# Scene Visual Object Segmentation and Recognition Based on CAD

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**Abstract.** In order to obtain the information of the target position and attitude of the workpiece and realize the accurate grasping of the workpiece by the industrial robot, the author proposes a scene vision object segmentation and recognition method based on CAD. The template training is carried out based on the geometric information of the 3D CAD model of the object, and the workpiece with clear contour can be recognized efficiently. Combining the efficient pyramid model hierarchical search strategy and the matching method with normalized similarity measure, the most suitable template can be trained in the whole local range. The test object is the metal cage workpiece with obvious contour and reflective characteristics, the recognition and positioning experiments are carried out in the randomly stacked workpiece. The experimental results show that the target in the randomly stacked workpiece can be accurately identified by this method, and the average positioning error of the target workpiece in the X, Y, Z axis direction is 0.948 mm, 1.078 mm, 2.175 mm. It is proved that the CAD 3D model creation template matching method can accurately match the objects in the image under any posture and any position of the object; it can accurately identify the target objects in random stacking and complex environment, with high stability and reliability.

**Keywords:** Identification; location; CAD model; Template training; Pyramid search.
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## 1 INTRODUCTION

Vision enables humans to perceive and understand the surrounding world, and is the most important means for humans to obtain knowledge from nature. According to statistics, visual information accounts for about 80% of the information acquired by human beings, and other information such as auditory information, taste information, and touch information together account for about 20%. This shows the importance of visual information to human beings, and image is the main way for human beings to obtain visual information [1].

The three-dimensional objective world is projected onto the human retina to form a two-dimensional image, and the information about the three-dimensional world is extracted from the two-dimensional image through the binocular visual function, this is the human visual process. Computer vision, also known as machine vision, refers to the use of computers and some auxiliary equipment to realize human visual functions, thus realizing the perception of external things and the objective three-dimensional world [2-3].

Computer vision is a new discipline, its development benefits from the research of animal visual system in neurophysiology, psychology and cognitive science, the research goal of computer vision is to enable computers to recognize three-dimensional environmental information through two-dimensional images. This capability will not only enable the machine to perceive the geometric information of the total object in the three-dimensional environment, including its shape, position, posture, motion, etc., they can also be described, stored, identified and understood. With the rapid development of human understanding of vision and computer technology, using computer to simulate human vision system has become an inevitable trend of scientific and technological development [4].

Computer vision has become one of the interesting frontier research fields, because it is necessary to use computer vision technology to prove the correctness of the understanding of vision mechanism, and through the simulation of human vision, it can help people to recognize human vision mechanism again, thus making a major breakthrough in many unknown problems.

In computer vision system, information processing and analysis can be divided into two stages: Image processing stage (also known as low and medium level stage of vision), image analysis and understanding stage (also known as high level processing stage). When a person looks at an image or a scene, his vision can obtain information about the whole and local details of the object, the main task of computer vision is to use certain theories and algorithms, and computer technology to achieve human-like visual functions. However, in recent years, people have raised questions about 3D reconstruction and gradually realized that the theoretical framework is seriously inadequate [5]. In the process of solving practical problems of vision, concepts such as active vision have emerged. The proposal of some new vision theories has touched on the underlying fundamental problems of computer vision at a deep level.

## 2 LITERATURE REVIEW

Because computer vision has a wide range of sensitivity to spectrum, high measurement accuracy and relatively stable detection results, therefore, it has made significant contributions to improving production efficiency, ensuring product quality and improving product accuracy in many fields[6-7]. The application of visual system in the world has been enduring since the 1980s. Visual inspection has achieved vigorous development, and new concepts, theories and methods are emerging, it has been widely used in various aspects.

As early as the 1980s, visual inspection systems have been widely used in American manufacturing industry. The most widely used visual inspection technology is those occasions where the same parts or products need to be repeatedly inspected. At that time, more than 100 companies in the United States were involved in the operation market of visual inspection systems, it can be seen that visual inspection systems are indeed promising.

In China, industrial vision system is still in the concept introduction period, after solving the problem of production automation; leading enterprises in various industries began to turn their attention to visual measurement automation. However, the research and application level of visual inspection in China is at least 20 years behind that of foreign countries. It can be seen that it is of great significance to further carry out theoretical exploration and practical research of visual inspection in China, absorb advanced foreign technology and academic ideas, and expand the application field of visual inspection [8]. Lee, H proposed a method to effectively reconstruct 3D CAD models containing machining features into 3D voxels through 3D codec network. Establish 3D CAD model data set to train 3D CAD model reconstruction network [9]. Xiwei, W. U carried out a literature review on navigation and positioning based on factor graph, analyzed and classified the methods of navigation and positioning based on factor graph, discussed the research status of navigation and positioning based on factor graph, and focused on its practical application, and finally gave suggestions [10]. Kholmatov, U studied the possibility of applying adaptive recognition theory to realize the automation of multi-connected targets [11].

