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Research on Visual Image Stitching Method of Micro Flapping Wing Flying Robot Based on Block Matching

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Abstract. In order to solve the problem of limited field of view and the inability to carry out wide-field navigation planning during the visual navigation of the flapping-wing flying robot, and realizing the wide-field navigation planning of the flapping-wing flying robot, this paper proposes a visual image stitching method for the flapping-wing flying robot based on block matching. Block matching is used to perform image registration on the visual image data of the flapping-wing flying robot, and the image fusion algorithm is used to improve the image clarity. While ensuring the large field of view perception and navigation of the flapping-wing flying robot, the features of the flapping-wing flying robot's visual target are extracted through block matching, which provides technical support for the flapping-wing flying robot's target tracking based on dynamic vision. An experimental verification system was built with a flapping-wing flying robot system and an airborne camera. The visual image stitching method of the flapping-wing flying robot based on block matching is experimentally verified, and a series of experimental results verify the feasibility and effectiveness of the method in this paper. The innovation of this paper is embodied in two aspects, the visual image registration method of flapping-wing flying robot based on block matching and the visual image fusion method of flapping-wing flying robot based on wavelet transform.

Keywords: flapping-wing flying robot, image stitching, block matching, image registration, image fusion

1. Introduction

1.1. Flapping Wing Flying Robot Vision System

In recent years, the technology of flapping-wing flying robots has developed rapidly. Due to its low cost, high efficiency and flexibility, it has been widely used in various fields such as investigation and anti-terrorism. The flapping-wing flying robot integrates various latest cutting-edge technologies such as new material technology, MENS technology, energy power technology, mechanical structure and control technology, and its dynamic model and control system are more complex. It was not until the end of the last century that a number of significant scientific research results were formed [1].

The flapping-wing flying robot has obvious advantages for missions that cannot be reached by large drones due to its small size, light weight, and flexible mobility. It can replace humans to complete monitoring and tracking tasks in long-distance and dangerous areas [2]. Micro flapping-wing flying robots are widely used in military and other fields, including counter-terrorism detection, battlefield detection, and communication relay. In the field of people's livelihood, including dangerous goods detection, fire search, disaster monitoring, and traffic monitoring, flapping-wing flying robots have broad prospects in the fields of military and people's livelihood.

With the rapid development of artificial intelligence technology, vision-based robot navigation technology is based on artificial intelligence technology, using visual sensors to guide the robot to avoid obstacles and complete tasks [3]. Robot navigation technology based on visual perception is divided into the following three steps, (1) visual image processing. (2) pattern recognition and environment understanding. (3) path planning and navigation control process.

Flapping-wing flying robot is a very typical nonlinear complex system with using flexible structures. Its body size is small, its weight is lighter, and it is easily affected by environmental factors [4]. Moreover, as

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the size of the fuselage decreases, the control difficulty of the actuator is greatly increased, and robot visual feedback is needed as an auxiliary control method to complete the task of flying robots. Traditional sensors cannot meet the task requirements of flapping-wing flying robots. It requires robot vision technology and image processing algorithms to provide flying robots with operating environment information to achieve precise control of the flying robot.

At present, in terms of the visual system research of flapping-wing flying robots, Europe and the United States have been at the world's leading level after years of development. The domestic flapping-wing flying robot vision technology is also booming, and forming their own unique achievements.

1) Airborne visual perception

DelFly II [5] of Delft University of Technology in the Netherlands is equipped with two cameras, which can complete the task of avoiding walls and realize the autonomous control of flapping-wing aircraft. However, the flapping-wing aircraft has a short battery life, poor visual imaging quality, and a visual range of only 4m. The Dove flapping-wing aircraft developed by Song of Northwestern Polytechnical University [6] has a visual perception system composed of a micro color camera and an image processing unit. The flight time is up to 30 minutes, and the video transmission distance has reached more than 4km.

