



Features Extraction of Reconstruction Model Using in Augmented Reality System of Teleoperation Mobile Robots

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Abstract. In manned deep space exploration, teleoperation robot can cooperate with or even replace astronauts to perform various dangerous tasks in unfamiliar environment. By combining augmented reality system with teleoperation robot, the higher reliability and accuracy required by teleoperation robot can be obtained. The real-time tracking algorithm is one of the key and difficult points in the realization of on orbit teleoperation augmented reality system. Feature extraction based on reconstruction model is the basis of real-time tracking of the system. This paper studies the feature extraction algorithm based on reconstruction model, analyzes the feature points extraction of Harris and sift from the principle level combined with the task characteristics, studies the relationship among the time, image size and number of feature points of the two kinds of feature extraction through experiments, and tests and analyzes the practical application effect of the selected feature extraction methods in the system, and obtains the SIFT The conclusion is that feature point extraction is more suitable for on orbit augmented reality teleoperation system, and the future work is prospected.

Keywords: augmented reality · teleoperation mobile robots · reconstruction model · SIFT · features extraction

1 Introduction

Teleoperation robot is an intelligent robot that can perform scientific tasks such as remote inspection and detection of harsh environment, sampling and analysis, and material handling under remote control. [1] Operators monitor or control remote robots to complete various tasks, so as to achieve the purpose of carrying out tasks in inaccessible or dangerous environments. In manned deep space exploration missions, for unfamiliar, dangerous or inaccessible environments, teleoperation robots can be used to perform rich tasks [2]. It is imperative for robots to land on unknown celestial bodies such as the moon and asteroids or engage in dangerous work instead of humans, so as to prevent humans from

being hurt during deep space exploration and protect people's lives. In order to accurately teleoperate the robot, it is first necessary to obtain the surface environment of the celestial body where the robot is located, and judge the moving range and distance according to the environment [3–5]. Because the unknown celestial environment is strange and complex, the two-dimensional environment model is not enough to express the real situation of its surface, and it is impossible to accurately judge the distance in the environment. In the previous research, we used Metashape software to reconstruct the 3D environment model based on the collected 2D images, which laid a technical foundation for the subsequent 3D environment reconstruction and 3D model reconstruction for deep space exploration teleoperation tasks [2]. By developing the augmented reality simulation control system of teleoperation robot based on ARToolKit, the augmented reality control platform is built at the remote control end of the robot, which improves the working efficiency of teleoperation robot. [6] Real-time tracking algorithm suitable for on-orbit teleoperation augmented reality system is one of the key and difficult points to realize this system, and feature extraction based on reconstruction model is the foundation to realize real-time tracking of this system. In this paper, the feature extraction algorithm based on reconstruction model is studied, which lays the foundation for real-time tracking of on-orbit teleoperation augmented reality system.

2 Principle and Experiment

2.1 Principle of Point Application

In the manned space exploration mission, due to the particularity of the environment, the augmented reality system applied to the on-orbit teleoperation robot must realize two important functions: one is to reconstruct the three-dimensional environment based on two-dimensional images; The second is to realize real-time tracking based on the reconstructed model. Figure 1 is the system flow chart of real-time tracking in the augmented reality system of on-orbit teleoperation robot based on ARToolKit As shown in the figure, in the implementation process, the 3D environment reconstruction based on 2D images provides a reconstructed 3D model for the follow-up tracking process, which can be attributed to an offline process, and will not be described in detail in this article. The real-time tracking algorithm based on the reconstructed model is to use the reconstructed three-dimensional model provided by the offline process for real-time tracking. Among them, the useful information of the prior model includes: the original image used for reconstruction, the matching relationship between the two-dimensional feature points of the reconstructed image and the three-dimensional points of the model, etc. Because of the use of the relevant information of the reconstructed 3D model, the real-time tracking algorithm can effectively avoid the influence of external conditions, such as the change of illumination or the change of scene.

