Research and application of appearance inspection system for spacecraft low frequency electrical connector based on machine vision

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Abstract. In order to improve the accuracy and efficiency of the inspection of the appearance quality of the electrical connector in the acceptance process of the low frequency cable, the machine vision recognition technology is studied to realize the appearance quality inspection of the electrical connector on the existing low frequency cable, in order to improve the quality and efficiency of appearance inspection of low-frequency cable connectors, various kinds of defects such as slanting, missing and shrinking wires can be identified automatically.

1. Introduction
With the improvement of spacecraft assembly quality, the acceptance quality of low-frequency cable is becoming higher and higher. Therefore, it is necessary to ensure the accuracy and reliability of the inspection of the appearance quality of the electrical connector during the acceptance of the low frequency cable. At present, the inspection of the appearance quality of the electrical connector in the process of low frequency cable acceptance is mainly through the visual means of inspection personnel to determine whether the electrical connector has defects such as crooked needle, missing needle, shrinking needle, the accuracy of the test mainly depends on the personal experience of the inspector. A description of the quality problem is shown in fig.1.

![Defect description schematic diagram](image)

Fig.1 Defect description schematic diagram

In order to solve these problems, the traditional visual inspection methods usually only focus on SMT, pin row, USB, FPC, BGA, the inspection target of off-line mode FPC and BGA Stereo vision inspection has the same premise of pin arrangement rule and pattern[1-2]. Often machine vision is mainly oriented to the production process of a single model, style of products for on-line detection. If it is applied to off-line multi-class product detection, the imaging conditions of the detected objects must be consistent[3-5]. However, for many types of low-frequency electrical connectors, the imaging conditions can not be unified because of the variety of models and the different shapes of terminals and connectors. This series of factors bring certain difficulties to visual inspection, not only need to
choose a suitable lighting system, stable and effective software algorithm, but also need reasonable mechanical structure design, sometimes an effective optical structure is needed to complement it.

2. **Research on machine vision recognition technology**

2.1. **Target type identification techniques**

The function of code recognition is mainly used to identify the electrical connector automatically, and the recognition is based on the symbol coding on the data line of the electrical connector. Coding consists of uppercase letters and numbers, as well as common symbols.

Any one of the single algorithm will be subject to too many objects to be examined, size differences, training difficulties and other factors. Therefore, the model recognition (classification) technology in the system development process mainly from three directions to make a breakthrough, first of all, for the type information attached to the electrical connector using OCR character recognition technology. For the model information pasted on the cable or inconvenient to take photos, or in the absence of the case, call the machine learning model based on SVM to align the classification recognition, if the model has not been trained for this, then go to manual input, automatic matching process, the final common breakthrough in multi-model identification technology.

2.2. **Pre-processing of detection image and pre-positioning technique of stitch**

Firstly, different template matching methods are called according to different types, and the images in the ROI region are processed in the connected domain according to the detection parameters of each model, some special electrical connectors such as J30JH are directly involved in this process, and the removal conditions based on the area, perimeter, pixel distribution, proportion and other factors are realized.

But in the process of multi-model testing, we are not only faced with the problem of multi-model testing, but also with the difficulty of different imaging conditions. The ICP registration method is introduced to locate the point set sequence from the angle of geometric distribution, and then all pin contacts are pre-positioned, and the pin numbers are sorted according to prior knowledge and the pins are missing. After processing, the left and right ROI images and their point set (including noise) sequences are obtained.

2.3. **Multi-model technique for precise extraction of needle tip**

Because the precision of the coordinate sequence obtained after pin positioning can not meet the need of actual detection, further accurate extraction is needed. Pin-to-pin images of electrical connectors are classified, and each classification corresponds to a different method.

