Flexible Connection of Cockpit Canopy Defect Detection Device Based on Machine Vision

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Abstract. In this paper, a detection device for air bubbles, impurities and other defects inside the flexible connection of aviation aircraft canopy is designed. This device is mainly composed of prism, industrial camera, lighting and analysis software. The prism is repeatedly optimized using light tools optical simulation software to achieve the best imaging results. The internal situation of the glued surface of the entire cockpit canopy is realized by the stitching algorithm based on SURF algorithm with additional feature points on images. At the same time, the image processing method based on OpenCV is used to realize the intelligent detection of the bonding surface defects. Compared with manual visual inspection, the device can complete the image capture, quantitative analysis and health monitoring of the surface of the flexible connection, effectively ensuring flight safety. This detection device improves the detection efficiency by about 50%.

1. Introduction

The aeronautical transparent member forms a sealed structure with the metal skeleton through the flexible connection, which is a common connection form of the fighter cockpit canopies. The edge of the transparent member is bonded to the body through the flexible polyester ribbon. Therefore, the quality of bonding has an important impact on flight safety. In recent years, edge degumming in cockpit canopies with flexible connection between plexiglass and frame occurs frequently, which seriously affects the daily flight and training of the army, and attracts great attention from industrial departments, colleges and military. In addition to the perfect bonding process, the flexible connection technology must also check the quality through reliable testing methods. Peng Chun proposed to use the camera device to improve the clarity and defect characteristics of the observation based on the prism detection. Zhang et al. analyzed the influence of bonding defect area on bonding strength by artificially manufacturing quantitative defect area, and believed that when the defect area does not exceed 35%, flight safety can be guaranteed. But the defects in the process of bonding are often random and not quantitative, the previous detection methods cannot determine whether the defects are within the tolerance range, and whether the defects change during the use of cockpit canopy cannot be effectively identified. Li Zhisheng put forward the use of plastic film instead of paste gel brushing to reduce the connection defects caused by glue shortage, Yu Guoliang et al. improved the identification of defect features by adding pigments. All domestic institutions are exploring methods to reduce the defect rate of adhesion or improving detection methods,
but they have not achieved quantitative analysis of bonding defect and judged whether the defects are within tolerance.

Compared to visual inspection, machine vision can quantitatively and qualitatively analyze target object defects, and can also classify defect types. Machine vision is widely used in various industries, such as auto parts, food packaging, medicine detect and so on. Bao Ting, Tang Xia, et al. \cite{10} proposed the use of machine vision to detect the defects of automobile shock absorbing discs. The main test is whether the parts on the damper disc are missing. The detection system has high real-time performance and the efficiency meets the needs of enterprises. In the pharmaceutical industry, the traditional manual inspection has always been used in drug detection, which is inefficient and the rate of false detection increases over a long period of time. Machine vision is used to detect drugs with specific shapes \cite{11}, so that the detection rate can be guaranteed and the batch production demand can be met at the same time. However, in the field of machine vision, there is currently no report on the analysis about transparent material. In this paper, a set of highly integrated visual inspection device is used to study the optimal imaging scheme of the image of the flexible connection area, the device will finally store and quantify the capture images.

2. Mechanical Structure Design

2.1. Integrated Design

The mechanical structure of the device mainly includes a camera fixing device, a holding structure and a prism fixing structure. In order to adjust the lens to the best angle, the camera fixture and the grip structure are connected in a way that can rotate at a certain angle. The prism is placed in the fixing device, which is connected with the base through a U-groove. This design allows the prism to move backwards and forwards, and the two-way adjustment increases the flexibility of the whole device, Then the prism fixing device and the base can be fixed by the fixing screw. The overall mechanical structure is shown in Figure 1.

2.2. Prism Design

Since the internal adhesion of the glued surface is observed, it is necessary to use a prism. According to the principle of refraction, one of its surfaces is bonded to 10mm of the glued surface through a coupling agent (the purpose is to remove air), Then refract the internal adhesion of the glued surface to the other side of the prism. Figure 2 is a road diagram of light passing through the prism\cite{12} and glued surface simulated by Light Tools simulation software.
As shown in Figure 3, the measured surface close to the prism needs to be totally reflected to reach the field of view, while the surface away from the prism can be observed only by refraction, the depth of observation is affected, so the design of the prism structure needs to be optimized. Using the principle of reverse ray tracing\cite{13}, you can find the best imaging field of view and imaging position.

3. Design of the software algorithms

3.1. Integrated Design

The camera in the above mechanical structure is connected to a PC with high performance that contains image processing program. One of the functional modules is used to control the camera to capture images; the other functional module is used for multiple image stitching; the last functional module is used to detect and display the internal adhesive defects of the glued surface.
A flow chart of the entire software operation is shown in Figure 4, the main part of which is the image stitching and defect detection. We can see the main window of the entire software from Figure 5. The display area is used to match the camera to capture the internal images of the glue surface, which...
ensures that the prism fits the cockpit canopy transparently. The “real-time display” window displays a frame-by-frame image captured by the camera, which greatly facilitates the operator to find the right location for the captured image and improves the accuracy of capturing images. A thumbnail of the total captured images is shown in “Captured images” window, which is convenient for the operator to observe. The middle of the "Stitching display" window is used to display the effect of the images stitching. The bottom control area is the function block of camera communication, such as capture mode setting and picture stitching. A display diagram of capture images and stitching images during operation of the device is shown in Figure 6.