For the tracking algorithm, how to establish the correspondence between the three-dimensional target and the two-dimensional image sequence is the key point of the tracking algorithm. In the real-time tracking algorithm adopted in this system, the following methods are adopted: firstly, the k-d tree of the reconstructed model is established, and this k-d tree contains the three-dimensional point information of the model; Then, in the online tracking stage, the feature points of each frame in the input image sequence are

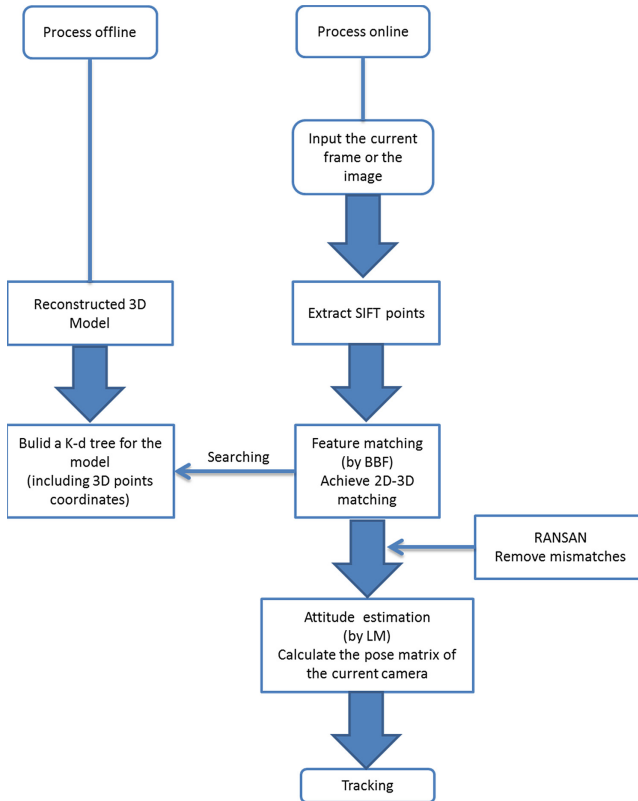


Fig. 1. System Flow Chart

searched by BBF, so as to find the 2D-3D matching relationship. Only after the matching relationship between the three-dimensional points and the two-dimensional feature points of the image is established can the current camera matrix, that is, the P matrix of the camera, be obtained. In the off-line process, the prior model includes the 3D points of the original image and model used for reconstruction and the corresponding 2D points of the image, and the k-d tree of the model is established by using this information. At this time, the established k-d tree already contains the coordinates of three-dimensional points, which can be well used for feature matching in the following tracking process.

2.2 Feature Point

To use 2D images for 3D reconstruction, the first step is to extract the feature points in the images. Feature extraction is not only used for 3D reconstruction, but also used in real-time tracking of the system. Therefore, the process of feature point extraction and matching is the basis of online process, which is related to the final effect of the whole on-orbit teleoperation augmented reality system.

Features can be corner, junction, edge point, sometimes called edge pixels and points extracted by other interest operators. The attribute parameters or descriptive features of

a feature can be the gray value and distribution of the image around the feature point, as well as the relationship with the surrounding feature points, moment invariants and angles. Similarity measure can adopt normalized correlation coefficient (for example, the gray values around the feature points are used as matching entities), or it can adopt a designed measurement function, and then combine with other constraints. Feature matching is an image matching method that takes the points with some local special properties extracted from two pictures or two images in a video sequence as conjugate entities, takes the attribute parameters of feature points, namely feature description, as matching entities, and realizes the registration of conjugate entities by calculating similarity measures.

Commonly used feature points and matching algorithms mainly include Harris feature algorithm and SIFT feature algorithm. Feature extraction generally uses Harris feature extraction algorithm to extract the feature points in the current image frame and obtain the two-dimensional image coordinates of the feature points. Harris operator is a signal-based point feature extraction operator proposed by C. Harris and M. J. Stephens in 1988. Inspired by the autocorrelation function in signal processing, this operator gives the matrix M associated with the autocorrelation function. The eigenvalue of the matrix m is the first-order curvature of the autocorrelation function. If both curvature values are high, then the point is considered as the point feature. Harris corner is the most classic feature point, which is invariant to the translation and rotation of gray scale. However, Harris corner is sensitive to scale, and its matching is easily affected by illumination and scale. Therefore, the extraction and matching of Harris corner can't be suitable for large visual changes, and its application in tracking system has certain limitations.