The author puts forward a method based on 3D CAD model as training template, taking the plane information of the target workpiece under the monocular camera as the reference object, matching the projection of each face of the 3D model, this method does not depend on its surface characteristics and the influence of light on the workpiece, for metal parts with reflective characteristics in industrial production, it can accurately and quickly identify and determine the three-dimensional coordinates of the target workpiece at any position and attitude in the random workpiece.

## 3 RESEARCH METHODS

### 3.1 3D CAD Model Template Matching and Positioning Principle

3D CAD model matching is a method based on projection, which projects the 3D model of an object under the conditions of multiple views and different distances, and uses a monocular camera to obtain the image of the object from the work plane, the plane information of the target object in the image is matched with the projection of the 3D model at different angles of view and different distances [12]. The camera's internal and external parameters are obtained through camera calibration and the position and attitude relationship among the object coordinate system, camera coordinate system and world coordinate system are determined, the 3D attitude of the object in the world coordinate system is converted by coordinates, and its work flow chart is shown in Figure 1.

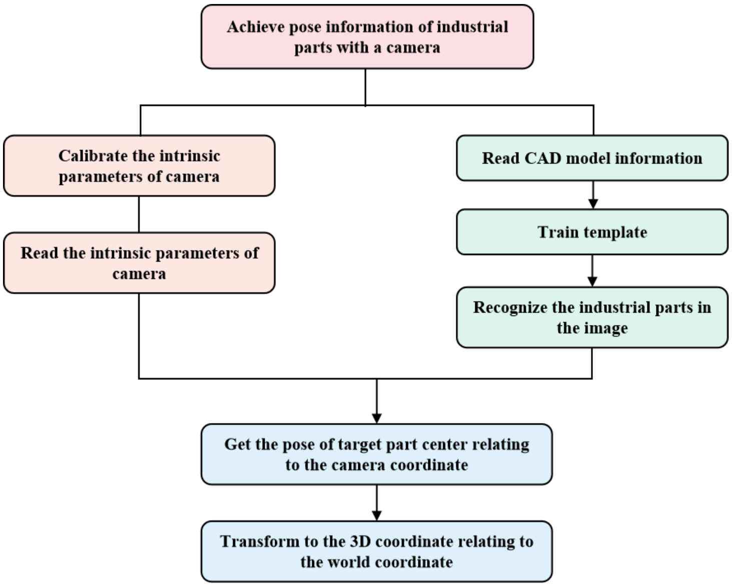


**Figure 1**: 3D model template matching and positioning flow chart.

### *3.1.1 Training template using 3D object model*

The 3D model of an object can be built by the 3D drawing software and stored in DXF, OFF, STL or PLY format, the 3D outline of an object is composed of the plane information of the object in different positions and different angles of view in the 3D space. The acquisition of these 2D views can be conceived as placing numerous virtual cameras around the 3D model of the object in the form of a sphere in the 3D space, and projecting the 3D model into the virtual camera at different positions [13]. The two-dimensional contour model generated in each virtual camera is stored in the shape template, the data in the shape template is searched to match the imaging information of the object in the real camera, and then the three-dimensional pose of the object in the image under a certain angle of view is recognized.

Suppose that the 3D model is in the center of a sphere with a defined geographic coordinate system, and the virtual camera used to obtain the 2D view of the object will surround the object in the way of pointing to the center of the sphere, the coverage of the virtual camera can be limited to a certain area of the sphere surface, the range of this area is determined by the geographical coordinate parameters $\lambda$ (spherical longitude), $\varphi$ (spherical latitude) and d (distance from the origin of the 3D model to the surface of the sphere).

### *3.1.2 Determine the template search strategy*

Search strategy refers to the method of finding the maximum similarity in the search space to obtain the matching position. When the template trained by 3D model is used to search the target object in the image, a good search strategy can improve the speed and robustness of the whole image matching process. The image is a set of images arranged in a pyramid with gradually reduced resolution, the bottom of the pyramid is a high-resolution representation of the image to be processed, while the top is an approximation of the low resolution [14].

The principle is to find the initial matching point on the low-resolution image of the image pyramid using template matching method, and then match layer by layer as the number of pyramid layers gradually decreases, the search area of each layer of matching points is set according to the matching results of the upper layer, and the search range is cycled until the more accurate matching point position is obtained.

