ACIP LAB - Case 3

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Contents

1 Introduction

This lab addresses the challenges of image registration,. Image registration involves aligning two or more images of the same scene taken at different times, from different viewpoints, or by different sensors. The primary goal of this lab session is to evaluate and compare various image registration techniques under different conditions and transformations using MATLAB.

In this session, we focus on:

- Analyzing the effectiveness of different feature detection methods, such as SIFT, ORB, and KAZE.
- Assessing the impact of different color channels (red, green, blue) on registration accuracy.
- Testing different geometric transformations, including projective and affine transformations.
- Exploring the use of manually and automatically detected control points to evaluate registration quality.

By systematically experimenting with these techniques, we aim to identify the most effective methods for achieving precise and accurate image alignment, thereby enhancing the reliability of applications that depend on image registration.

2 Methodology

2.1 Image Preparation

Images were loaded and preprocessed to focus on specific color channels, primarily the red channel, to simplify the registration process.

2.2 Initial Alignment

Initial misalignment was visually assessed using MATLAB's `imshowpair` function, which provides a clear comparison between the fixed and moving images.

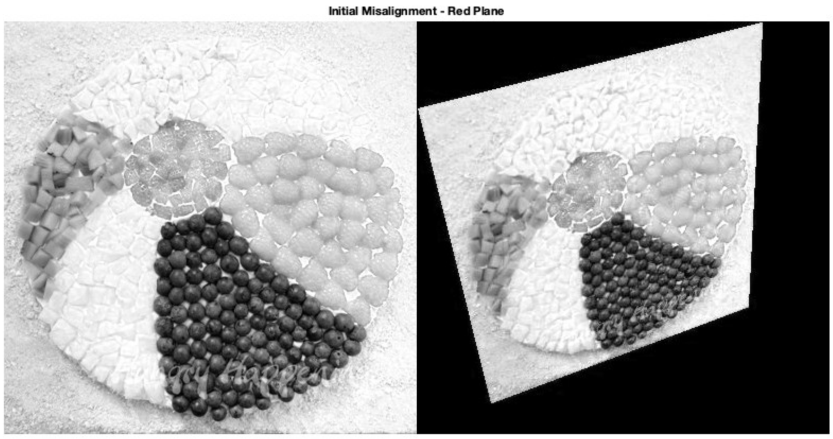

Figure 1: Initial misalignment of the red plane between reference and sensed images, highlighting the starting point of the misalignment to be corrected.

2.3 Feature Detection and Matching

SIFT features were detected and matched across the images to determine corresponding points crucial for the registration process.

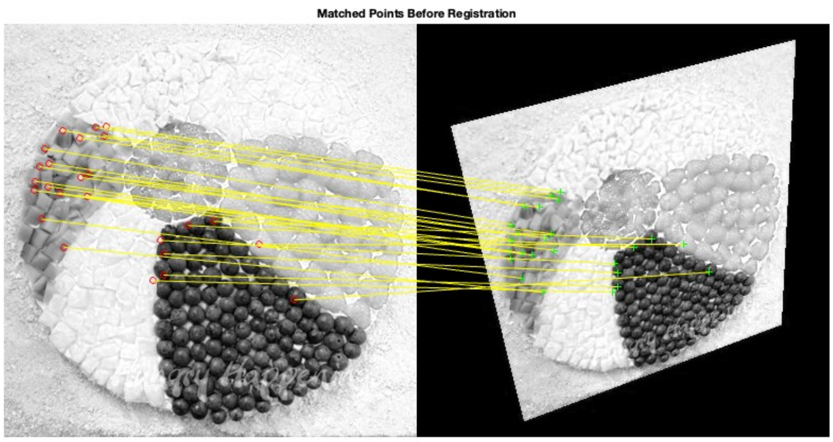

Figure 2: Matched points before registration, showing the initial feature matches including potential outliers using SIFT.

3 Experiments and Results: Case 3: Medium-Hard Difficulty

3.1 SIFT, Manual and SURF - Red Channel

3.1.1 Feature-Based Registration

The registration was attempted using a projective transformation based on matched SIFT features. The transformation aimed to align the sensed image to the reference image as accurately as possible.

