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厦门大学

博 士 学 位 论 文

# 无人机遥感图像快速拼接方法研究

# Research on the Methods of Fast Stitching for Remote Sensing Images of Unmanned Aerial Vehicle

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# 摘 要

无人机遥感技术(UAVRS)作为一种新兴的航空遥感技术，具有成本低、机动灵活、反应快速、图像分辨率高、可实现云下摄影等优点，是传统航天遥感与有人机航空遥感的有力补充，已逐渐成为摄影测量与遥感、计算机视觉、图像处理、环境监测等领域的研究热点。由于无人机有效载荷有限，搭载的成像设备一般为普通数码相机，获取的图像与传统的航片相比，存在像幅小、数量多、基线短、重叠度不规则且倾角过大等问题，无法直接获取大面积的遥感图像。因此，无人机遥感图像的快速拼接技术成为无人机遥感技术能否在实时性要求比较高的应用中得到有效利用的重要前提，开展该技术的研究具有重要的理论意义和广泛的应用前景。

本文在综述图像拼接技术研究现状的基础上，针对图像拼接中配准速度慢，常用配准算法透视鲁棒性差以及多幅图像拼接存在误差累积现象等问题，开展了基于二值型特征描述子、透视不变描述子的图像快速配准以及图像拼接中的累积误差消除算法和技术的研究。主要研究工作以及创新点如下：

1、针对传统基于浮点型特征描述子图像配准算法实时性较差的问题，提出了一种基于二值型特征描述子的图像配准算法(Compressed Binary Discriminative Feature, CBDF)。该算法首先针对 FAST 特征点存在边缘响应和单角点多响应的问题，提出利用 Harris 角点响应值去除边缘响应点，然后利用非极大值抑制去除单角点的多响应点。通过在多尺度金字塔图像上提取特征点使算法具备尺度不变性，在此基础上利用特征点邻域图像梯度统计信息进行比较生成二值描述子。针对原始描述子维度过高的缺点，本文设计了一种改进的 LDA 算法实现描述子的降维。实验结果表明，CBDF 算法具有较强的鲁棒性。

2、针对 CBDF 算法中图像特征描述子提取速度较慢的问题，提出了一种基于改进 AdaBoost 的二值特征描述子(Robust Binary Feature Descriptor，RBFD)。算法首先将特征点邻域图像按照矩形进行分块，利用积分图像对各子块提取梯度统计信息，然后对各子块进行两两排列组合，对组合后子块梯度统计信息进行两两对比生成二值描述子，为进一步提高描述子判别力，本文利用多分块和多邻域策略，提取特征点在不同策略下的描述子，最后利用改进的 AdaBoost 算法进一

步增强描述子判别力，同时保证描述子的紧凑性。实验结果表明，RBFD 描述子在具备二值描述子生成速度快的优点的基础上其鲁棒性比 CBDF 算法更强。

3、针对常用算法对存在大视角变化的图像匹配鲁棒性比较差的问题，提出了一种基于 PIBC(Perspective Invariant Binary Code)的图像配准算法。算法利用相机成像时的共线条件方程，推导出不同视角图像与参考图像之间的单应变换矩阵，利用该单应变换矩阵对成像时的两个方位角进行离散采样，模拟出测试点对坐标在不同视角下分布。利用不同视角点坐标分布方式生成单个特征点在多视角情况下的二值描述子，使配准算法具备了透视不变性。通过 3 组不同类型图像的实验结果表明, 本文提出的方法有效提高了对大视角变化图像配准的鲁棒性。

4、针对 PIBC 算法只对视角进行固定方式离散采样，而图像间的视角变换在参数空间则为连续的，所以固定采样不能保证匹配的结果为最优的问题，本文提出了一种基于粒子群优化算法的图像配准算法，该算法将视角估计问题转化为优化问题，采用自适应粒子群优化算法解决该问题。实验结果表明，该方法进一步提高了算法对视角变化图像的鲁棒性。

5、针对无人机航拍序列图像拼接中误差累积问题进行了研究，提出了一种分级拼接策略来分散累积误差。首先对序列图像拼接中的累积误差问题进行了深入的讨论，通过对对称和非对称误差所导致误差累积的理论分析，证明了通过均匀分散累积误差可以将融合图像的质量至少提高一倍以上，在此基础上提出了一种分级拼接策略来消除累积误差对最终融合图像质量的影响。针对重叠率高的问题，提出了一种重复率测度，利用该测度来去除冗余图像，提高图像拼接效率。

综上所述，本文从图像快速拼接着手，提出了鲁棒性更强的 CBDF 算法和 RBFD 二值描述子，并针对大视角变换图像的配准问题设计了一种具有透视不变性的二值描述子 PIBC，并对其优化采样进行了研究，最后通过关键帧选择和分级匹配策略实现了图像的快速拼接。在低空遥感数据库上的实验表明，本文算法能够提高现有算法的配准效率和拼接性能，验证了本文方法的有效性。

