorithm

clustering analysis while the fitting circle set as one class like all the edge points.

IMAGE EXTRACTION AND PREPROCESSING

Seal image extraction: The image collected may contain material guide rail or other seals, etc., which affect the seal defects inspection and are unfavorable to seal defects automated inspection, so the seal should be extracted which is convenient for subsequent image defects inspection. Template matching is a technique in digital image processing for finding small parts of an image which match a template image. It can be used in manufacturing as a part of quality control, a way to navigate a mobile robot, or as a way to detect edges in images. Template matching is adopted to establish new coordinate system of the collected image and then extract the seal from the collected image according to the new coordinate system, the template matching result is shown in Fig. 3.

Median filter: In the process of collection, transmission and transformation, the seal image will inevitably produce noise which mainly include salt and pepper noise and random noise and impulse noise. The noise will cause bad quality of the seal image, seriously affect the seal defects inspection, so it is necessary to preprocess noise removal before defects inspection of seal image. Due to the seal image is more likely to exist salt and pepper noise and to ensure clear edge information in

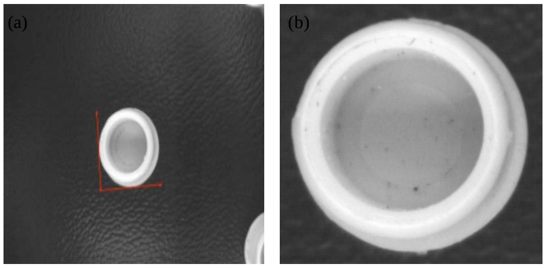

Fig. 3(a-b): Template matching result of (a) New coordinate system and (b) Extracted seal

the subsequent inspection. Median filter was chosen for image noise removal which replace each pixel value with the median of the gray values in the local neighborhood, are very effective in removing salt and pepper and impulse noise while remaining image details because they do not depend on values which are significantly different from typical values in the neighborhood (Shen *et al*., 2011).

Advanced automatic thresholding: After median filtering, in order to detect the defects of seal inner ring, the target image (the inner ring) must be separate from the background. The camera focused on the inner ring when image acquisition, so processing the collected image with thresholding can remain the inner ring and defects at the same time eliminates the outer ring and bottom and makes the inner ring independent from background. Thresholding is a method to convert a gray scale image into a binary image so that objects of interest are separated from the background. A binary image is obtained using an appropriate segmentation of a gray scale image. If the intensity values of an object are in an interval and the intensity values of the background pixels are outside this interval, a binary image can be obtained using a thresholding operation that sets the points in that interval to 0 and points outside that range to 255 (Shi *et al*., 2004).

Let us assume that a binary image g(x, y) which is obtained using a threshold T for the original gray image f(x, y). Thu:,

$$g(x,y)=\begin{cases}255 & f(x,y)\geq T\\ 0 & f(x,y)<T\end{cases} \quad (1)$$

The binary image will be divided into two areas after thresholding, the objects and the background. Threshold is the key of thresholding which can decide the result of thresholding and makes the image processed remain the object information as much as possible while minimize the interference of background and noise as far as possible.

As the change of workshop lighting environment, the best segmentation threshold of seal defects and background also in change, the best threshold of different image is various also. Therefore, the same threshold values may not work in a new domain, the threshold should be adaptive for different images.

Automatic thresholding of images is often the first step in the analysis of images in machine vision systems. Many techniques such as iterative threshold method (Ohlander *et al*., 1978), OTSU (Otsu, 1979), MEM (Kapur *et al*., 1985), minimum error threshold method (Kittler and Illingworth, 1986), have been developed to select a proper threshold value automatically with the intensity distribution in an image and the information about the objects of interest. But automatic thresholding operation will be complexity and time consuming with the improvement of automation. According to the features of seal inner ring, this paper proposed an average threshold method which is efficient to inspect inner ring defects and deduces a specific average weighted coefficient α which suitable for seal. The average threshold method algorithm getting image grayscale average and set coefficient automatically, is simple and strong real-time performance and adaptive well. Formula as follows:

$$T=\alpha*\frac{\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}f(x,y)}{M*N} \quad (2)$$