### *3.1.3 Selected similarity measures*

When the pyramid model is used for template matching in the image, similarity measurement is an important basis for similarity comparison between matching point pairs, there are three common methods for similarity comparison: Mean square difference measure, correlation matching measure and normalized correlation matching [15]. These three commonly used comparison methods all have their normalized form, which not only reduces the template, but also reduces the impact of noise and image light changes while normalizing the measurement coefficient.

The reason for reducing the impact of noise is that even if a feature is lost during template search in the image, noise will cause a random direction vector; however, these vectors will not have an important impact on the whole process of template search. For isotropic pixel points, the direction vector can be set as zero vectors, only anisotropic pixel points can be reserved, and their normalized direction vector can be calculated, in this way, the features of occlusion and chaos will not affect the synthesis. Another advantage of normalizing it is to reduce the influence of light; the modulus of the direction vector depends on the brightness of the image. Normalize the similarity measure, and all the direction vectors are 1, so that the influence of any light change will not affect the similarity measure [16].

### *3.1.4 3D object positioning*

Using the 3D model of an object to create a template can recognize the position and pose of an object in 3D space relative to the world coordinate system with only one camera. The 3D model is created according to the actual scale of 1:1; the template with high similarity to the object in the image is identified by using the image pyramid search strategy and the similarity measurement algorithm with normalized form. In the image, after the three-dimensional contour of the template is projected onto the object contour, the Levenberg-Marquardt nonlinear optimization algorithm is used to carry out multiple iterations to enhance the robustness, and the template contour (wireframe model) is fully meshed with the object contour, after meshing, the three-dimensional pose of the object in the image can be known through the geometric relationship between the three-dimensional model and the object in the image [17].

Using the internal parameters obtained by calibrating the camera, the actual size of the template and the scale in the image, as well as the 3D pose of the 3D model in the image, the corresponding relationship between the object origin and the optical axis center is obtained, and the coordinates of the object origin relative to the camera coordinate system of 6 degrees of freedom are obtained, the formula for calibrating the camera internal parameters is as follows (3.1):

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} k_x & k_s & u_0 \\ 0 & k_y & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1/z_1 \\ y_1/z_1 \\ 1 \end{bmatrix} = M_{in} \begin{bmatrix} x_1/z_1 \\ y_1/z_1 \\ 1 \end{bmatrix} \tag{3.1}$$

Where: $M_{in}$ is the internal reference of the camera; $k_s$ is the radial distortion coefficient of the image; $k_x$ and $k_y$ are the length and width of the physical dimensions of each pixel; $u_0$ and $v_0$ are pixel coordinates in the image center; $x_1$, $y_1$ and $z_1$ are the actual coordinates of point $(u, v)$ in the image relative to the camera coordinate system, and $z_1$ is equal to the focal length $f$ of the camera. The coordinate of the object origin in the image is $(u_0, v_0)$, the template trained by the 3D model is projected on the target workpiece in the image plane, the coordinate $(x_0, y_0, z_0)$ of the workpiece center on the imaging plane relative to the camera coordinate system is obtained by the parameter $M_{in}$ obtained from the calibrated internal parameter.

According to the 3D model projected by the template on the image plane, the position and orientation relationship between the actual center of the object and the center of the object on the image plane can be obtained; the coordinate $(x, y, z)$ of the object relative to the camera coordinate system is obtained through the homogeneous transformation formula of spatial coordinates [18].

## 3.2 Overall Design

Local feature is the local representation of an image, which can express the characteristics in a certain area of the image. Therefore, it is very suitable for target location in the image. Moreover, local features have strong regional properties and good adaptability to light changes, rotation changes and size changes, and can also be effective in common scenes such as occlusion, rotation and translation of objects. The general process of feature matching is shown in Figure 2.

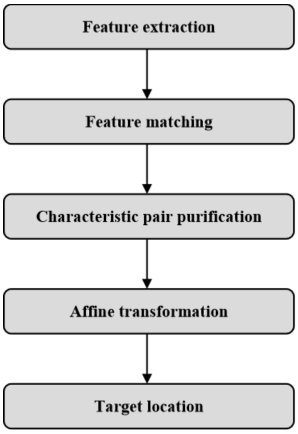


**Figure 2**: Traditional feature matching process.

Because local features contain high-dimensional information such as size, direction, response intensity, etc., the traditional feature matching process is in two still and high-definition images, the number of feature points is large, the repeatability is strong, and the matching accuracy is high, even under the interference of local occlusion and noise, the target can be accurately located. However, in engineering applications, it is necessary to use a moving camera to collect scene pictures in real time.