2) External visual perception system

The BinoicFlyingFox [7] flapping-wing aircraft of Germany Festo has constructed a motion capture system composed of two infrared cameras, and the flight process of the aircraft can be captured in real time. The real-time calculation of the motion path is carried out to realize the trajectory prediction. However, the aircraft does not have a camera onboard, and its application fields are limited. An insect-like flapping-wing micro-aircraft developed by Rosen [8], a micro-robot laboratory at Harvard University in the United States, has a wingspan of 16cm and a weight of only 3.2g. The aircraft is equipped with the Vicon T visual motion capture system, and the aircraft's flight data is captured and recorded simultaneously by the Vicon system, high-speed cameras and on-board sensors.

In short, the internal and external visual perception system with flapping-wing aircraft as the experimental platform has a relatively simple function. For the application of mature visual recognition, target tracking and navigation and positioning functions on fixed-wing and rotary-wing aircraft, flapping-wing aircraft have not been widely used.

3) Target detection and recognition technology

At present, the update iteration speed of fixed-wing aircraft and rotary-wing aircraft is relatively fast, and target detection and recognition technology are widely used in fixed-wing and rotary-wing aircraft, which promotes the visual target detection and visual recognition of unmanned aerial vehicle to become new scientific directions and research hotspots.

Baek [9] of the University of California, USA, used the onboard vision camera to detect the target position, controlled the X-wing flapping wing aircraft, and used the onboard camera to achieve the target navigation function of the flapping wing aircraft. In 2015, the YOLO target detection algorithm proposed by Redmon [10] of the University of Washington in the United States achieved better running speed and accuracy, and can be used in industrial applications. It currently represents the highest level of target detection algorithms.

In short, flapping-wing flying robots need visual perception to assist the robot system in order to achieve more complex functions. Due to the load limitation of the flapping-wing flying robot and the communication limitation with the ground station, to achieve advanced functions such as target detection and recognition, algorithms such as image stitching are required to provide the robot with intelligent information to realize the robot's visual perception and wide-field navigation.

1.2. Overview of image stitching methods

1) The shortcomings and splicing significance of the visual image of the flapping-wing flying robot

Limited by the size and weight of the airborne camera, the airborne imaging equipment is usually used to continuously image the area from different angles, and then the image sequence is stitched into a panoramic image through image stitching technology to meet the needs of wide field of view and high resolution. Because the images of flapping-wing flying robots are blurred, the resolution is low, and the field of view is small, it will increase the difficulty of image stitching. The quality of the stitched image directly determines the accuracy of the robot's environment perception and navigation. Therefore, the research on image stitching of flapping-wing flying robots has important engineering application value.

2) Definition and processing flow of image stitching technology

Image stitching refers to combining multiple images with overlapping areas into a panoramic wide-field image that meets the field of view and resolution requirements according to the relative relationship between the images [11]. The image stitching process includes image preprocessing, image registration, and image fusion. The stitching process is shown in Fig.1.

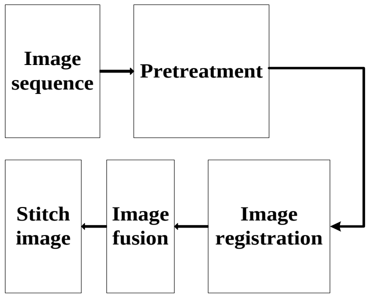


Fig. 1: Image stitching flowchart

Image preprocessing includes signal processing such as noise removal. Image registration is the process of finding and searching for points with the same name between two images to obtain the transformation relationship between the two images to achieve precise alignment of the same target position. Image registration is to find the same area between two images, which plays a decisive role in the image stitching of the flapping-wing flying robot, and directly affects the quality of the image stitching. Image fusion is the technology and process of synthesizing multiple registered images into one image. The information complementary between different images can be used to keep the information contained in the original image in the fusion image to the greatest extent, so as to obtain a better visual effect [12]. At present, the commonly used image fusion algorithms in image stitching include, direct average method, hat function weight method, fade-in and fade-out method, and contrast modulation method.

3) The development status of image stitching technology

According to different principles of image registration, image stitching methods can be divided into the following three categories, feature-based methods, region-based methods, and hybrid model-based methods. The feature-based image registration method is to analyze and match images through point features, line features, surface features, or virtual features. Image matching based on feature points is to associate the feature points between two images and determine the corresponding feature point pairs to determine the conversion relationship between the images.