α is the coefficient f(x, y) is the original image gray,M is the width of the image, N is the height of the image. The threshold is decided by the weighting coefficient α which is affected by the interference of image background. If α is too large, the shape of inner ring and defects will loss, but threshold is strong anti-interference; If α is too small, the inner ring and defects shape is lossless, but the false target like outer ring and bottom will appear which affect the inner ring defects inspection. α should make the inner ring and defects separated from the seal image well after thresholding.

Let us assume that seal image background gray value f_0, inner ring and defects part gray value f_t.Thus:

$$\alpha=\frac{f_b+\frac{f_t-f_b}{3}}{f_b} \quad (3)$$

Automatic thresholding operates the seal image with the threshold decided by Eq. 3 and 4 which makes the inner ring and defects part separated from the outer ring and bottom, low interference and well thresholding, as shown in Fig. 4.

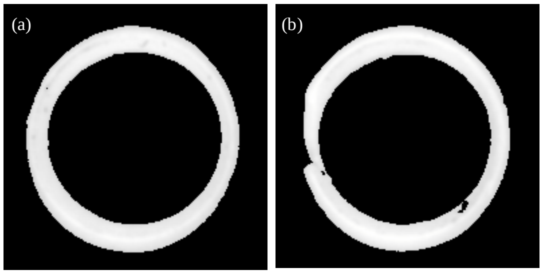

Fig. 4(a-b): Advanced automatic thresholding operation of (a) Qualified seal and (b) Defective seal

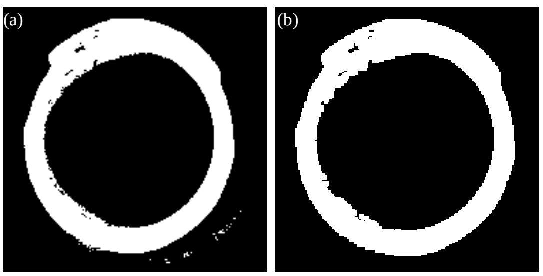

Fig. 5: Morphological opening operation

Mathematical morphology: The interference of workshop environment, the existence of dust and oil and other interference in the image and the noise in the cameras, will produce stray points in the seal image although after denoising and automatic thresholding operation. Stray points not only interfere the edge detection but also affect the judgment of defects point which must be removed. In mathematical morphology, an erosion followed by a dilation with the same structuring element will remove all of the pixels in regions which are too small to contain the probe and it will leave the rest. This sequence is called opening. Opening can remove isolated point, burr and bridges while overall location and shape remain the same which can effectively remove stray points in the seal image, as shown in Fig. 5.

ADVANCED CBL

According to the proposed algorithm, the fitting circle was set as one class when defects inspection with clustering analysis, so the accuracy of circle fitting decide the accuracy rate of defects inspection. Traditional least square circle fitting method fitting with all the edge points, although with high fitting precision, is susceptible to the noise and outliers, leads to a low fitting accuracy. The low accuracy fitting circle will result in erroneous judgement when defects inspection with clustering analysis. Therefore, it is important to advance the traditional least square circle fitting method.

The traditional least square circle fitting method based on the principle of minimum Mean Square Error (MSE), minimize the sum of squared residuals of fitting circle between practical circle in the image.