SIFT is the most widely used key point detection and description algorithm at present. It was first proposed by David. G. Lowe in 2004. This feature extraction makes full use of the local information of the image. It has the invariance of rotation, scale, translation, viewing angle and brightness, which is conducive to the effective expression of target feature information. In addition, it is robust to parameter adjustment. When describing features, the number of appropriate feature points can be adjusted according to the needs of the scene for feature analysis. The main features of this feature point are as follows: a) It is a local feature of the image, which is invariant to rotation, scaling and brightness changes, and stable to a certain extent to angle of view changes, affine transformation and noise. B) Good uniqueness and rich information, which is suitable for fast and accurate matching in massive feature databases. C) Quantity, even a few objects can produce a large number of feature vectors. D) High speed, and the optimized matching algorithm can even meet the real-time requirement.

2.3 Experiments

From the foregoing, it can be seen that feature point extraction is the basis of real-time tracking in on-orbit teleoperation augmented reality system, and its feature point extraction effect is directly related to the success or failure of on-orbit teleoperation task. In order to find a method to extract the feature points of the reconstructed model which is suitable for the on-orbit teleoperation augmented reality system, we carried out related experiments on Harris feature points and SIFT feature points extraction. The experiment

is based on a computer with Windows XP operating system. The computer configuration is Intel Pentium 4, 2.8GHz CPU, 512MB memory and GeForce 6600 graphics card. The algorithm is implemented by third-party development packages, including OpenGL, OpenCV and VXL. From the foregoing, it can be seen that feature point extraction is the basis of real-time tracking in on-orbit teleoperation augmented reality system, and its feature point extraction effect is directly related to the success or failure of on-orbit teleoperation task. In order to find a method to extract the feature points of the reconstructed model which is suitable for the on-orbit teleoperation augmented reality system, we carried out related experiments on Harris feature points and SIFT feature points extraction. The experiment is based on a computer with Windows XP operating system. The computer configuration is Intel Pentium 4, 2.8GHz CPU, 512MB memory and GeForce 6600 graphics card. The algorithm is implemented by third-party development packages, including OpenGL, OpenCV and VXL.

3 Results and Discussion

3.1 Analysis of Algorithm and Discussion of Experimental Results

From the angle of algorithm principle, Harris feature point was put forward earlier, which is the most classic feature point. It is invariant to the translation and rotation of gray scale, but Harris feature point is sensitive to scale, and its matching is easily affected by illumination and scale. SIFT feature point is an image local feature description operator, which is based on the feature detection method of invariant technology and is invariant to image scaling, rotation and even affine transformation. The descriptor of this feature point is a 128-dimensional vector. SIFT points keep certain deformation for image change factors such as rotation, scaling, affine transformation, angle of view change, illumination change, etc., and also keep good matching for factors such as object movement, occlusion, noise, etc., so that feature matching between two images with big differences can be realized. The tracking schematic diagram based on SIFT feature points is shown in Fig. 2.

The construction process of the 128-dimensional descriptor of SIFT points is as follows: for any key point, in its scale space (i.e., a layer of Gaussian pyramid structure), take the neighborhood with the key point as the center, then divide the neighborhood evenly into sub-regions (each sub-region has a size of f), and calculate the gradient direction histogram for each sub-region (the histogram is evenly divided into 8 directions). Then, the gradient histograms of eight directions in the sub-regions are sorted in turn according to their positions, thus forming a one-dimensional vector, which is the descriptor of the feature points with constant scale. The first dimension corresponds to the first gradient direction of the first subregion, the second dimension corresponds to the second gradient direction of the first subregion, and the ninth dimension corresponds to the first gradient direction of the second subregion, and so on.

