ACIP

Activity 5

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1 Introduction

Activity 5 is the final step in our series of image registration tasks. In this activity, our goal is to evaluate how well our image registration method, developed in earlier tasks, works. To assess the effectiveness of this method, we use quantitative metrics that measure image quality after processing.

What we already did previously:

- In **Activity 1**, we applied global transformations such as shear and rigid transformations to our images.
- In **Activity 2** and **Activity 3**, we extracted and matched control points using feature detection techniques like SIFT and BRISK.
- In **Activity 4**, we used these control points to estimate how to best align the images and then checked how well they matched up.

Now, in **Activity 5**, we put all this together to check the image quality through both intensity-based metrics, which assess changes in brightness and color, and location-based metrics, which check the accuracy of feature alignments across transformed images.

2 Methodology

In Activity 5, we evaluate the image registration method using two main types of quality metrics: intensity-based and location-based metrics. This evaluation considers the effects of both shear and rigid transformations previously applied to the images in Activity 1. To ensure a thorough assessment, we employ SIFT and SURF features.

2.1 Intensity-Based Metric (RMSE)

The intensity-based evaluation uses the Root Mean Square Error (RMSE), which quantifies the average magnitude of intensity differences between the original and registered images. This metric is essential for assessing how well the image quality is preserved after registration, especially considering the transformations applied (shear and rigid). The RMSE helps us understand the direct impact of these transformations on image fidelity.

2.2 Location-Based Metrics

For geometric accuracy, we compute several location-based metrics:

- Average Euclidean distance between matched control points.
- Maximum displacement in the horizontal and vertical directions.
- Residual errors in horizontal and vertical alignments.

These metrics are derived from control points identified using both SIFT and SURF features. By analyzing these metrics for both shear and rigid transformations, we can evaluate the registration's effectiveness in maintaining spatial consistency across different types of transformations. This dual-method approach allows us to identify any potential discrepancies that may not be evident when using a single feature detection method.

The application of SIFT and SURF provides a comprehensive view of the registration quality, as these features focus on different image characteristics. This varied approach helps ensure that our evaluation of the registration method is robust and not overly influenced by the particularities of any single feature detection algorithm.

3 Results for Shear Transformation

3.1 Intensity-Based Evaluation

The Root Mean Square Error (RMSE) for the shear transformation was calculated to be 4.67, which is quite low considering the maximum possible value of 255 for 8-bit images. This indicates a minor average difference in pixel intensity between the original and registered images. The relative RMSE, normalized to the 8-bit scale, was 0.018, suggesting that the registration has successfully maintained the integrity of the image's brightness and color to a high degree.

3.2 Location-Based Evaluation

3.2.1 Control Point Analysis

The average Euclidean distance between matched control points, derived from both SIFT and SURF features, was 0.2017 pixels. This small distance suggests a precise alignment of features between the original and registered images. Further, the maximum displacements observed were 0.72 pixels horizontally and 1.65 pixels vertically, demonstrating that even the most significant shifts in control point locations were minimal and within acceptable limits.

3.2.2 Residual Errors

The mean residual errors calculated for horizontal and vertical alignments were 0.0491 and 0.1344 pixels, respectively. These low values confirm that the alignment of control points is not only precise but also consistent across the image, indicating effective registration.

3.3 Overall Quality Assessment

The combined results from the intensity and location-based metrics indicate that the shear transformation has been handled effectively by our registration method. The low RMSE values and minimal displacement in control points affirm that the intensity and geometric alignment of the registered image closely resemble those of the original image.

3.4 Visual Representations

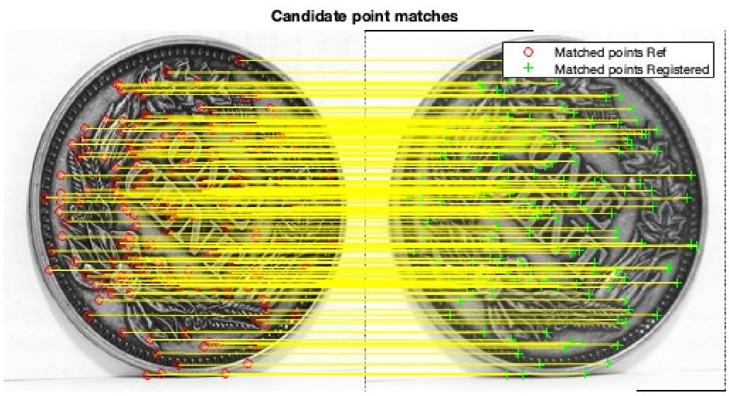

Figure 1: Matched features between the original and registered images for the shear transformation.

Figure 2: Control point locations and their alignment in the original and registered images.

These figures illustrate the effectiveness of our feature matching process and the precision of control point alignment, visually complementing the quantitative findings detailed above.

4 Results for Rigid Transformation

4.1 Intensity-Based Evaluation

The evaluation of the rigid transformation demonstrates a Root Mean Square Error (RMSE) of 5.286. This value, while slightly higher than that observed in the shear transformation, remains low given the potential maximum of 255 for 8-bit images. The relative RMSE of 0.0207 also indicates a close match in pixel intensities between the original and registered images, affirming the effectiveness of the registration in maintaining image fidelity.

