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COMPARING AREA–BASED AND FEATURE–BASED METHODS FOR CO–REGISTRATION OF MULTISPECTRAL BANDS ON GPU

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ABSTRACT

Registration is required as a previous step for processing multispectral images. The different bands captured by each sensor for each image, as well as the different images corresponding to the same area, need to be aligned. In this paper, a 2–level registration scheme comparing the results obtained by the hyperspectral Fourier–Mellin (HYFM) and hyperspectral KAZE (HSI–KAZE) registration methods is proposed. It is designed for efficient implementation in a multi-GPU system in which different scenes are registered in parallel on different GPUs.

***Index Terms*—** Multispectral, registration, CUDA, GPU.

1. INTRODUCTION

Image registration is a common operation previous to any type of image processing, in particular for multispectral remote sensing images. The objective is to determine the geometric transformation that aligns two or more images of the same scene or different bands of the same image. The images have been taken at different times and, in many cases from different viewpoints. They usually present changes in objects or illumination, among others. The registration algorithms can be classified into two categories according to their nature [1]: area–based and feature–based methods.

In the first group, methods such as those based on mutual information or Fourier transform [2] can be mentioned. These methods work directly with image intensity unlike feature–based methods which seek to detect distinctive features in objects or interest points at a higher level. This high level representation makes feature–based methods more resilient to intensity or noise changes. We can cite methods such as Speeded–Up Robust Registration Features (SURF) and KAZE within this group. Area–based methods are computationally more efficient and work better on images that are not rich in details.

As the computational cost of the registration is high, different algorithms have been proposed for their execution in specialized platforms such as GPUs. [3, 4] are examples for bidimendional images, while [2, 5] are specially adapted to hyperspectral images.

In this paper, the problem of hierarchical registration of multispectral frames corresponding to the same scene, i.e, the same geographical location, and captured by the same sensor but in different conditions, is studied. As the bands provided for each frame also need to be previously registered, a 2–level registration scheme is proposed. The scheme compares the results obtained by the registration methods, hyperspectral Fourier–Mellin (HYFM) [2] and hyperspectral KAZE (HSI–KAZE) [5], as representative of area-based and feature-based techniques, respectively. With the objective of decreasing execution time, the scheme is computed on a multi-GPU based system in which each GPU operates separate datasets in parallel.

2. REGISTRATION OF REMOTE SENSING MULTISPECTRAL IMAGES ON GPU

In this section, we present a first approach to a multi–GPU remote sensing image registration scheme that first registers bands of multispectral frames and, finally, the frames to construct a scene. Each GPU processes one scene, i.e., the different set of frames to construct that scene.

Figure 1 shows the proposed registration scheme that is executed on each GPU. As shown in the figure, in a first registration level the bands of each 5-band frame (the reference frame and the target frame) are co-registered by the two registration methods (HYFM and HSI–KAZE). In this process (blocks with the coreg prefix in the figure) the bands are registered by pairs, each band with the first one, although only one pair is represented in the figure. For each frame, first B_0 and B_1 are co-registered, then B_0 and B_2, B_0 and B_3,... Thus, the same process is executed for each pair with two registration

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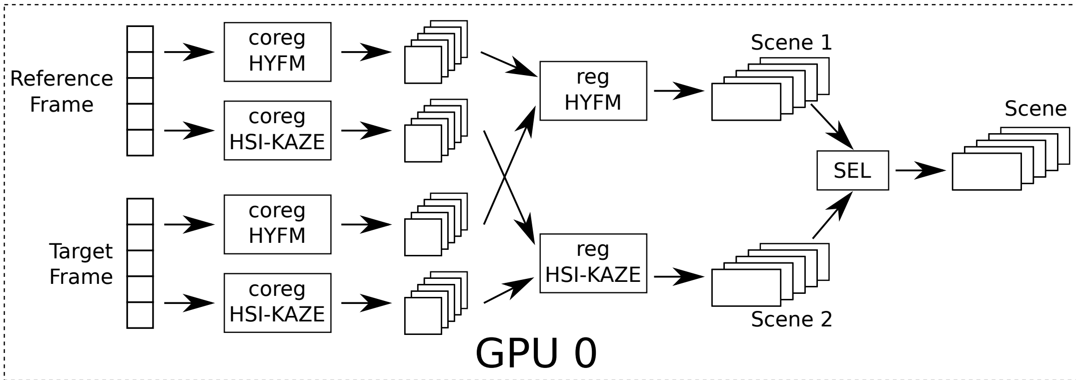