Theoretically, the scale invariant feature is a similar invariant, that is, it is invariant to the scale change and rotation of the image. However, due to the special treatment of many details in the construction of this feature, it has strong adaptability to the complex deformation and illumination changes of the image, and at the same time, the operation speed is faster and the positioning accuracy is higher. This feature point has the following



Fig. 2. Tracking based on SIFT points

properties: Theoretically, the scale invariant feature is a similar invariant, that is, it is invariant to the scale change and rotation of the image. However, due to the special treatment of many details in the construction of this feature, it has strong adaptability to the complex deformation and illumination changes of the image, and at the same time, the operation speed is faster and the positioning accuracy is higher. This feature point has the following properties:

- (1) **Stability.** This feature is a local feature of the image, which is invariant to rotation, scaling and brightness changes, and also stable to a certain extent to angle changes, affine transformation and noise.
- (2) **Accuracy.** Accurate positioning of key points not only improves the accuracy, but also greatly improves the stability of key points. But also rich in information, and is suitable for fast and accurate matching in massive feature databases.
- (3) **Quantity.** Even a few objects can produce a large number of feature vectors.
- (4) **High speed.** DoG(Difference of Gaussians) operator is used to detect key points in multi-scale space. Compared with the traditional detection method based on LoG(Laplacian of Gaussian) operator, the operation speed is greatly accelerated, and the optimized matching algorithm can meet the real-time requirements.
- (5) **Adaptability.** When constructing descriptors, the statistical characteristics of sub-regions are taken as the research object instead of single pixel, which improves the adaptability to local image deformation. For the sub-regions of the neighborhood sum of the key points, the gradient amplitude is weighted like Gaussian function, which strengthens the central region and weakens the influence of the edge region, thus improving the adaptability of the algorithm to geometric deformation. This feature is not only invariant to the general linear illumination model, but also adaptable to complex illumination changes.

(6) Scalability. It can be easily combined with other forms of feature vectors.

Firstly, SIFT algorithm performs feature detection in scale space, and determines the position and scale of key points. Then, the main direction of gradient in the key point field is used as the directional feature of the point, so as to realize the independence of operators on scale and direction. The algorithm is mainly composed of the following four steps:

- (1) Detecting extreme points of scale space: determining the positions of image features in all possible scale spaces of the image, and these positions are the selected positions in subsequent processing. The location of image features in the scale space is determined by a Gaussian difference filter, and the image features obtained by this Gaussian difference filter are well invariant to the rotation and scaling operations of the image.
- (2) Accurate location of extreme points is the key points: after a large number of alternative positions are obtained, more detailed screening and filtering are needed to ensure that the remaining features have sufficient stability. These screened image feature positions are called key points.
- (3) Specify main direction for key points: Based on the direction of the gradient of image grayscale near the key points, one or more directions are assigned to the key points. All subsequent processing is based on the direction, scale and position of key points.
- (4) Generating key point description sub-vector: according to the scale of each key point, calculate the gradient of the gray level of the points in the image in the neighborhood of the key point, and then establish the multi-dimensional information description of the key point, so as to ensure that the obtained key point description is not very sensitive to local image distortion and illumination changes.

In the actual calculation process, in order to enhance the robustness of matching, Lowe suggested using 16 seed points to describe each key point, so that 128 data can be generated for one key point, that is, a 128-dimensional feature vector can be finally formed. At this time, the influence of geometric deformation factors such as scale change and rotation has been removed from the feature vector, and the influence of illumination change can be further removed by further normalizing the length of the feature vector.

In order to verify the above theoretical analysis, we simply compare the actual operation effects of the two feature point detection and matching processes, and preliminarily select the feature extraction scheme of the reconstruction model suitable for the on-orbit teleoperation augmented reality system. The actual photos are used for simple experimental comparison, and the scene photos, Harris algorithm detection map and SIFT algorithm detection map are shown in Fig. 3 below.