2.4. **3D reconstruction and quality assessment techniques**

By identifying the "pinhead data" of the left and right views, we can find the corresponding point set of the left and right views in advance. We only need to calculate the parallax one by one for the corresponding labeled pins, the data obtained from Stereo calibration can be used for three-dimensional coordinate solution. According to the transformation relationship between the world coordinates and the image coordinates, the projection Matrix can be derived to convert the 3D points in the homogeneous coordinates to the 2D points in the homogeneous coordinates:

\[
\begin{bmatrix}
X \\
Y \\
Z \\
1
\end{bmatrix} =
\begin{bmatrix}
x \\
y \\
w \\
1
\end{bmatrix}
\]

Where the screen coordinates are (x/w, y/w). If given the screen coordinates and the camera inner parameter Matrix, the two-dimensional points are reprojected into the three-dimensional space according to the formula. The reprojection method is as follows:
Where $D$ is the parallax of the corresponding point on the two images and $Q$ is the reprojection matrix:

$$
Q = \begin{bmatrix}
1 & 0 & 0 & -c_x \\
0 & 1 & 0 & -c_y \\
0 & 0 & 0 & f \\
0 & 0 & -1 & \frac{(c_x - c_y)T_z}{T_z}
\end{bmatrix}
$$

The obtained 3D data schematic is shown in fig. 2, which is provided for circular connector identification.

![Fig. 2 Stereo coordinate simulation diagram](image)

After the 3D data is obtained, the corresponding test template data is loaded from the database according to the number of the electrical connector. Through a set of practical algorithm evaluation system, the collection point set is evaluated according to the standard point set, the judgment of "crooked needle" and "contracted needle" and the detection of concrete data are realized, and a series of functions such as user's view are supported.

3. **System Hardware Integration Process**

The method of hand-held loading and degree-of-freedom limitation should be introduced in the detection operation, and the inconsistency of imaging conditions should be compensated by software algorithm. Because of the need to calculate the three-dimensional coordinates, so the first consideration of binocular vision detection, imaging, in order to highlight the tip of the pin contact features, it is necessary to give circular lighting for enhancement. The visual inspection system is arranged as shown in fig. 3.
4. Electrical connector pin contact quality assessment verification
Because of the symmetry of the distribution of the contact parts, it is necessary to place the No. 1 pin on the upper right and stick it to the device to detect the pin number. Get the point set to the point set and the detection template as shown in fig.5. The green".” Set is the collected point set, the purple”**” is the standard detection template point set, the SVD least square rigid transpose method is used to register the point set, the registration principle is the global distance minimization.
4.1. Evaluation validation of crooked needle judgments
After the point set matching is completed, the testing standard is aligned with the principal component (x axis), the secondary principal component (y axis) and the third principal component (Z axis) of the acquired point set. After the fitting plane is aligned, the distance between each point and the template point is calculated, according to the size of the standard to judge the position of the deviation of the pin, can be considered skew needle situation, if the threshold is exceeded, it will be shown, the effect is as shown in fig.6.

![Fig.6 Test results shown](image)

4.2. Evaluation and validation of needling (high and low) judgment
Similarly, after alignment, the plane equation of the contact part is obtained by fitting the top plane of the pin. The height of the pin can be calculated by using the distance from the pin to the plane, and then the height of the pin can be judged, as shown in fig.7.

![Fig.7 Shows a shrinking needle (high and low) test](image)

4.3. Validation of needling assessment
The method of judging the missing pin has been described above, and the accuracy of the sorting is ensured because the sorting and the missing pin have been made up during the pre-positioning of the pin contact. In addition, as shown in fig.8, the missing needle test results.
4.4. Application of appearance inspection system for spacecraft low frequency electrical connector

According to the research results, the appearance inspection system of spacecraft low frequency electrical connectors based on machine vision has been applied to the final assembly inspection record, and the inspection record of electrical connectors for multiple satellites has been completed, the techniques of object recognition, image preprocessing and Pin pre-positioning are used to record the acceptance of the electrical connector, and improve the accuracy and efficiency of the detection.

5. Conclusion

Based on the results and discussions presented above, the conclusions are obtained as below:

A low-frequency electrical connector appearance detection system based on machine vision is designed and constructed, and the feasibility of the proposed method is verified. This system saves a lot of manual time and improves the working efficiency to a great extent compared with the traditional way of appearance acceptance and information recording of spacecraft low-frequency electrical connectors.

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