As early as the 1970s, people used local remote sensing images captured to synthesize scene images in a large area, and applied image stitching technology to various fields. In 2003, American scientists used the Martian surface images returned by the Mars rover to stitch together a panoramic image of the Martian surface.

The application of image matching methods based on point features has been relatively mature. It mainly includes Harris algorithm, SIFT algorithm, etc. In 2004, the description operator and matching method of SIFT local features studied by David [13] are very typical and practical representatives. In 2011, Ethan Rublee [14] improved and discovered the ORB algorithm based on fusion of other algorithms. The calculation speed of this solution is 100 times that of SIFT.

Image block matching is to select an image block on the original image, and search for the corresponding image block on the image to be matched for matching. Typical search methods include full search method, three-step method, new three-step method, four-step method and diamond search method. Among them, the full search method considers the cost function of each position in the search window, and the calculation amount of the algorithm is relatively large. The hierarchical search algorithm proposed by Nam [15] is better than the fast search algorithm in terms of search quality and accuracy, but its algorithm complexity is significantly higher than that of the fast search algorithm.

2. Flying Robot Image Matching Principle and Image Stitching Principle

The flapping-wing flying robot is a non-linear and complex system, and its flexible body is susceptible to external interference. During the operation of the flying robot, the target is often blocked by surrounding objects. Traditional sensors cannot meet the requirements of operating tasks. As the size of actuators and sensors decreases, their performance parameters are significantly reduced. For this reason, the visual perception and visual feedback of the flapping-wing flying robot are needed to complete the tasks of the flying robot.

More than 70% of the information in the human brain comes from human vision. Robot vision is the core and key technology to realize robotic artificial intelligence [16]. Vision-based robot navigation is a core key technology that uses robot visual perception to guide robots to avoid obstacles and complete tasks [17]. In recent years, artificial intelligence and brain cognitive science have developed rapidly. Realizing vision-based robot navigation control by imitating human vision and human brain cognitive technology is an important development direction in the field of robotics. As an important part of artificial intelligence and robotics, robot vision technology can obtain images of the environment through visual sensors, analyze and interpret them, so that the robot can recognize objects and determine their orientation [18]. Robot vision has very broad application prospects in many fields such as electronics, machinery, intelligent machines, medical treatment, and military affairs.

2.1. Image basic theory

Imaging is the projection of a spatial information scene on the image plane, a process of mapping out a three-dimensional spatial scene and information in a two-dimensional coordinate system. The light intensity information of the spatial scene point is expressed by the gray value of the image pixel, and the position of the point in the image is determined by the imaging model and projection method of the imaging system [19].

Perspective projection assumes that all reflected rays in the scene are projected onto the imaging plane through an optical center point. The perspective model is composed of three parts, optical axis, optical center and image plane. As shown in Fig.2, O_c is the optical center. O_c-$X_cY_cZ_c$ is the camera coordinate system. $O_{x,y}$ is the image plane coordinate system. Z_c axis coincides with the optical axis and is perpendicular to the image plane. O_w-X_w, Y_w, Z_w are the world coordinate system. The distance from the optical center to the image plane is the camera focal length f.

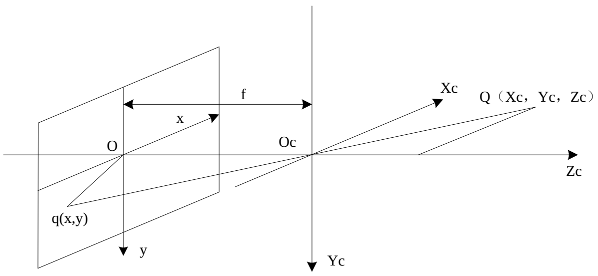


Fig. 2: Perspective projection diagram

The coordinates of the projection imaging point q of the three-dimensional scene point Q (X_c, Y_c, Z_c) are (x, y). Then the projection relationship of the two points can be expressed as,

$$Z_c \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & f & 0 \end{bmatrix} \begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} \tag{1}$$