According to the actual operation results, we can see that the number of Harris feature points is small, and the matching relationship is simple, so the calculation time is relatively short. Without considering the accuracy requirement, the matching process of Harris feature points is simpler, and the calculation amount is relatively low, so it is suitable for the scene where the calculation ability is constrained. In order to ensure the normal realization of various functions in the space environment with strong radiation, most spacecraft use aerospace-grade components. Under the same power consumption, weight, volume and other conditions, their computing power is not the same as that of

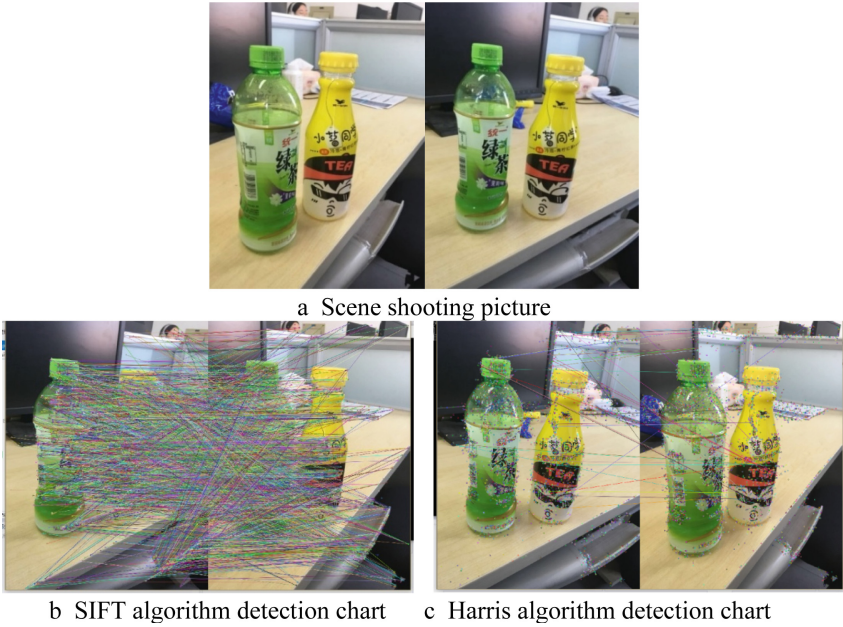


Fig. 3. Preliminary experiment of feature point extraction method of figure

civil devices used daily on the same scale. From this point of view, Harris feature points are more suitable than SIFT feature points for feature extraction of reconstruction model of on-orbit teleoperation augmented reality system.

However, as mentioned in the previous analysis of Harris algorithm, Harris feature points are sensitive to scale, and their matching is easily affected by illumination and scale. In the manned deep space exploration mission, the task of on-orbit teleoperation robot is to be able to perform scientific tasks such as long-distance inspection and detection of harsh environment, sampling and analysis, material handling, etc. under remote control, and its environment is mostly unknown celestial bodies such as the moon and asteroids that have no atmosphere around it. In such an environment, because there is no atmosphere for reflection and scattering, the natural light from the outside or the illumination light from the extravehicular floodlighting equipment carried by the spacecraft itself will be more direct, and the contrast between light and dark will be stronger. Therefore, it is extremely unfavorable for Harris feature point matching process which is easily influenced by illumination and scale. In addition, the manned deep space exploration mission belongs to the deep space exploration mission with people involved, and the implementation process is costly in all aspects, and human life cannot be lost, so the reliability of the system is extremely high. Harris algorithm is not as good as SIFT algorithm in terms of stability and reliability, although it requires less computing power of devices. From the point of view of the requirements of manned deep space exploration mission on the accuracy, stability and reliability of the system, it is found that the more SIFT feature matching points are, the more advantageous it is to match feature points based on 3D scene reconstruction model, and even to some extent, it has a relatively

stable feature tracking ability for images taken from any angle. From the point of view of maximizing the stability and accuracy of the system, SIFT feature matching points are more suitable.