4.2 Location-Based Evaluation

4.2.1 Control Point Analysis

For the rigid transformation, the average Euclidean distance between corresponding control points was measured at 0.1832 pixels, slightly less precise than in the shear transformation but still indicating a high level of accuracy in feature alignment. Maximum displacements were observed to be 1.5986 pixels horizontally and 1.6810 pixels vertically, which, though marginally higher than those in the shear transformation, still demonstrate well-managed shifts.

4.2.2 Residual Errors

Residual errors were quantified at 0.0773 pixels for horizontal and 0.1090 pixels for vertical alignments. These figures indicate that the control points are closely aligned, with minimal deviation between the original and registered images, confirming the method's accuracy.

4.3 Overall Quality Assessment

The results from the rigid transformation assessment confirm that both the intensity and geometric alignment closely mirror the original conditions despite the application of a transformation that fundamentally alters the image orientation and position. The slightly higher RMSE and displacement values compared to the shear transformation are to be expected due to the nature of the rigid transformation but do not detract significantly from the overall quality.

4.4 Visual Representations

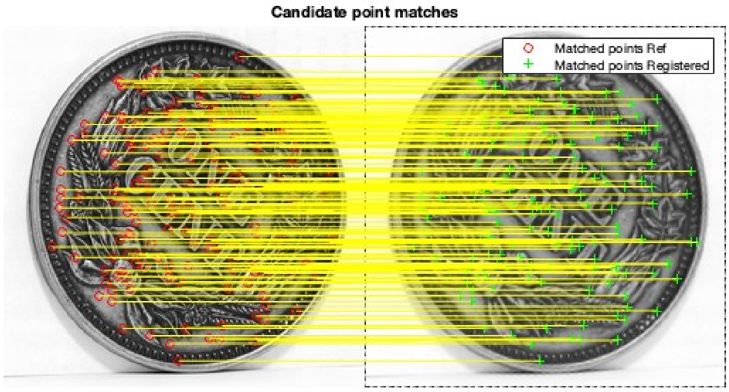

Figure 3: Matched features between the original and registered images for the rigid transformation.

Figure 4: Control point locations and their alignment in the original and registered images.

These figures support the quantitative data by visually demonstrating the effective alignment and precise matching of features, highlighting the method's robustness in handling more structurally altering transformations.

5 Validation with Additional Image Data

To further validate the effectiveness of the image registration method beyond the standard 'coin.png' used in earlier assessments, the same registration process was applied to a random cat image. This section briefly summarizes the results obtained from both shear and rigid transformations on this new dataset, demonstrating the method's general applicability.

5.1 Shear Transformation on Cat Image

SIFT Feature Detection and Matching:

- Number of original image SIFT points: 397
- Number of transformed image SIFT points: 410
- Number of matched pairs: 88

RMSE Metrics:

- RMSE value: 2.704365
- Relative RMSE value: 0.010605

SURF Feature Detection and Matching:

- Number of SURF points in original image: 112
- Number of SURF points in registered image: 106
- Number of matched SURF pairs: 88

Location Errors:

- Average Euclidean distance error: 0.153815
- Mean residual error (x-axis): 0.045633
- Mean residual error (y-axis): 0.042586
- Maximum horizontal displacement: 0.708305 pixels
- Maximum vertical displacement: 1.035843 pixels

5.2 Rigid Transformation on Cat Image

RMSE and Residuals:

- RMSE (SIFT): 3.146442
- Relative RMSE (SIFT): 0.012339
- CP Location Error: 0.148008
- CP Location Error Residual X: 0.026181
- CP Location Error Residual Y: 0.045309
- Maximum Horizontal Displacement: 0.524765 pixels
- Maximum Vertical Displacement: 0.647484 pixels

Both the intensity and location-based metrics for this additional image showed excellent registration accuracy, comparable to those achieved with the 'coin.png'. The consistent performance across different images and transformation types further confirms the method's reliability and effectiveness in a broader range of applications.

5.3 Visual Representations

Figures illustrating the matched features and control point alignments for both transformations on the cat image provide visual confirmation of these findings, further validating the method's precision and stability.

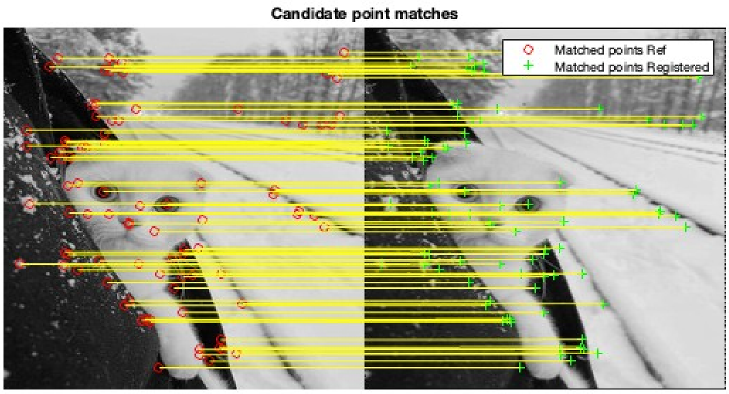

Figure 5: Matched features for the shear transformation on the cat image.