The relationship between the 3D scene point Q in the camera coordinate system and the world coordinate system is as follows,

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} = \begin{bmatrix} R & T \\ 0 & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_x \\ r_{21} & r_{22} & r_{23} & t_y \\ r_{31} & r_{32} & r_{33} & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix} \tag{2}$$

In the formula, the matrix R is an orthogonal rotation matrix containing 3 independent variables. The vector $T=(t_x,t_y,t_s)$ is a translation vector containing 3 independent variables. The spatial position of the optical axis of the camera is the external parameter of the camera, which is determined by the above 6 parameters. Substituting formula (2) into (1), the relational expression between image point $q(x, y)$ and scene point $Q(X_w, Y_w, Z_w)$ can be obtained,

$$Z_c \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & f & 0 \end{bmatrix} \begin{bmatrix} R & T \\ 0 & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \\ 1 \end{bmatrix} \tag{3}$$

Euclidean transformation is more commonly used in image processing, and the Euclidean distance between any two points in the image remains unchanged after the transformation. The formula for transforming point (x,y) to (x',y') is,

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} t_x \\ t_y \end{bmatrix} \tag{4}$$

The Euclidean transform can be decomposed into two parts, rotation and translation, with 3 degrees of freedom. In the above formula, θ is the angle of rotation and $(t_x, t_y)^T$ is the amount of translation.

Image fusion refers to the process of processing and extracting feature information of multiple images, and finally synthesizing one image. Image fusion can use the fusion algorithm to convert the blurred image into a clear image, and to enhance the display of some contour features of the image. Therefore, image fusion has a wide range of applications [20].

The direct averaging method of image fusion is to use the mean value of the gray value of the pixels in the overlapping area to perform image fusion. This method is similar to the low-pass filter processing of the region, the image is prone to band-shaped regions after fusion, the effect is not good, and the visual effect of the stitched image is easily affected [21]. The calculation formula of the averaging method is as follows,

$$f(x,y) = \begin{cases} f_1(x,y) & (x,y) \in f_1 \\ (f_1(x,y)+f_2(x,y))/2 & (x,y) \in (f_1 \cap f_2) \\ f_2(x,y) & (x,y) \in f_2 \end{cases} \tag{5}$$

In the formula, (x, y) represents the pixel coordinates of the overlapping area, f_1 and f_2 represent the input image, and f represents the fusion image.

2.2. Principles of image matching and image stitching

Image matching is the process of identifying points with the same name between two or more images through a matching algorithm. The image block matching method is derived from the target motion estimation. The block matching method can be used to find the relevant information of the two images. It has a wide range of applications, such as image denoising, image stitching, etc. [22]. Continuous video sequence at least 24 frames per second can not affect the look and effect of video playback. Only a small range of motion occurs in the scene of two consecutive frames. The next frame can be predicted based on the motion vector between the previous frame and the two frames. The motion estimation method is to find the motion vector of the adjacent frame of the image [23].

The principle of the block matching method is to divide the reference image into image blocks of a set size, and find the most similar matching block to the reference block in the image to be searched through the search and matching iteration of the algorithm. As shown in Fig.3, a is the reference block and a' is the matching block.

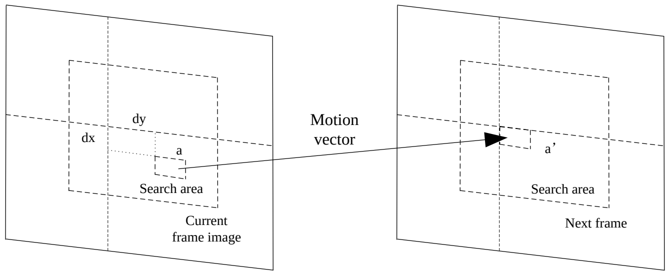


Fig. 3: Block matching schematic

As an effective image processing method, block matching is used by more scholars to match between images, and it can also be used to generate wide-field and large-scale panoramic images.