3.2 Experiment and Discussion of SIFT Feature Point Extraction

Traditional visual tracking systems often use Harris corner to track and extract features, but the change of visual angle will block Harris corner, or the extraction will fail due to the influence of illumination. The extraterrestrial environment is full of various unknown factors, such as obstacles, light changes, harsh environment and so on. In order to avoid the influence of occlusion, illumination change and environment, the feature extraction of reconstruction model applied to on-orbit teleoperation augmented reality system is realized by SIFT algorithm. As the result of the previous experiment shows, the number of SIFT feature points is more, the calculation is more and the time is longer. In order to further analyze the feasibility of applying SIFT algorithm to feature extraction of reconstructed model of on-orbit teleoperation augmented reality system, and to study the influence of image size and image texture on the number and time of extracting SIFT feature points, the following two groups of experiments were carried out in this paper.

(1) Comparative analysis of Harris feature points and SIFT feature points extraction time

Harris points and SIFT points of images with the same size and different textures are extracted respectively. The size of each image is 256×256 , but the texture information of each image is different. The image of the experiment is shown in Fig. 4. The experimental data are shown in Table 1.

The data in Table 1 shows that for images of the same size, regardless of the complexity of the image texture or background, the time taken to extract Harris points is about 0.74 s; Even if the image size is the same, the time and the number of feature points used to extract SIFT points are different due to different textures. Images of Harris point and SIFT point are extracted as shown in Fig. 4 and Fig. 5 respectively. The experimental results are shown in Fig. 5.

Figure 4 and Fig. 5 show that the time taken to extract Harris feature points is basically independent of the richness of image texture; However, the time taken to extract SIFT feature points is closely related to the richness of image texture. The richer the texture of the image, the more SIFT feature points are extracted, and the longer it takes.

(2) Experiment on extracting time of SIFT points of different sizes in the same image

The SIFT points of the same image with different sizes were extracted to study the relationship between extraction time and the number of feature points. The original image of the experiment is shown in Fig. 3. The experimental data are shown in Table 2. For the same image with different sizes, extract the relationship curve between the number of SIFT points and the time taken and the image size, as shown in Fig. 6.

It can be seen from Fig. 6 that for images with the same texture, when the image size increases, the time taken to extract SIFT points and the number of extracted SIFT points also increase. From the results of the above two groups of experiments, it can be concluded that the image size and texture information both affect the time taken to

extract SIFT points and the number of SIFT points extracted. On the one hand, with the increase of image size, the time for extracting SIFT points also increases; On the other hand, from the comparative experiment, it can be seen that the extraction of Harris feature points is basically not affected by image texture, while the extraction of SIFT feature points is closely related to the richness of image texture. If the texture of the image is richer, the number of extracted SIFT feature points will be more, and the corresponding time will be more.

Table 1. Time for extracting Harris points and SIFT points

No	Time to select Harris point (s)	Time to extract SIFT points(s)	Number of SIFT points
1	0.76	1.87	339
2	0.74	1.90	345
3	0.74	3.15	888
4	0.68	1.28	204
5	0.74	2.23	494
6	0.76	2.02	396
7	0.81	1.59	225
8	0.73	1.76	272
9	0.77	1.06	93
No	Time to select Harris point (s)	Time to extract SIFT points(s)	Number of SIFT points