This will inevitably lead to motion blur in the image scene due to jitter, illumination, exposure time and other factors, the number of feature points in the image is reduced, the information contained is inaccurate, and the repeatability of features is reduced. It greatly affects the accuracy of feature matching, thus making the target location inaccurate. Aiming at the above problems, the author designed a real-time system for target location based on local feature matching, and the process is shown in Figure 3 below.

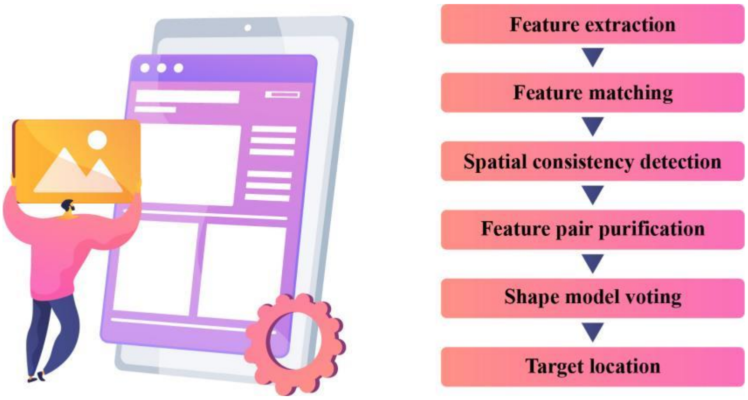


**Figure 3**: Feature matching process.

Firstly, the feature points of the target and scene are extracted, aiming at the problems existing in the engineering application, the improved purification method is used to filter and obtain the matching that conforms to the spatial consistency, finally, the shape model voting method is used to calculate the target location in the scene. Compared with the traditional feature matching algorithm, the author's algorithm is more suitable for engineering application scenarios and improves the matching accuracy on low-quality images [19].

## 3.3 Feature Matching

### *3.3.1 Shape model voting mechanism*

In the scene, buildings are generally used as the search target. The building is a rigid structure, the changes in the picture only show different morphological changes due to different observation angles and positions. The relative position information of the building itself, such as windows and doors, is unchanged. If you know the position and rotation information of a point in a building, you can calculate the position of the whole building.

Assume that the feature point on the template image is KP, its coordinate is p=(x, y), the size is S, and the main direction is $\alpha$, width and height are W and H respectively, the feature point searched by the nearest neighbor in the scene image is $KP'$, due to the rotation, translation and far and near changes of the scene image, its coordinate is $P' = (x', y')$, its size is $S'$, and its main direction is $\alpha'$. From the width and height of the template image, the coordinates of the template center point are as follows (3.2):

$$p_c = \left(\frac{W}{2}, \frac{H}{2}\right) \tag{3.2}$$

The distance from the feature point KP to the center point $p_c$ is as follows (3.3):

$$d = \sqrt{\left(x - \frac{W}{2}\right)^2 + \left(y - \frac{H}{2}\right)^2} \tag{3.3}$$

The included angle between the line segments from the feature point KP to the center point and the horizontal direction is as follows (3.4):

$$\theta = tanh^{-1}\left(\frac{\frac{H}{2}-y}{\frac{W}{2}-x}\right) \tag{3.4}$$

From the geometric relationship shown in Figure 4, the included angle between the line segment from the feature point KP to the center point and the main direction of the feature point KP is $\beta = \alpha - \theta$. In the scene picture, due to the problem of shooting angle, the building will rotate and translate, however, the angle between the line from the feature point to the center point and the main direction of the feature point is constant [20].

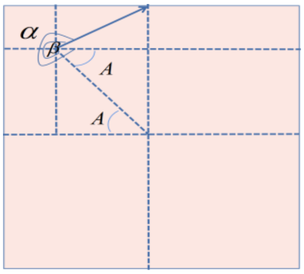


**Figure 4**: Relationship between the line from the feature point to the center point and the main direction.

For the feature point $KP'$ of the scene that matches the feature point KP, according to the main directions $\alpha'$ and $\beta$ of $KP'$, the included angle between the line between the center of the building and the feature point and the horizontal direction can be calculated as follows (3.5):

$$\theta' = \alpha' - \beta + \pi \tag{3.5}$$

From the size $S'$ of $KP'$, we can see that in the scene image, the building size changes to the original $S'/S$, which means that in the template image, the distance between the feature point KP and the center point $p_c$ changes to $d'$, as shown in the following formula (3.6):

$$d' = \frac{S'}{S}d \tag{3.6}$$

Therefore, the center point coordinate of the target in the scene image is $p_c' = (p_x, p_y)$, as shown in the following formula (3.7) and (3.8):