The panoramic image of the robot is stitched to obtain a larger field of view of the robot for global path planning [24]. The image stitch block matching process is divided into two steps, image registration and strategy search.

The image matching criterion is used to measure the similarity of two image blocks. Therefore, there are certain requirements for the calculation speed and complexity of the algorithm. Typical image matching criteria include, Mean Absolute Error (MAD), Sum of Absolute Error (SAD), and Mean Square Error (MSC), etc. The details are as follows,

(1) Sum of Absolute Error (SAD)

$$R(P,Q)=\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(P_{ij}-\bar{P})(Q_{ij}-\bar{Q})}{\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}(P_{ij}-\bar{P})^2}\sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}(Q_{ij}-\bar{Q})^2}} \tag{6}$$

$-w \le m,n \le w$

(2) Mean absolute error method (MAD)

$$MAD(\mathrm{i},\mathrm{j})=\frac{1}{M\times N}\sum_{i=1}^{M}\sum_{j=1}^{N}\left|Q(\mathrm{i},\mathrm{j})-P(\mathrm{i},\mathrm{j})\right| \tag{7}$$

$-w \le m,n \le w$

(3) Mean Square Error Method (MSE)

$$MSE(\mathrm{i},\mathrm{j})=\frac{1}{M\times N}\sum_{i=1}^{M}\sum_{j=1}^{N}\ Q(\mathrm{i},\mathrm{j})-P(\mathrm{i},\mathrm{j})\ ^2 \tag{8}$$

$-w \le m,n \le w$

Among them, $M\times N$ is the size of the image block, $Q(i, j)$ is the gray value of the image block to be matched at position (i, j). w is the search window size, and $P(i, j)$ is the gray value of the reference image block at position (i, j). It can be seen from the formula that when the value of the normalized cross-correlation function method is the largest, the value of the to-be-matched block Q and the reference block P at the position (i, j) are the closest. If the value is small, the gray value difference between them is large.

Through the comparison of the above methods, the normalized cross-correlation function method requires a large number of operations due to the need to open the root. Both the absolute error sum method and the average absolute error method both need to perform a square operation, and the amount of calculation is still relatively large. However, the absolute error sum method has greater advantages due to its simple operation, and its application prospects are broad.

In the inspection of the flapping-wing flying robot, due to the limitation of the robot load and camera pixels, in order to obtain a panoramic image of the robot's operating environment for path planning, it is necessary to shoot from multiple angles and synthesize a panoramic image. However, there are many repeated modules in each picture during the synthesis process. Therefore, removing redundant repeating modules during the synthesis process and using block matching technology to perform image stitching has become the key to the vision technology of flapping-wing flying robots.

Image stitching refers to the stitching of multiple images into a wide-view panoramic image through image registration and fusion algorithms. According to the image transformation theory and matrix theory, the matching feature point pairs of the two images are obtained, and the transformation matrix H can be obtained according to the image transformation relationship. The transformation relationship between the image to be registered I' and the original reference image I can be obtained as follows,

$$\begin{bmatrix} x^{'} \\ y^{'} \\ 1 \end{bmatrix} = H \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \tag{9}$$

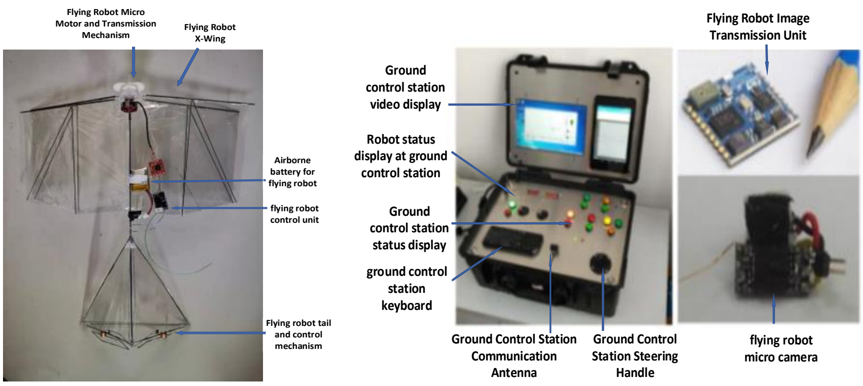
In the above formula, (x', y') and (x, y) are the matching point pairs of the image I' to be registered and the original image I. Image fusion can be divided into three levels, pixel-level fusion, feature-level fusion and decision-level fusion. Feature-level fusion is widely used, which is to perform image fusion on features such as the direction, edge, and shape extracted from the image. The above features can express the key feature information in the image.