Assume that the centre of fitting circle (a, b), the radius of fitting circle r, the edge points set N, thus the MSE by the CBL as follows:

$$\varepsilon_i^{\ 2} = \sum_{i \in N} \left[(x_i - a)^2 + (y_i - b)^2 - r^2 \right]^2 \tag{4}$$

$\epsilon_i^{\ 2}$ partial differential a, b, r, then set partial differential value to zero, simplify the formula as follows:

$$\begin{cases} a^2 - 2xa + b^2 - 2yb - r^2 + \overline{x^2} + \overline{y^2} = 0 \\ xa^2 - 2\overline{x^2}a + xb^2 - 2\overline{xy}b - xr^2 + \overline{x^3} + \overline{xy^2} = 0 \\ ya^2 - 2\overline{xy}a + yb^2 - 2\overline{y^2}b - yr^2 + \overline{x^2 y}\overline{y^3} = 0 \end{cases} \tag{5}$$

where the moment of x, y is:

$$\overline{x^m y^n} = \frac{1}{N} \sum_{i \in N} x_i^{\ m} y_i^{\ n} \tag{6}$$

Thus, the centre (a, b) and the radius r as follows:

$$(a, b) = \begin{bmatrix} \frac{1}{2}\left[x(\overline{x^2} + \overline{y^2}) - \overline{x^3} - \overline{xy^2} \right] \\ \frac{1}{2}\left[y(\overline{x^2} + \overline{y^2}) - \overline{y^3} - \overline{x^2 y} \right] \end{bmatrix}^T \begin{bmatrix} x^2 - \overline{x^2} xy - \overline{xy} \\ xy - \overline{xy} y^2 - \overline{y^2} \end{bmatrix}^{-1} \tag{7}$$

$$r = \sqrt{a^2 - 2xa + b^2 - 2yb + \overline{x^2} + \overline{y^2}} \tag{8}$$

The traditional least square circle fitting method fits circle with all the edge points, gets a high fitting precision circle, as shown in Fig. 5a. The method works well while the discrete points under the condition of relatively homogeneous, the fitting circle is very accurate and stable, but works bad while the points are dispersive, especially when there are outliers in the points, the fitting circle differs the practical circle a lot (Liu *et al*., 2004).

In order to eliminate the noise of stray points especially the interference of outliers, the advanced least square circle fitting method fit circle with the edge points weighted. Firstly, get a fitting circle by the traditional least square circle fitting method and then calculate the shortest distance between every edge point and the

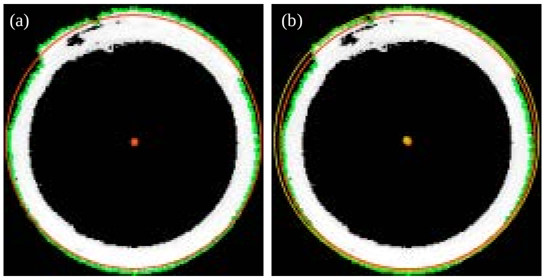

Fig. 6(a-b): Fitting circle results of (a) Traditional method and (b) Advanced method

fitting circle which will decide the weight of each edge point in the subsequent iterations. Because of the large outliers may hinder the algorithm convergence to the correct solution, so the RANSAC algorithm may be required in extreme cases (Fischler and Bolles, 1981).

Assume the edge points $(x_i, y_i) = (i = 1, 2, 3, \ldots, N)$, so the distance absolute value between each point and the fitting circle is:

$$|d_i| = \left|\sqrt{(x_i - a)^2 + (y_i - b)^2} - r\right| \tag{9}$$

Thus, the average value of the absolute distance as follows:

$$D_m = \frac{1}{N}\sum_{i=1}^{N}|d_i| \tag{10}$$

The weighting coefficient is:

$$k = \left|\frac{D_m}{d_i}\right| \tag{11}$$

After the weighting coefficient of each point is calculated, fit circle with the edge points multiplied by weighting coefficient by the traditional least square circle fitting method iteratively, the new fitting circle will be more accurate, as shown in Fig. 6b. The green points stand for the edge points, the red fitting circle stands for the traditional methods fitting circle, the yellow fitting circle stands for the advanced algorithm fitting circle. Can be seen from the Fig. 6, the advanced algorithm fits much higher accurately than traditional methods and is relatively undisturbed by the noise and outliers and is robust.