Fig. 1. Multi–GPU scheme for the registration of remote sensing multispectral images. Example for one of the GPUs (GPU 0).

methods independently. In a second registration level, both resulting co-registered reference and target frames need to be registered to align them for composing a scene. In this process any of the frames can act as reference frame. Following the figure, the bands of both images are co-registered using HYFM and then these frames are also registered by HYFM producing Scene 1. Analogously, the same process using HSI–KAZE produces Scene 2. A selection module (SEL in the figure) selects one of them as the final Scene based on registration quality. The registration quality is measured, as explained in Section 3, in terms of RMSE.

2.1. HYFM and HSI-KAZE on GPU

Efficient implementations of HYFM and HSI–KAZE, the selected registration methods for the scheme presented in Figure 1 were presented in [2, 5] for hyperspectral images on a single GPU using CUDA. All the instances of these methods represented in Figure 1 use these implementations with small changes.

Several GPU optimization strategies were applied such as reducing the number of operations, using warp-level primitives to avoid shared memory latency, and efficiently exploiting the different memory spaces of the GPUs.

The implementation details are described in [2, 5]. Both methods begin with a first stage in order to select one or more bands from each frame representing the most relevant information. In the case of co-registering individual bands, this step is not performed as all the bands are taken by pairs. The methods differ in the following steps.

In the case of HYFM, the method continues with a phase correlation applied to each pair of selected bands using the MLFFT (Multilayer Fractional Fourier transform) technique to approximate the log–polar grids. Next, the different log–polar grids computed from each pair of principal components are combined. This combination highlights some peaks of this grid. Finally, the highest peaks are evaluated to determine the registration parameters. For this method, 75% of the computation time is used for processing the MLFFT, the phase correlation and the high–pass filter. The use of the cuFFT library permits obtaining high speedups for these stages.

In the case of HSI–KAZE, after the band selection, keypoints of each selected band are extracted and described using KAZE and their spectral signature. Then, the keypoint matching process is carried out in pairs of bands. In the next step, all matched keypoints from the different bands are joined. Finally, in the last stage, registration, the correspondences between a number of keypoints of both images are analyzed. The registration parameters are calculated using an exhaustive search based on histograms. Keypoint matching and band combination are the most costly stages. They have been highly optimized mainly by the approximation of the Euclidean distance using matrix computations and reducing the memory use.

3. RESULTS

The experiments were carried out on a PowerEdge R730 server with two quad–core Intel Xeon E52623v4 CPUs at 2.6 GHz and 128 GB of RAM under Ubuntu 18.04. Regarding the GPUs, the code runs on two Tesla P40 with 30 SMs and 128 CUDA cores each. It was written in CUDA and compiled using nvcc version 11.0.194, as well as the CUB 1.8.0 version. CUB is used in the band selection method of HSI–KAZE to compute parallel reductions and histograms. Both HYFM and HSI–KAZE use single precision.

Two different datasets or scenes named *House* and *Reservoir* were considered for the tests[1]. Each scene consists of five and three different frames of 1280×960 pixels, respectively. The radiance bands, ranging from 475 to 842 nm., were captured by a MicaSense RedEdge MX sensor on 18/07/2018 in different UAV flights and, as a result, have different spatial resolutions.

Although the sensor captures all the bands at the same time, their co-registration is required. Figure 2 shows one frame of the *House* scene before co-registration. Fuzzy edges and separation of the green, blue and red channels are clearly

[1]These images were obtained in partnership with the Babcock company, supported in part by the Civil Program UAVs Initiative, promoted by the Xunta de Galicia.

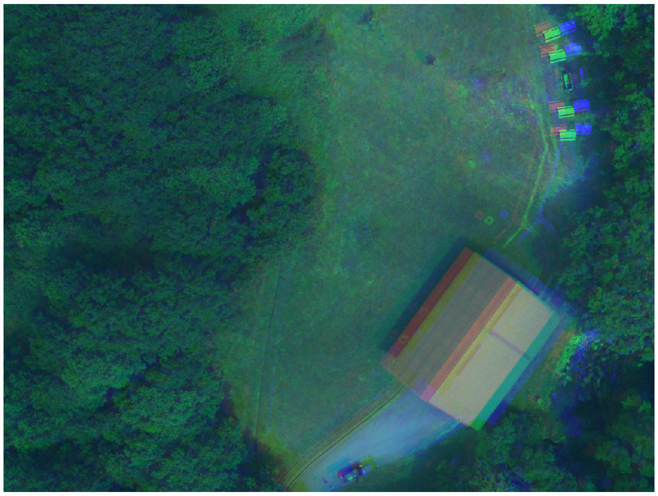


Fig. 2. False–colour composite of the reference frame of the *House* scene before co-registration.

observed, for example, in the roof and the small regular constructions. This problem does not appear in the frames once they are co-registered, as it can be observed in Figure 3.