3. Flapping-Wing Flying Robot Visual Image Stitching Experimental Platform and Experimental Process

3.1. Visual image stitching experiment platform and experiment process of flapping-wing flying robot

The experimental system of the micro flapping-wing flying robot is mainly composed of the airborne body and the ground console, as shown in Fig.4. The body of the flapping-wing flying robot is composed of carbon fiber body, transmission mechanism, on-board circuit board, X-shaped flexible wing, and micro-motor. The body of the flapping-wing flying robot adopts a carbon fiber soaked cork processing technology, and the mechanical transmission mechanism adopts a flexible connection method.

The flapping-wing flying robot system adopts an enhanced integrated fuselage and a bionic elastic wing that incorporates the long-range feature of MEMS technology. The X-wing is easy to implement in engineering, the number of robot drive motors is small, and the motor and control system are relatively easy to implement. And fly drive is realized by flapping up and down with single degree of freedom of wings.



(a) (b)

Fig. 4: Flapping-wing flying robot body and control system hardware diagram

The wing of the robot will deform greatly during the flapping process, and the forward component force will be generated by using the fluid-structure coupling effect to form the driving force of the flapping-wing flying robot. And the flying robot can realize functions such as smooth flight and turning.

The airborne unit of this system uses micro electronic devices with high integration and low power consumption. The ground console includes a low-noise line amplifier, a receiving antenna, a data processing computer, and a portable video recording unit. The ground amplifying and receiving unit is used to receive the image and video information returned by the onboard camera of the flying robot, and display the data. The miniature camera unit on the onboard part completes the collection of images and videos.

The flapping-wing flying robot has a wingspan of 14cm, can fly continuously for more than 13 minutes, and weighs only 6g. It has functions such as video image acquisition, autonomous obstacle avoidance, self-stabilized flight and other functions. The wireless communication receiver completes the demodulation of the FM signal, and its receiving sensitivity can reach 90dBm.

The experimental tasks of the flapping-wing flying robot are described as follows. The flapping-wing flying robot's visual image unit is used for visual perception, and the flapping-wing robot is used to collect multiple images for image stitching to form a panoramic robot perception image. It provides powerful basis and decision-making information for the vision-based navigation and path planning of the flapping-wing flying robot.

Table 1: Flapping-Wing Flying Robot Gyro Data Sheet

Time（ms）	q_i	q_j	q_k	q_s
621	0.7094	-0.1968	0.2120	0.6427110
623	0.7106	-0.1952	0.2136	0.6413420
632	0.7096	-0.1961	0.2128	0.6424398
633	0.7113	-0.1948	0.2139	0.6405872
663	0.7120	-0.1947	0.2138	0.6398730
671	0.7125	-0.1951	0.2091	0.6407472
673	0.7126	-0.1948	0.2135	0.6392746

The flapping-wing flying robot body is equipped with a miniature gyroscope used to record the flying attitude of the robot. The data of the gyroscope is recorded by the quaternion method. The data record is shown in Table 1.

3.2. Experimental results and analysis of visual image stitching and image fusion methods for flapping-wing flying robots based on block matching

In this paper, a flapping-wing flying robot is used in the power cable inspection experiment scene for experimental verification, so the flying robot’s target rod is used as the flying reference object. Considering that the image stitching process of flying robots requires detailed analysis of the image size scale, the experimental scene setting is carried out by using the method of image characters with digital image reference, which can obtain a clear bitmap reference on the spot, and also obtain accurate relative positions to achieve image stitch verification experiment requirements. This paper uses the flapping-wing flying robot body and the aircraft handle controller as the experimental basic equipment, and using the external visual perception equipment of the flapping-wing flying robot to record the experimental scene to obtain the live image of the flapping-wing flying robot, as shown in Fig.5.