$$p_x = x' + d' * cos\ \theta' \tag{3.7}$$

$$p_y = y' + d' * cos\ \theta' \tag{3.8}$$

At this time, a voting matrix of the same size as the scene image is constructed, and all the feature points on the template are found according to the above process to find the corresponding center point coordinates, and vote on the voting matrix. Because of camera imaging, even feature points with constant scale will have voting results that are not gathered together, therefore, a convolution check voting matrix is used for convolution, and the coordinate of the maximum value is the center point of the target. In the scene image, the width and height of the target become the following formula (3.9) and (3.10):

$$W' = \frac{S'}{S}W \tag{3.9}$$

$$H' = \frac{S'}{S}H \tag{3.10}$$

From the center, width and height of the target, we can get a rectangular box R, which is the target box.

### *3.3.2 RANSAC purification and spatial consistency detection*

The random sampling algorithm assumes that in a group of data, both correct data and wrong data are included, at the same time, it also assumes that given a group of all correct data, there is a transformation matrix that conforms to this data. In image processing, it is assumed that there is a spatial transformation relationship between the two images, that is, the template image can be transformed into the scene image according to the affine transformation, the affine transformation matrix $H$ is as follows (3.11):

$$H = \begin{bmatrix} h_0 & h_1 & h_2 \\ h_3 & h_4 & h_5 \\ h_6 & h_7 & h_8 \end{bmatrix} \tag{3.11}$$

Assume that the corresponding relationship between point $(x, y)$ in the template image and point $(X, Y)$ in the corresponding scene image is as follows (3.12):

$$\begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} = H \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \tag{3.12}$$

The algorithm flow of RANSAC is as follows:

1. Four pairs of samples are randomly selected from the matching set.
2. According to these four pairs of samples, calculate the H matrix.
3. According to the affine transformation matrix $H$ calculated in the second step, calculate the distance $d$ of the remaining samples in the matching set after $H$ transformation, and set a threshold $T$, if $d$ is less than $T$, the matching pair is considered to be correct, and the set and number of correct matching pairs corresponding to the transformation matrix are recorded.
4. Perform operations 2 and 3, and the number of iterations is $N$ times preset.
5. After the generation, find the transformation matrix $H$ corresponding to the set with the largest number of correct matching pairs.

In a building, there will be many similar structures, such as windows, doors, etc. These structural features will have many similarities. This will cause feature matching errors. The corridor in the middle of the building is highly similar, resulting in a match between the feature points of the multi-story building and a feature point in the scene. It can be seen from the above process that RANSAC is a continuous iterative process. If not filtered, a large number of error features will affect the accuracy and speed of RANSAC. Therefore, the idea of spatial consistency detection is that if the correct points are matched, the space of the surrounding points should also be the same [21-22].

The author divides the template into four areas, in these four areas, the number of feature points (M) on the template and the number of feature points (N) in the scene image are detected respectively, when $\frac{N}{M} > t$ (t is the threshold), it is considered to conform to the spatial consistency, otherwise these matching pairs are removed, and then the final matching result is obtained by using RANSAC purification method. Through the above method, a large number of wrong matching points can be filtered out, the accuracy of matching can be effectively guaranteed, the accuracy of target location can be improved, and the amount of calculation for feature point purification can also be reduced.

For example, the traditional matching algorithm uses the RANSAC algorithm to purify the matched feature points, and then uses the affine transformation matrix calculated by the RANSAC algorithm, map the template image to the scene image to get the target coordinates of the scene image. Due to the influence of image blurring and other factors, the matching error occurs in this algorithm, which results in the error of the calculated radiation transformation matrix, and the accuracy of target positioning cannot be guaranteed. The spatial consistency detection algorithm can avoid the above situations and improve the feasibility of engineering applications.

### *3.3.3 KD tree*

KD tree is mainly used for multidimensional space retrieval, from the perspective of data structure; it is a binary search tree. Each node is a K-dimensional binary tree; non-leaf nodes use a hyper plane to divide the space into two. KD tree is a fast method to calculate KNN. Assuming that the number of categories is N and the dimension of features is K, the complexity of KD tree algorithm is $O(Klog_2(N))$ theoretically, less than the direct search complexity $O(KN)$.

It should be noted that when calculating the nearest center point of a feature, search along the KD tree and finally arrive at a space with only one category. As shown in Figure 5, the line represents the space division, and the black point is the input retrieval feature, in the space where A is located, the dotted line is a circle centered on a black point, it is very intuitive to see that C is actually a more ideal point. Therefore, in the actual search, it is not necessary to find the nearest point by directly looking for the space where the input point is located, it is also necessary to determine whether there is a point closer to it.