The result of the advanced least square circle fitting method is prominent, the details of the fitting circle fit by the advanced CBL is shown in Fig. 7. The advanced CBL can be seen from the figure is not affected by the defects point and the fitting circle is very accurate which is helpful to subsequent defects inspection.

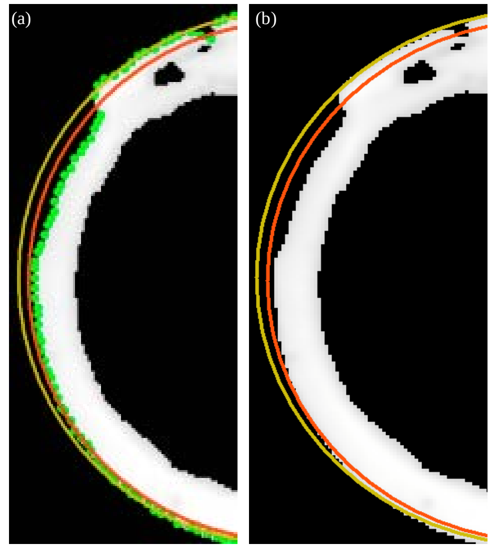

Fig. 7: Details of fitting circle

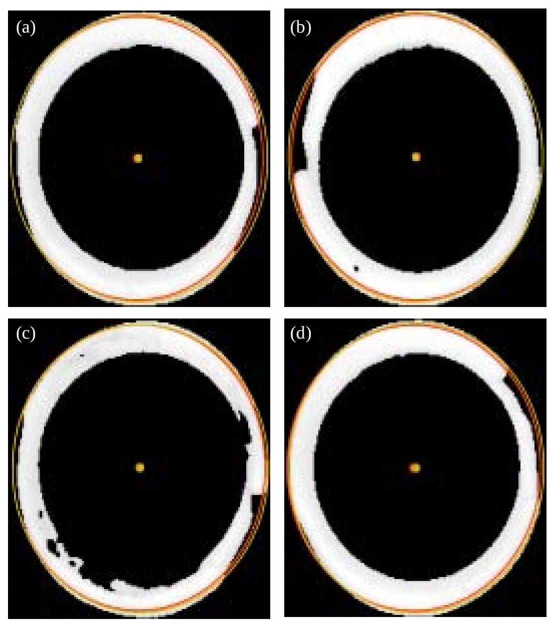

Fig. 8: Results of advanced CBL

Fit different seal ring containing defects with the advanced least square circle fitting method, results are shown in Fig. 8 which prove that the advanced method is not affected by the defects and fits circle accurately and precisely.

DEFECTS INSPECTION WITH CLUSTERING ANALYSIS

Defects inspection will proceed after image preprocessing and circle fitting with the advanced least square circle fitting method. Due to the inner ring defects rendered into the random shape, the defects points must also show no rules after edge detection, so we proposed a method which classifies the defects points and qualified points with clustering analysis. Clustering analysis can classify the samples and separate them which is according to a certain standard to divide the samples into different classes, making the samples in each class similar as far as possible and the gap between classes as big as possible, lead to the same samples gathered as much as possible and the different samples separated as far as possible which separates the defects points from the edge points completely (Yang, 2005).

Clustering analysis is the key of defects inspection, as the distance between the qualified inner edge points and the fitting circle is shorter than the distance between defects points and the fitting circle, so distance classification is used to clustering analysis. Distance classification which calculates the distance d_{ij} between two points, the smaller the value indicates the closer between two points and the greater the value shows the farther between two points. Calculate the distance d_{ij} between any two points, Arranged to matrix D:

$$D = \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \dots & \dots & \dots & \dots \\ d_{n1} & d_{n2} & \dots & d_{nn} \end{bmatrix} \quad (12)$$

where, D is a real symmetric matrix and $d_{11} = d_{22} = \dots = d_{nn} = 0$. Classify the edge points according to D, the points closer classified to one class, the points farther classified to another. Combining with the features of seal ring defects, this study adopts the shortest distance method of clustering analysis to seal defects inspection. Steps as follows (Sun *et al*., 2008):

