Application of 3D vision intelligent calibration and imaging technology for industrial robots

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Abstract. During modern flexible lean manufacturing, flexible operation of irregular and complex workpieces with different specifications and arbitrary placement is an essential ability of industrial robots, while it cannot be met by traditional clamping methods. Vision technology brings flexibility and convenience to industrial robots, but the common two-dimensional technology only involves three degrees of freedom (plane displacement and rotation), which hinders the positioning of arbitrarily placing workpieces (often six degrees of freedom) and disorderly sorting. In addition, for typical visual tasks in industrial environments like defect detection, accurate distinguishing of such defects as pits and scratches is challenging under two-dimensional plane imaging. The introduction of three-dimensional information provides an effective solution to this problem. Thus, in the face of increasingly complex, flexible, intelligent and personalized manufacturing needs, the acquisition and processing of 3D visual information are of much importance.

1. Introduction

The existing 3D visual information acquisition methods include binocular stereo vision, laser 3D scanning and structured light 3D imaging technology. The traditional binocular stereo vision technology strongly depends on the object’s surface texture and it is mostly used for dynamic tracking and measurement of specific signs in industrial applications. However, this method can not achieve high-density 3D point cloud reconstruction. Laser 3D scanning technology mostly adopts point-by-point or line-by-line scanning, resulting in slow measurement and potential harm. Its main application is industrial static measurement[1-2]. Specifically, a camera of a binocular vision system is replaced by projection equipment, and the optical pattern containing specific coding information is projected to the object surface, thus solving the matching problem in stereo vision. Moreover, the three-dimensional spatial coordinates at the projection coding features are recovered through the principle of triangulation. This technology is characterized by a simple system structure, fast scanning, as well as
high point cloud density and measurement accuracy. The difference between structured light three-dimensional scanning technologies mainly lies in the structured light coding method. The existing strategies in this regard can be divided into time and space sequence coding [3-4]. The former draws on the combination of gray code and phase-shift fringe to obtain high-density and high-precision point cloud data. However, it is usually used for three-dimensional scanning of static objects since the projection of multiple patterns is needed. The spatial coding method realizes the three-dimensional reconstruction of the object surface by projecting a single coding pattern. Its coding information is generated by spatial coding features or their different permutations and combinations. The coding and decoding processes are completed in a single image, thus meeting the real-time requirement. Nonetheless, it is limited by low point cloud density and poor accuracy [5-6].

2. 3D vision intelligent calibration and 3D imaging technology

The current three-dimensional reconstruction methods of structured light mainly focus on the coding algorithm combining sinusoidal phase shift and gray code. Specifically, the projected sinusoidal fringe is shifted 4-5 times and the brightness information of the projected fringe is generated through the camera. Then, it calculates the phase value and eliminates the sinusoidal period confusion combined with the gray code method. However, for the non-Lambertian surface with reflection characteristics, the formation of an image saturation area and a low contrast dark area may not be avoided, resulting in a large calculation deviation of gray value and phase value. This seriously affects the accuracy of 3D reconstruction. Especially in the manufacturing field, most of the targets to be detected are metal materials, where the structured light coding method based on traditional sinusoidal phase shift is not applicable [7-10]. This problem can be solved by spraying anti-reflective treatment on the object surface in advance. The detailed step is to spray a layer of powder on the object surface so that the surface is no longer reflective. In this way, satisfactory measurement results can be obtained. Obviously, this cumbersome process and the possible corrosion caused by spraying and cleaning impede mass production and testing, especially for the three-dimensional reconstruction of metal parts, works of art and network commodities with high surface accuracy. How to improve the existing algorithm for direct high-precision and fast three-dimensional reconstruction of metal and other non-diffuse surfaces has become a challenging task in the research of structured light three-dimensional reconstruction.

2.1. System parameter calibration

The traditional calibration strategy is adopted to calibrate the camera module, and then the projection module is modeled based on the reverse camera model. The internal and external parameters of the projector unit are calibrated by the camera assisted calibration strategy. It is followed by the calibration of the robot hand eye system. With the use of the external reference strategy, the spatial transformation parameters of the coordinate system between the vision system and the manipulator system are calculated (Fig. 1).

Figure 1. Geometric diagram of the structured light system
2.2. **Structured light coding algorithm based on binarization with displacement fringes**

The pixel level displacement operation is performed by the binary fringe, with the periodic value equal to the fringe width. The detected fringe edge sub-pixel position information experiences locally unique coding. Subsequently, the gray code coding strategy is introduced to eliminate the periodic confusion and realize the globally unique coding. Finally, combined with the calibration information, the three-dimensional spatial coordinates of the edge points are obtained (Fig. 2).

![Gray code + high-frequency binary displacement fringe coding pattern and edge positioning strategy of displacement fringe](image)

**Figure 2.** Gray code + high-frequency binary displacement fringe coding pattern and edge positioning strategy of displacement fringe

2.3. **Structured light decoding and 3D reconstruction**

Given the complex surface reflection of metal parts, the edge of the coding stripe is eroded by the reflective area. Detecting the exact position of the stripe edge from a single photo is not easy. Here, conjugate fringes are projected and such constraints as edge continuity are introduced. Furthermore, sub-pixel edge detection technology is employed to obtain accurate edge coding feature position information. Then, in combination with calibration parameters, fast scene 3D reconstruction is realized.

3. **3D visual solder joint**

The test data of various industrial products are integrated, followed by the sorting and extraction of general features, such as length, width, area and brightness of welding materials. Then, the correlation between solder joints and adjacent points within multiple specified ranges: dispersion, linear correlation, curve correlation, geometric correlation, etc. is examined. Based on the characteristic data from the industrial Internet, a standard database combined with an appropriate deep learning algorithm is built. The standard visual robot can quickly obtain a learning model with high prediction accuracy and also complete the solder joint recognition when detecting the solder joints of products with few spot welding sample data (Fig. 3).

![3D visual spot welding](image)

**Figure 3.** 3D visual spot welding
4. Conclusion
A highly robust 3D reconstruction method based on high-frequency binary grating displacement fringes is developed. It uses binary fringes to replace the traditional sinusoidal gray fringes, endowing the projected structured light features with a stronger anti-surface texture interference and reflection ability. Moreover, high-precision and fast 3D reconstruction of complex stacked and texture missing scenes such as metal parts are effectively realized with improved stability, accuracy, and scanning speed in comparison to the existing methods.

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