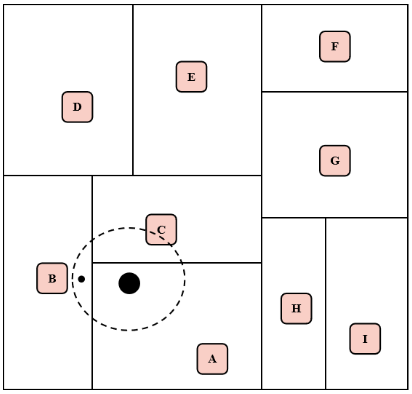


**Figure 5**: KD tree search.

## 4 RESULT ANALYSIS

### 4.1 Identification Object Positioning Experiment in Randomly Stacked Workpieces

The camera model selected for the experiment is Basler acA1300-60gm, with a resolution of 1280 pixel × 1024 pixel. The lens is a PENTAX TVLENS lens with a focal length of 12.5 mm. The selected target workpiece is the cage part of the bearing in the front wheel of the automobile, it is a circular metal part with a spherical surface shape on the outer surface, the surface is smooth without texture and has certain reflective characteristics. In order to identify the contour of the workpiece, the work plane is selected with white as the background, which can be clearly distinguished from the metal color of the workpiece, the camera's field of vision is 440 mm × 355 mm, 6~8 target workpieces can be placed in different positions, the reference point of the world coordinate system is the coordinate system established with the center of the black rectangle at the lower right corner of the work plane as the origin, the $X_wY_w$ plane of the world coordinate system is parallel to the $X_cY_c$ plane of the camera coordinate system.

In order to test and identify the stability of the workpiece in a complex environment, add some other interference in a single environment, such as stacking objects, adding multiple objects with the same target, and adding other tools as interference factors.

The final pose of the object is the pose relationship between the object center and the world coordinate system, the following six groups of data are the world coordinate system established with the intersection point of the work plane on the image and the optical axis of the camera as the origin, and measure the pose in six directions between the object center and the world coordinate system [23].