- Assume that the edge points set $S = \{p_1, p_2, \dots, p_n\}$, has n samples, classify each sample p_i to one class, the fitting circle p_c classify to another class, thus there are n+1 classes $p_1, p_2, \dots, p_n, p_c$
- Find out the class which is similar most with p_c from all the points classes p_i. Due to this paper adopting the method of distance classification, so just find out the class p_i which is closest between the fitting circle p_c, the formula as follows:

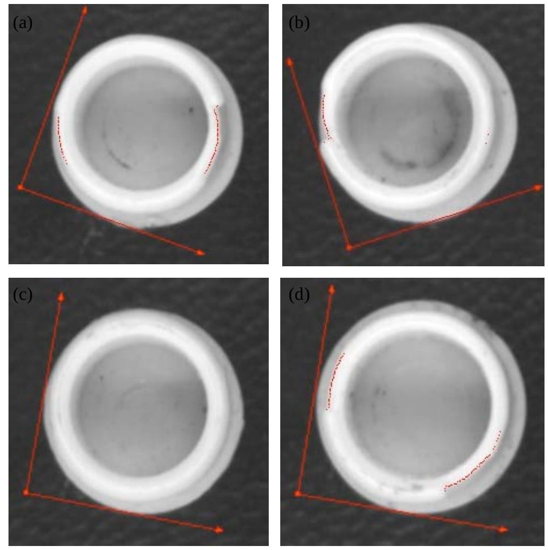

Fig. 9: Defects inspection results

$$d(p_i, p_c) = \min_{\forall p_u, p_v \in S, p_u \neq p_v} d(p_u, p_v) \quad (13)$$

- Merging p_i and $p_c$into a new class and the existing class number minus 1
- Repeat steps (2) and (3), till S separated

After clustering analysis, the points close to the fitting circle which fit by the advanced CBL were classified to the fitting circle class, while the defects points were classified to the others. At this point, the defects points can be detected easily, defects in seal image also can be ruled out. The points close to the fitting circle which fit by the advanced CBL were classified to the fitting circle class, while the defects points were classified to the others and defects inspect the seal with clustering analysis. Seal defects inspection with clustering analysis has a good result, with a low false inspection rate and high defects detection rate, the results are shown in Fig. 9. The seal has a red mark in the place where there are defects existing.

EXPERIMENTAL RESULTS

To verify the effectiveness of the seal ring defects inspection based on clustering analysis, inspect the set includes 314 defects-free samples and 186 defective testing samples with the proposed algorithm, the result is shown in Table 1. As can be seen from Table 1, 177 defects samples can be detected as defects product in 186 defects, 9 other mistaken for qualified, 314 qualification assessment for qualified for 301, the rest of the 13 mistaken for defects.

From the defects seal of detected successfully, the proposed algorithm can successfully in a variety of defects types, while the camera, light source and the workshop environment request is not high, has a strong anti-interference and universality. The defects misjudgment mainly suffers the interference of presence of dust, grease and other interference in seal which seriously affect defects inspection.

CONCLUSIONS

According to the features of seal ring, this paper proposed a seal ring defects inspection algorithm based on clustering analysis and proposed an algorithm combining least square method with cluster analysis which is used to circle defects inspection and has opened up a new way to rings defects inspection. This paper proposed an advanced CBL which is more accurate than the traditional one. The inspection rate of defects in seal is high while clustering analysis combining with the advanced CBL. Experiment of defects inspecting with a large number of seal shows the proposed algorithm is strong anti-interference and universality.

This study mainly concentrates on the inner ring defects inspection on condition that the disturbance is not serious. The next research focuses on how to inspect the inner ring defects in the case of serious interference such as dust and oil existing.

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