**关键字：**无人机低空遥感；图像配准；图像拼接；二值描述子；透视不变；累积误差；粒子群算法

# Abstract

Unmanned aerial vehicle (UAV) low altitude remote sensing system is a new technique for acquiring remote sensing data. Since UAV has the advantage of low cost, mobility, fast response, real-time, high resolution, take photo under the cloud. It becomes one of the powerful supplements of traditional satellite remote sensing and man-machine airborne remote sensing, and has gradually become of the research hot spots of photogrammetry and remote sensing, computer vision, image processing, environment monitoring and other fields. This technology is suitable for low level high resolution image real-time acquisition; it has incomparable superiority to conventional remote sensing technology in regional, physical and severe remote sensing applications. Since the payload of UAV is very limited, it only carries ordinary digital camera, and the area of the image taken by ordinary digital camera is limited. So fast UAV remote sensing image stitching technology is the important prerequisite of UAV remote sensing technique can be utilized in emergency response. Therefore the research on low-altitude aerial image fast stitching has important theoretical significance and broad real application prospects.

Based on a comprehensive survey of the current image stitching technology, we found that the traditional method has slow matching speed, low robust to perspective transform and severe error accumulation problems. We focused our research on robust binary feature descriptor, perspective invariant image matching algorithm, error accumulation elimination algorithm. Our major works and contributions are as bellow:

1. In order to solve the slow speed of the traditional floating-point feature descriptor based image matching algorithm, we proposed a new binary feature descriptor based image matching algorithm CBDF(Compressed Binary Discriminative Feature). For the FAST feature extraction method has edge point response and multi-response problem, we first use the Harris corner point response value to remove edge response points, and then use the non-maximum suppression to

remove the multi-response points. This performance allows us to generate stable FAST feature points. FAST feature points are extracted on the multi-scale pyramid images to make the algorithm have scale invariance. We generate our binary feature descriptor by comparing the gradient statistics information. In view of the dimension of the original descriptor is too long, this paper designed a kind of improved LDA algorithm to reduce the dimension of the descriptor. The experimental results show the advantage of our method.

2. To improve the generate speed and robustness of CBDF, we proposed a novel image matching method based on integral image and modified AdaBoost method. Firstly, we divide the feature point surrounding image patch to rectangular blocks. By using integral image, we extract the gradient of each sub-block, and then build our binary descriptor by comparing these statistic information. To further improve the discrimination of this descriptor, we use a multi-gridding and multi-support region strategy. An improved AdaBoost method is finally used to enhance the discrimination of this descriptor, meanwhile to ensure that RBFD is compact. Experimental results show that RBFD descriptor has quick extract speed and also has stronger robustness than CBDF algorithm.

3. Aiming to solve the poor robustness to perspective, a perspective invariant binary feature descriptor is proposed. We deduced the homography between images with different viewpoint by using the collinearity condition equation. By using this matrix, we simulated the different point distribution mode under different viewpoints. Then we build the multi-viewpoint descriptor for a single point. This performance make our method perspective invariant. Experiments on three different kinds of images show that our method improves the method’s robustness to viewpoint changed images.

4. In view of the discrete sampling does not guarantee than the matching result is optimal, and the direction given method has poor performance on rotated image matching, an APSO based sampling strategy is used to solve these problems. We

transform the viewpoint estimation problem into an optimization problem, and using the adaptive particle swarm optimization algorithm to solve this problem. Experimental results show that our method improves the algorithm's robustness to view changed images.

5. To solve the error accumulation problem on sequence image stitching, a hierarchical stitching strategy is proposed. We first discussed the accumulative error of the sequence image stitching deeply, based on the analysis of the symmetric and asymmetric error, we proof than the image stitching quality can be improved at least more than double by dispersing the cumulative error uniformly. In view of the overlap rate of UAV remote sensing image is too high, and a large number of redundant image exists, a key image selection measure is proposed. By using this measure we eliminate the redundant images.

To sum up, this thesis aims at construct a fast image stitching technique. CBDF algorithm for image registration and RBFD binary feature descriptor are proposed, we also designed a binary feature descriptor for large viewpoint changed image matching and optimized it with APSO method. Finally through the selection of key frames and the hierarchical matching strategy, we achieved the fast image stitching. Experimental results on UAV remote sensing image database show that our methods can improve the performance of image matching and stitching, comparing with the current algorithms. Our research results can also be used in target recognition, image retrieval, etc.



**Key words**: UAVRS, Image Registration, Image Stitching, Binary Feature Descriptor, Perspective Invariant, Accumulative Error, PSO.

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