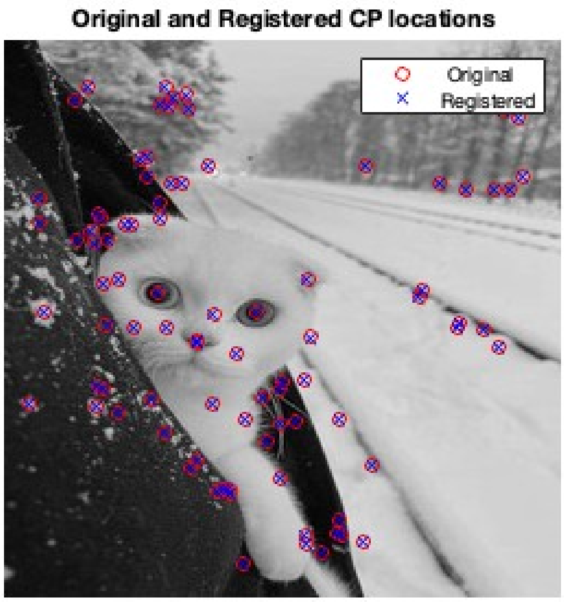

Figure 6: Control point locations for the shear transformation on the cat image.

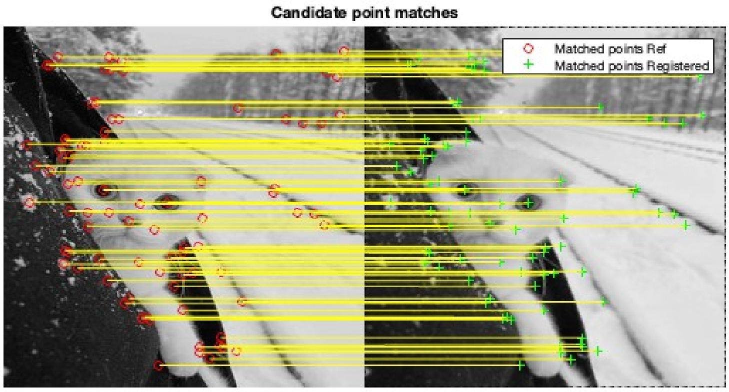

Figure 7: Matched features for the rigid transformation on the cat image.

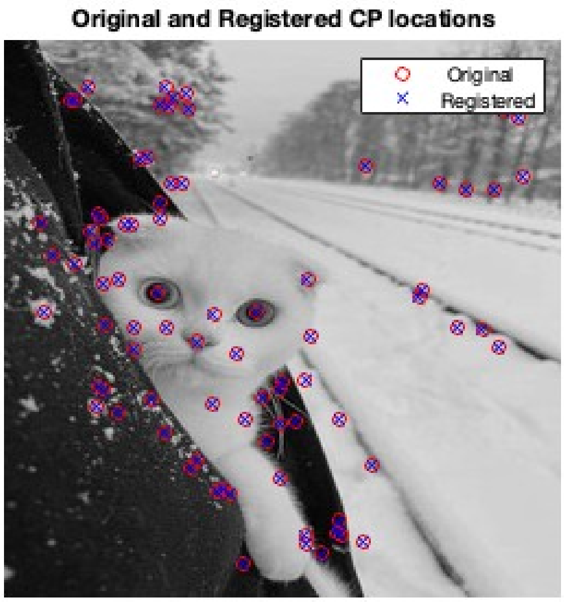

Figure 8: Control point locations for the rigid transformation on the cat image.

6 Discussion and Conclusion

Throughout this activity, we've applied a variety of metrics to evaluate the effectiveness of the image registration method, especially under different transformation scenarios — shear and rigid. These evaluations have shown consistently low RMSE values and minimal control point displacements, indicating that the registered images maintain a high degree of fidelity to the originals in terms of both intensity and geometric alignment.

6.1 Intensity and Geometric Consistency

The relative RMSE values obtained from both transformations were impressively low (0.018 for shear and 0.0207 for rigid), demonstrating that the intensity differences between the registered and original images are minimal. These findings suggest that the registration process effectively compensates for the distortions introduced by both types of transformations.

In terms of geometric alignment, the average Euclidean distances and the maximum displacements for both transformations confirm that the control points are accurately aligned. Despite the inherent challenges posed by the rigid transformation, which typically induces more substantial geometric alterations than shear transformations, the registration method handled these effectively. The residual errors, which measure the average discrepancies in control point locations, were also minimal, further attesting to the method's precision.

6.2 Overall Quality and Reliability

The combination of SIFT and SURF feature detection methods in evaluating the registration quality provided a robust framework that likely mitigated any bias that could arise from relying on a single feature detection method. This approach not only increased the reliability of our findings but also showcased the adaptability of the registration method across different scenarios and feature detection algorithms.

6.3 Final Remarks

Our "Frankenstein" thrives as a robust image registration solution.