The procedure used to test the scheme is as follows. Two evaluations are performed, in terms of accuracy of the registration and in terms of execution time. The accuracy is measured by means of root-mean-square error (RMSE) in pixels. RMSE is computed as the average Euclidean distance between the reference points in the original reference band and the reference points in the target band once the registration transformation is applied. Five reference points were manually selected for each band in order to carry out the evaluation. Figure 3 shows the reference points for the represented frames.

Table 1 summarizes the accuracy results in terms of RMSE after band registration (first level). Each row shows the average RMSE of the registered bands 2, 3, 4 and 5 with respect to the first one (reference band). The best results are provided by HSI–KAZE, with an average of 1.38 pixels of RMSE, while in the case of HYFM the error reaches 4 pixels.

As we explained before, the methods were originally designed to deal with hyperspectral images. Because of that, they have a first stage in which a band selection method is performed to reduce the amount of redundant information. In the case of registering the frames, we study two approaches. In the first one, one band is selected at this stage. In the second, all the bands (5 for the scenes of the experimental dataset) are used to register the images.

Table 2 shows the RMSE for the frame registration stage (second level) using HSI–KAZE and both approaches. HYFM results are not displayed because this method, which is less sensitive to changes and deformations [1], does not manage to correctly register all the frames. RMSE increases as the perspective of the frames changes. This is the case of target frame 4 for the *House* dataset. As shown in the table

Table 1. Band registration (first level). Results in terms of RMSE (pixels).

Scene	Frame	HSI—KAZE	HYFM
House	Reference	1.26	4.49
	Target 1	1.74	5.85
	Target 2	1.27	5.25
	Target 3	1.02	2.66
	Target 4	1.57	5.34
	Average	1.37	4.72
Reservoir	Reference	1.05	2.74
	Target 1	1.53	5.18
	Target 2	1.56	4.21
	Average	1.38	4.04

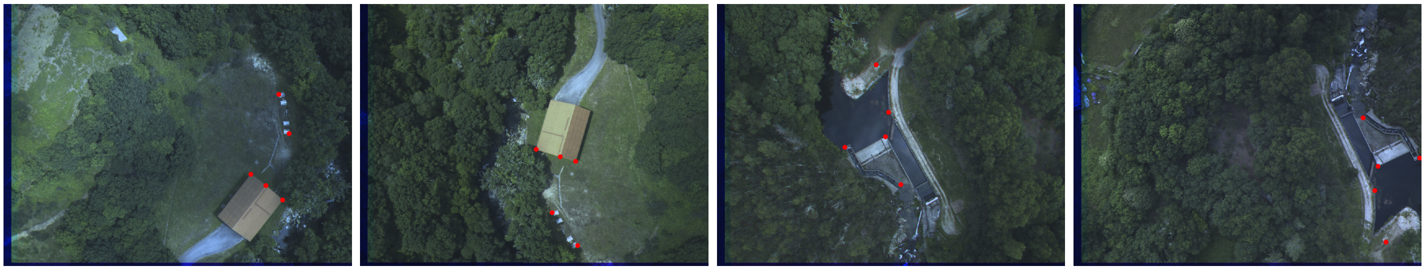
Table 2. Frame registration (second level). Results of HSI–KAZE in terms of RMSE (pixels) exploiting the information of 5 bands or only one.

Scene	Frame	5 bands	1 band
House	Target 1	2.79	3.69
	Target 2	3.00	3.07
	Target 3	9.54	10.71
	Target 4	24.92	20.84
	Average	10.06	9.58
Reservoir	Target 1	6.62	10.83
	Target 2	10.63	7.50
	Average	9.11	9.30

the results in terms of registration accuracy are very similar considering all the bands or only one.