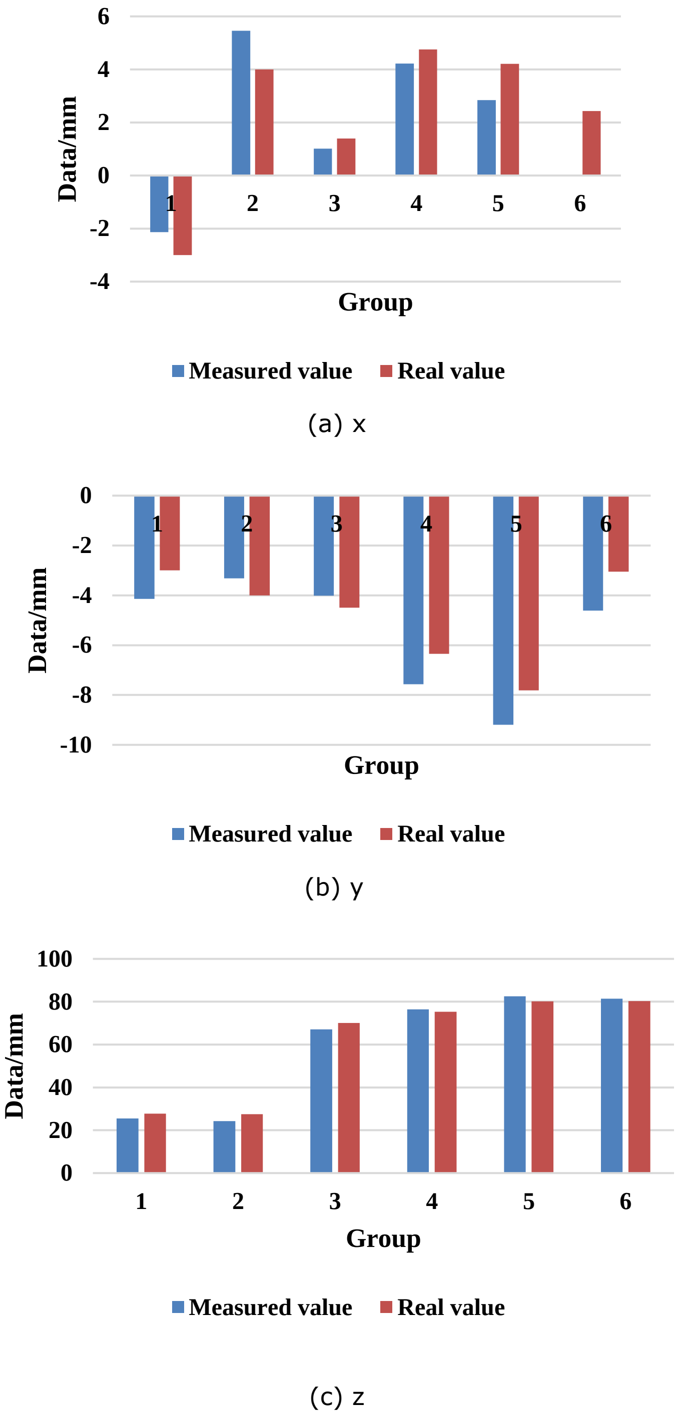


**Figure 6**: Measured data and actual data.

Place the workpiece in six different positions at random, compare the visual positioning data with the actual position and pose of the object relative to the world coordinate system, and list them in Figure 6.

After calculation, the maximum positioning error of the workpiece in the axial direction is 1.454 mm, and the average positioning error is 0.948 mm. The maximum positioning error of the workpiece in the axis direction is 1.563 mm, and the average positioning error is 1.078 mm. The maximum positioning error of the workpiece in the axis direction is 3.269 mm, and the average positioning error is 2.175 mm. It can be seen that the positioning accuracy of the workpiece in the Z axis direction is significantly lower than that in the X and Y axis directions. It can be seen from formula (3.1) that the camera internal reference focal length f is related to the value in the Z axis direction of the workpiece relative to the camera coordinate system, so the accuracy of the calibration of the focal length f in the camera internal reference directly affects the positioning accuracy in the Z axis direction of the workpiece. Because the final pose of the workpiece is relative to the pose in the world coordinate system, the precision of the Z axis is also related to the pose in the world coordinate system on the work plane, from the formula (3.2) to (3.8), the position and attitude of the world coordinate system relative to the camera coordinate system affects the attitude of the workpiece in the world coordinate system, so the selection of the reference point of the world coordinate system also affects the positioning accuracy in the axis direction.

## 5 CONCLUSION

The author puts forward a method to identify and locate randomly stacked workpieces with a monocular camera. The experimental results show that, the CAD 3D model creation template matching method adopted can accurately match the objects in the image under any posture and any position of the object; it can accurately identify the target objects in random stacking and complex environment, with high stability and reliability. At present, there is a certain deviation in recognition accuracy, which may be related to image quality, algorithm optimization and calibration results, after optimizing these factors, the error range of positioning can be reduced and the positioning accuracy can be improved.

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## REFERENCES

[1] Han, M.; Zhang, Z.; Jiao, Z.; Xie, X.; Zhu, Y.; Zhu, S.-C.; Liu, H.: Scene reconstruction with functional objects for robot autonomy, International Journal of Computer Vision, 130(12), 2022, 2940-2961. https://doi.org/10.1007/s11263-022-01670-0

[2] Jurado-Rodríguez, D.; Jurado, J.-M.; Pádua, L.; Neto, A.; Muñoz-Salinas, R.; Sousa, J.-J.: Semantic segmentation of 3D car parts using UAV-based images, Computers & Graphics, 107(9), 2022, 93-103. https://doi.org/10.1016/j.cag.2022.07.008