Fig. 5: Original picture of robot working environment

The image stitching process consists of the following three steps, (1) image registration. (2) image fusion. (3) image stitching. The following three sets of image experiments are used to verify the image stitching algorithm of flapping-wing flying robots based on block matching effectiveness.

1) Image registration experiment

The experimental subjects were photographed from different angles, and two scene figures and digital experimental pictures were obtained on the experimental site.

(a) (b)

Fig. 6: Image registration original image

It can be seen that the two pictures have overlapping images and overlapping pixel areas, and image registration is performed on the two pictures. It can be seen from Fig.6 that due to the relatively small overlap area of the two pictures, the image registration method based on block matching may not be accurate enough, and the picture may be misaligned as shown in Fig.7.

(a) (b)

Fig. 7: Misalignment occurs after image registration

(a) (b)

Fig. 8: Image registration original image

As shown in Fig.8, the overlapping pixel area of the two pictures is relatively large, and the image registration method based on block matching has a better effect. As shown in Fig.9, it can be seen that there is no misalignment in the pictures after registration and stitching. Therefore, it can be seen that the image registration method based on block matching requires a certain proportion of the image overlap area to accurately iteratively find the precise overlap area part. Provide accurate overlapping area position and expansion position for image registration, and realize accurate image registration and image stitching.

2) Image fusion experiment

Image fusion refers to the process of extracting and processing features from multiple images to form an image. Due to the lens and the slightly darker light of the two captured images, some of the images are blurred, as shown in Fig.10.

(a) (b)

Fig. 9: Accurate image registration

(a) (b)

Fig. 10: Original image of image fusion experiment

This paper uses wavelet transform to process blurred image pixels. Wavelet transform is an effective data processing method. Wavelet transform can analyze the frequency characteristics of image pixels, decompose the image by frequency characteristics, and use conventional methods such as weighted average to perform image fusion to obtain a clearer fused image. For this reason, fusion of two unclear images has achieved the goal of reducing the negative impact of light and clear images, as shown in Fig.11.

Fig. 11: Wavelet transform image fusion

(a) (b)

Fig. 12: Original image of image stitching experiment

3) Image stitch experiment

Through the above two steps, image registration and image fusion are performed respectively, and images are stitched by the method of region block matching, and the original image is shown in Fig.12.

The registration method of block matching is used for image registration. After image fusion, the image stitching result is shown in Fig.13. It can be seen that not only the image characters and the background wall are clear. At the same time, there is no picture misalignment, which indicates that the overlapping area block matching of the two pictures is very accurate, and the boundary is accurate and clear. Therefore, it can be seen that the image registration and image stitching methods of flapping-wing flying robots based on block matching are feasible and effective.

(a) Grayscale image (b) Color image

Fig. 13: the result graph of image stitching method based on block matching

In summary, using the above-mentioned flying robot image registration and image fusion experiments, it is verified that the effect of the image stitching method of flapping-wing flying robot based on block matching is very effective.

4. Conclusion

This paper proposes a visual image stitching method for micro flapping-wing flying robot based on block matching. Aiming at the characteristics of the limited field of view of the flapping-wing flying robot, a new method of image registration of the flapping-wing flying robot is proposed, and the experimental verification of image fusion and image stitching is carried out. Compared with the traditional vision-based flapping-wing flying robot control, the method in this paper greatly improves the field of vision of the flying robot, and greatly improves the accuracy and operation efficiency of the overall path planning of the flapping-wing flying robot.

A flapping-wing flying robot experimental system is built with a micro flapping-wing flying robot equipped with a miniature camera. Aiming at the experimental tasks, the feasibility and effectiveness of the image stitching method of the flapping-wing flying robot based on block matching is verified through the physical experiment and comparison of the flying robot. Future research work will mainly focus on the following aspects, (1) Flapping-wing flying robot visual perception and information recognition to improve the information perception ability of intelligent systems. (2) Formation control and experimental verification of multi-flapping-wing flying robots.

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