Fig. 4. Original picture of 256 × 256

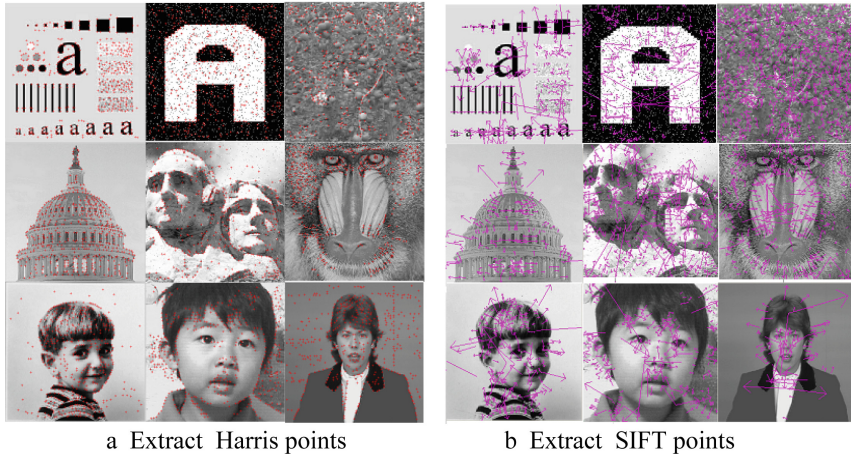


Fig. 5. Comparison between extraction results in 256×256 image.

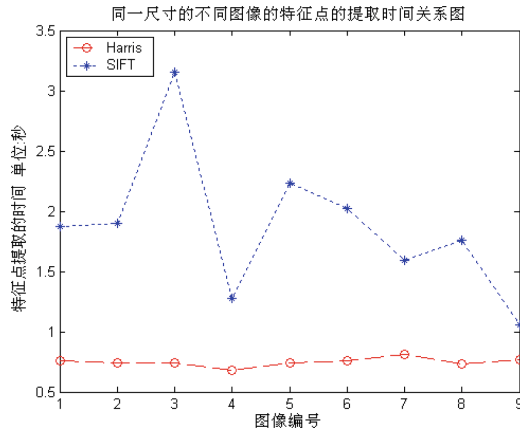


Fig. 6. Time relations of feature points extracted from 256×256 images

This characteristic of SIFT point is not ideal for tracking system, especially for real-time tracking system, which will affect the real-time performance of tracking system. However, considering the high stability of SIFT point, it can well solve the influences of occlusion, illumination and environment, which is very important for tracking system. On the other hand, the tracking system doesn't need too many feature points, as long as it can track the target object. Therefore, in the tracking algorithm studied in this paper, SIFT feature points can effectively track features (Figs. 7 and 8).



Fig. 7. Image of the experiment

Table 2. Relationship between extraction time of SIFT feature points and image size

No	Image size	Time to extract SIFT points(s)
1	160 × 120	0.532
2	314 × 235	2.5
3	448 × 336	4.609
4	640 × 480	7.40
5	800 × 600	11.656
6	1024 × 768	23.25

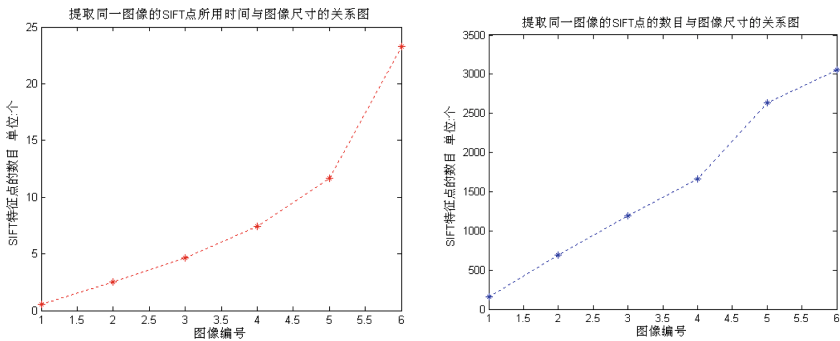


Fig. 8. Relationship between the time taken to extract SIFT feature points of the same image and image size

3.3 Analysis of Practical Application Effect

Combined with the above analysis results, we apply SIFT algorithm to the reconstruction model feature extraction experiment in the augmented reality system of on-orbit

teleoperation, and further analyze and verify its feasibility. In the experiment, a 640×480 stone table image was used as the experimental image. The test input image is shown in Fig. 9a. The experimental results after extracting SIFT feature points are shown in Fig. 9b. After many experiments, it takes about 5–6 s to extract SIFT points from a single image with the size of 640×480 , and the number of extracted SIFT points is about 1200. The result of extracting SIFT points from the current frame image in Fig. 9a is shown in Fig. 9b. The number of SIFT points in the current frame image is 1221, and the consumed time is 5.265 s.