Table 3 shows the average time of ten independent executions for each level of the registration scheme for the cases when only the first band and all the bands are considered for registration. The *House* scene is registered in GPU 0 and the *Reservoir* scene in GPU 1. These tables also indicate the number of performed co-registrations (band registrations called Co-reg. in the table and frame registrations, called Reg. in the table) at each level. When the scheme is executed over a scene in a particular GPU, the number of co-registrations and registrations depends on the number of bands of the frames and the number of frames, respectively.

As shown in the table, HSI–KAZE results in larger executions times than HYFM, around 50 times larger and in different times depending on the image, because, as a feature–based method, the computational cost is related to the number of extracted keypoints. HSI–KAZE performs an exhaustive search to recover the registration parameters considering all the possible pairs of matches (4 keypoints) which requires higher computational costs. On the other hand, HYFM, as an area–based method, works directly with image intensity, which makes it computationally less costly. Although the dif-



(a) (b) (c) (d)

Fig. 3. False–colour composite of some co-registered frames of the *House* and *Reservoir* scenes. (a) *House* Reference frame, (b) *House* Target frame 3, (c) *Reservoir* Reference frame, and (d) *Reservoir* Target frame 2. The reference points are in red colour.

Table 3. CUDA GPU execution times (in seconds) exploiting the information of 5 bands or only one. # Reg. indicates the number of registrations computed.

GPU 0 - House scene (5 frames)

Stage	1 band	5 bands	# Reg.
Initialisation	7.07	6.96	-
Image transfers	1.45	1.84	-
Co–reg. HSI–KAZE	866.87	885.09	20
Co–reg. HYFM	15.31	16.50	20
Reg. HSI–KAZE	103.08	534.12	4
Reg. HYFM	4.40	8.58	4
Total	998.18	1453.08	48

GPU 1 - Reservoir scene (3 frames)

Stage	1 band	5 bands	# Reg.
Initialisation	6.95	6.88	-
Image transfers	0.87	0.89	-
Co–reg. HSI–KAZE	447.34	447.87	12
Co–reg. HYFM	8.65	8.64	12
Reg. HSI–KAZE	56.52	256.49	2
Reg. HYFM	1.46	2.91	2
Total	521.80	723.67	28

Table 4. 16–thread OpenMP CPU and CUDA GPU computation times (in seconds) and speedups for the *House* scene.

Approach	CPU (s) 16 Threads	GPU (s)	Speedup
1 band	10,456.19	998.18	10.48×
5 bands	15,505.00	1,453.08	10.67×

ferences in terms of registration accuracy between the selection of one band or the use of all of them are low, performing a band selection is more efficient in terms of execution times, as we can see in the tables.

Table 4 shows the comparison between the execution time of a 16–thread OpenMP implementation and the multi-GPU implementation described as well as the speedup obtained. The time for the multi-GPU implementation is the time of the slowest GPU as it operates over a higher number of frames.

4. CONCLUSIONS

In this paper, a GPU scheme for a two–level registration of multispectral images is proposed. The first level consists on registering the different bands of each multispectral frame available for a scene. Registering the resulting frames is the objective of the second level. The scheme compares the results obtained by HYFM and HSI–KAZE as representative of area–based and feature–based registration methods, respectively. From the point of view of registration quality HSI–KAZE achieves better results for both datasets considered, although it is 50 times more costly in GPU execution time. HYFM does not achieve successful registrations for all the frames. The GPU implementation is around 10 times faster than an optimized multicore OpenMP one for the datasets considered.

5. REFERENCES

[1] Barbara Zitova and Jan Flusser, "Image registration methods: a survey," *Image and vision computing*, vol. 21, no. 11, pp. 977–1000, 2003.

[2] Álvaro Ordóñez, Francisco Argüello, and Dora B Heras, "GPU accelerated FFT-based registration of hyperspectral scenes," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 10, no. 11, pp. 4869–4878, 2017.

[3] Sudhakar Sah, Jan Vanek, YoungJun Roh, and Ratul Wasnik, "GPU accelerated real time rotation, scale and translation invariant image registration method," in *Image Analysis and Recognition*, pp. 224–233. Springer, 2012.

[4] Rob Ramkumar, B.and Laber, Hristo Bojinov, and Ravi Sadananda Hegde, "GPU acceleration of the KAZE image feature extraction algorithm," *Journal of Real-Time Image Processing*, 2019.

[5] Álvaro Ordóñez, Francisco Argüello, Dora B Heras, and Begüm Demir, "GPU-accelerated registration of hyperspectral images using KAZE features," *The Journal of Supercomputing*, pp. 1–15, 2020.