[3] Tiwari, B; Gupta, S.-H; Balyan, V.: Comparative exploration of diverse substrate materials on performance of ultra-wide Band antenna design for on body WBAN applications, Wireless Personal Communications, 124(4), 2022, 3661-3684. https://doi.org/10.1007/s11277-022-09532-1
[4] Li, Q.; Xie, X.; Zhang, C.; Zhang, J.; Shi, G.: Detecting human-object interactions in videos by modeling the trajectory of objects and human skeleton, Neurocomputing, 509(4), 2022, 234-243. https://doi.org/10.1016/j.neucom.2022.08.008
[5] Parhizkar, M.; Amirfakhrian, M.: Car detection and damage segmentation in the real scene using a deep learning approach, International Journal of Intelligent Robotics and Applications, 6(2), 2022, 231-245. https://doi.org/10.1007/s41315-022-00231-5
[6] He, Z.; Fan, X.; Peng, Y.; Shen, Z.; Jiao, J.; Liu, M.: EmPointMovSeg: sparse tensor-based moving-object segmentation in 3-d lidar point clouds for autonomous driving-embedded system, IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, 42(1), 2022, 41-53. https://doi.org/10.1109/TCAD.2022.3172031
[7] Maharaj, R; Balyan, V; Khan, M.T.-E.: Design of IIoT device to parse data directly to scada systems using LoRa physical layer, International Journal on Smart Sensing and Intelligent Systems, 15(1), 2022, 1-13. https://doi.org/10.21307/ijssis-2021-023
[8] Li, X.; Cao, R.; Feng, Y.; Chen, K.; Yang, B.; Fu, C.-W.; Heng, P.-A.: A sim-to-real object recognition and localization framework for industrial robotic bin picking, IEEE Robotics and Automation Letters, 7(2), 2022, 3961-3968. https://doi.org/10.1109/LRA.2022.3149026
[9] Lee, H.; Lee, J.; Kim, H.; Mun, D.: Dataset and method for deep learning-based reconstruction of 3D CAD models containing machining features for mechanical parts, Journal of Computational Design and Engineering, 9(1), 2022, 114-127. https://doi.org/10.1093/jcde/qwab072
[10] Xiwei, W.-U.; Bing, X. I. A.-O.; Cihang, W.-U.; Yiming, G. U.-O.; Lingwei, L.-I.: Factor graph-based navigation and positioning for control system design: A review, Chinese Journal of Aeronautics, 35(5), 2022, 25-39. https://doi.org/10.1016/j.cja.2021.09.001
[11] Kholmatov, U.: The possibility of applying the theory of adaptive identification to automate multi-connected objects, The American Journal of Engineering and Technology, 4(03), 2022, 31-38. https://doi.org/10.37547/tajet/Volume04Issue03-05
[12] Farahsari, P.-S.; Farahzadi, A.; Rezazadeh, J.; Bagheri, A.: A survey on indoor positioning systems for iot-based applications, IEEE Internet of Things Journal, 9(10), 2022, 7680-7699. https://doi.org/10.1109/JIOT.2022.3149048
[13] Shang, S.; Wang, L.: Overview of WiFi fingerprinting based indoor positioning, IET Communications, 16(7), 2022, 725-733. https://doi.org/10.1049/cmu2.12386
[14] Lee, H.; Lee, J.; Kim, H.; Mun, D.: Dataset and method for deep learning-based reconstruction of 3D CAD models containing machining features for mechanical parts, Journal of Computational Design and Engineering, 9(1), 2022, 114-127. https://doi.org/10.1093/jcde/qwab072
[15] Maninis, K.-K.; Popov, S.; Nießner, M.; Ferrari, V.: Vid2cad: Cad model alignment using multi-view constraints from videos, IEEE Transactions on Pattern Analysis and Machine Intelligence, 45(1), 2022, 1320-1327. https://doi.org/10.1109/TPAMI.2022.3146082
[16] Korbi, A.; Tlija, M.; Louhichi, B.: A CAD model for the tolerancing of mechanical assemblies considering non-rigid joints between parts with defects, Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 236(3), 2022, 219-232. https://doi.org/10.1177/09544054211025775
[17] Campi, F.; Favi, C.; Germani, M.; Mandolini, M.: CAD-integrated design for manufacturing and assembly in mechanical design, International Journal of Computer Integrated Manufacturing, 35(3), 2022, 282-325. https://doi.org/10.1080/0951192X.2021.1992659
[18] Guo, H.; Liu, S.; Pan, H.; Liu, Y.; Tong, X.; Guo, B.: ComplexGen: CAD reconstruction by B-rep chain complex generation, ACM Transactions on Graphics (TOG), 41(4), 2022, 1-18. https://doi.org/10.1145/3528223.3530078

[19] Seidl, P.; Renz, P.; Dyubankova, N.; Neves, P.; Verhoeven, J.; Wegner, J.-K.; Klambauer, G.: Improving few-and zero-shot reaction template prediction using modern hopfield networks, Journal of chemical information and modeling, 62(9), 2022, 2111-2120. https://doi.org/10.1021/acs.jcim.1c01065

[20] Tu, Z.; Coley, C.-W.: Permutation invariant graph-to-sequence model for template-free retrosynthesis and reaction prediction, Journal of chemical information and modeling, 62(15), 2022, 3503-3513. https://doi.org/10.1021/acs.jcim.2c00321

[21] Palla, S.-R.; Sahu, G.; Parida, P.: Human gait recognition using firefly template segmentation, Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization, 10(5), 2022, 565-575. https://doi.org/10.1080/21681163.2021.2012829

[22] Losper, B.; Balyan, V.; Groenewald, B.: Development of Distributed Data Acquisition System, Lecture Notes in Networks and Systems, 371, 2022, 867-878. https://doi.org/10.1007/978-3-030-93247-3_82

[23] Zhou, Y.; Zhang, Y.: SiamET: a Siamese based visual tracking network with enhanced templates, Applied Intelligence, 52(9), 2022, 9782-9794. https://doi.org/10.1007/s10489-021-03057-z