![Display area](image)

![Stitching display](image)

**Figure 6. Image acquisition and stitching process diagram**

3.2. Image stitching

3.2.1 Additional Feature Points Detection

A key step in the image stitching process[14]–[15] is feature points detection. Among them, the traditional SIFT detection algorithm, based on this improved SURF algorithm[16], as well as the ORB detection algorithm[17] with high computational speed and real-time performance. In terms of detection speed, ORB is the fastest, SURF is the second and SIFT is the slowest, in terms of rotational robustness, all three are similar, SURF is superior to SIFT in terms of invariance of scale transformation, while ORB does not have scale transformation characteristics. To summarize, the SURF detection algorithm is selected. The biggest difference between the SURF and SIFT is when looking for image feature points, the SIFT algorithm searches for feature points in DOG images, while SURF searches for feature points in images consisting of Hessian matrix determinant approximations, formula (1) is calculation formula:

$$
det (H_{approx}) = L_x^2 L_y^2 - (0.9L_x L_y)^2
$$

(1)

The Hessian matrix formula for calculating a pixel in an image is as follows:
\[ H(x,\sigma) = \begin{bmatrix} L_{xx}(x,\sigma)L_{xy}(x,\sigma) \\ L_{xy}(x,\sigma)L_{yy}(x,\sigma) \end{bmatrix} \] (2)

Where \( L_{xx}, L_{xy}, \) and \( L_{yy} \) are the second derivatives of the Gaussian filtered image in each direction respectively. There is no SIFT drop step sampling process in the SURF algorithm, so the processing speed is increased. Moreover, when constructing feature descriptors, SIFT uses 128-dimensional, while SURF uses 64-dimensional, so the SURF algorithm workload is reduced by half.

The two images adjacent to the inside of the glued surface captured by the camera are shown in Figure 7 and Figure 8 respectively. The internal features of the glued surface are not obvious, so the feature points are added artificially on images. The feature points detected by SURF in two of the images have been marked.

Figure 9 is a feature matching image of figure 7 and figure 8, in which the matching points are 354 and the mismatching rate is about 5%.

3.3. Defect detection

After optimizing the prism, the field of view is optimized, but the maximum length of a single image is still only about 60 mm, while the total length of the whole flexible connection surface is about 1000 mm. If the image stitching cannot be realized, the image rendering effect and detection efficiency will be greatly affected.

After the image captured is completed, the final stitching effect can be achieved through image registration, image copying and image fusion. The middle part of Figure 6 is the stitching effect of the image after continuously capture some glued surface images. The result shows that multiple images can be successfully stitched together, but the fusion effect of images needs to be improved. After the images are stitched, the entire image can be detected for defects. The first step is filtering. Median filtering\(^{[18]}\)-\(^{[19]}\) has a good filtering effect on the noise caused by outliers and a small number of pixels. The purpose of this filtering is to eliminate some additive noise in the image and prevent the influence of calculating
the feature in the subsequent algorithm on the result parameters. The original images and median filtered images are shown in Figure 10 and Figure 11 respectively. There is no difference on the surface, and they have little influence on background images and defect areas on the glue surface.

After transforming the collected image into gray scale image, a contrast stretching method is adopted to enhance the contrast of defect area and make the defect more obvious, as shown in Figure 13.

In order to solve the problem of uneven illumination of the glued surface due to capture, an improved OpenCV local adaptive fast binarization method is adopted, and then subjected to morphological processing, and finally the target contour is drawn, as shown in Figure 14 and Figure 15.

According to the threshold setting for defect area, the program will automatically eliminate some contours that are not within the threshold range, and eventually mark the selected defect contours. Considering the complexity of defects, the program also makes manual circle selection of defects, and then automatically calculates the defect area.
In order to facilitate statistical analysis, the program shows the number and area of defects in tabular form, which are shown Figure 16 and Figure 17 respectively.

![Figure 16. Defect area labeling](image)

The unit of the defect area is square millimeter. The camera needs to be calibrated by checkerboard before use. The program finally gives the physical size of the defect and will be displayed in the “defect statistics” window. According to the actual set judgment standard, the “result judgment” will give “qualified” or "unqualified" prompt.

4. Conclusion

Through various tests and trials, the overall efficiency of the device based on machine vision for detecting flexible connection defects of transparent parts of cockpit canopy has been improved by about 50% compared with the prism-based equipment. At the same time, it has the following advantages:

1. The light Tools optical simulation software optimizes the design of the prism to obtain the best viewing field of view for the flexible connection.

2. The stitching algorithm based on SURF algorithm with additional feature points is used to get the whole image of transparent glued surface. Image acquisition and archiving function can be used as the basis of whether the defects of plywood of cockpit canopy have expanded or not during flight, and the health monitoring of key bearing areas can be realized.

3. The image processing method based on OpenCV can realize the quantitative analysis of the glued surface defects with an accuracy of 0.1mm, which can accurately determine whether the defect area is within the safe tolerance range.

The device also has certain limitations. Due to factors such as small color difference between the white rubber layer and the bubble, interference of the couplant bubble, optical distortion through the prism, etc., the defect recognition and stitching effect have certain deviations. In special cases, the
operator is also required to circle or filter the defect area for quantitative analysis. The algorithm needs to be further optimized to accelerate the detection efficiency on the basis of the guaranteed function.

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