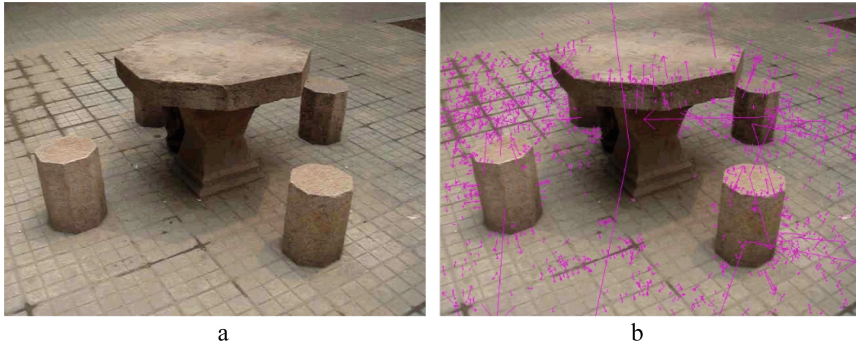


Fig. 9. Image input by experiment and image after feature extraction

The experimental results show that there are more than 1000 SIFT feature points extracted from the image, which takes about 5–6 s. For the real-time tracking algorithm, the speed of extracting feature points is slow, which has two impacts on the tracking algorithm: on the one hand, the more features that can be tracked, the easier it is to find the feature matching between images, thus providing accurate 2D-3D matching point pairs for camera attitude estimation in the following tracking process in the whole system process, so as to ensure the tracking accuracy; On the other hand, the more features that can be tracked, the greater the amount of data, and the slower the computing speed. In the follow-up, it is still necessary to improve and perfect the feature point extraction algorithm. On the premise of ensuring the accuracy and stability of feature point extraction, the running amount is further reduced and the extraction speed is increased.

4 Summarize and Prospect

Man-machine cooperation can give full play to the respective advantages of man and machine, and man-machine cooperation mode is an important feature of people participating in deep space exploration missions in the future. Based on the requirements of human-machine cooperation tasks such as on-orbit augmented reality teleoperation in unknown celestial environment, this paper analyzes the extraction process of Harris feature points and SIFT feature points through research and experiments, and compares the number and time of feature points extracted by two different algorithms in combination

with the actual working background and environmental requirements of feature extraction in the reconstruction model of on-orbit teleoperation augmented reality system. After the corresponding conclusion is drawn, the relationship between the extraction time and number of SIFT feature points in different image sizes is analyzed, and it is actually applied to the further experiment of reconstruction model extraction in orbital teleoperation augmented reality system. Through research, the following conclusions are drawn:

- (1) For the same feature extraction target picture, Harris algorithm can be used when the number of feature points extracted is small and the time is short, and the accuracy requirement is not considered. The SIFT algorithm extracts a large number of feature points and takes a long time. However, considering the requirements of the manned deep space exploration mission for the accuracy, stability and reliability of the system, SIFT feature points are more suitable for the feature extraction process of the reconstruction model of the on-orbit teleoperation augmented reality system.
- (2) Compared with Harris feature points, with the increase of image size, the extraction time of SIFT feature points increases. This is because the extraction of SIFT feature points is greatly affected by the degree of image texture, which is closely related to the richness of image texture. The richer the image texture is, the more SIFT feature points are extracted, and the longer it takes. Considering that the system requires high stability and accuracy, SIFT feature points can be selected as the feature extraction method of the reconstruction model of this system.
- (3) In the practical application verification of the system, both the size and texture information of the image affect the extraction of more than 1000 SIFT feature points, which takes about 5–6 s. For the real-time tracking algorithm, the speed of extracting feature points is still slow. In the follow-up research work, it is necessary to study the improvement of feature point extraction algorithm, further improve the extraction speed of SIFT points, improve the visual tracking performance of augmented reality on-orbit teleoperation system, and improve the human-computer interaction experience in the process of on-orbit teleoperation as a whole.

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