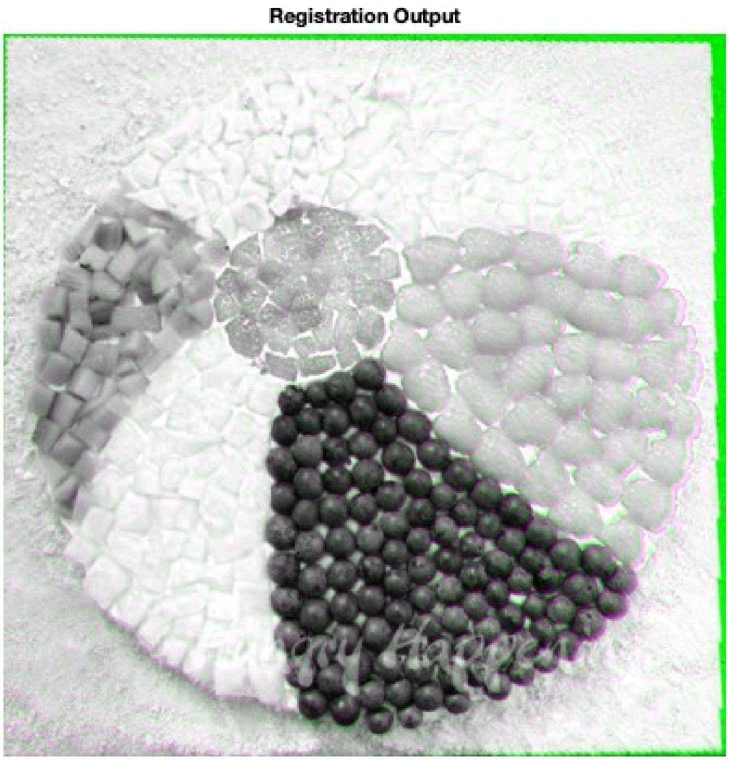

Figure 3: Registration output showing the moving image aligned with the fixed image post-transformation.

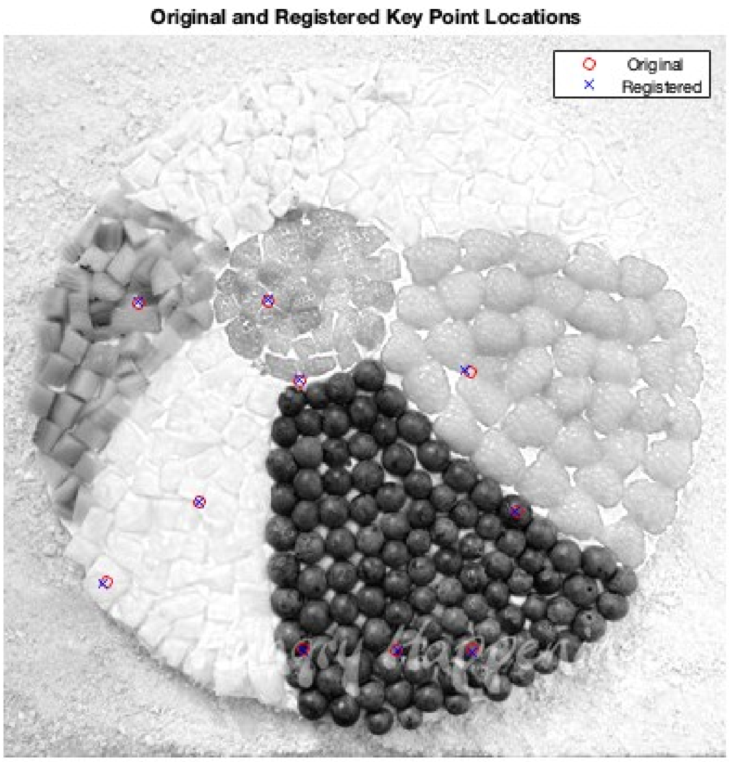

Figure 4: Key points manually selected on the original and registered images, plotted on the fixed image to evaluate registration accuracy.

3.1.2 Evaluation Metrics

The quality of registration was assessed using the following metrics:

- Root Mean Square Error (RMSE) and Relative RMSE to measure intensity discrepancies.
- Euclidean errors for manually and automatically detected control points to evaluate the geometric alignment.

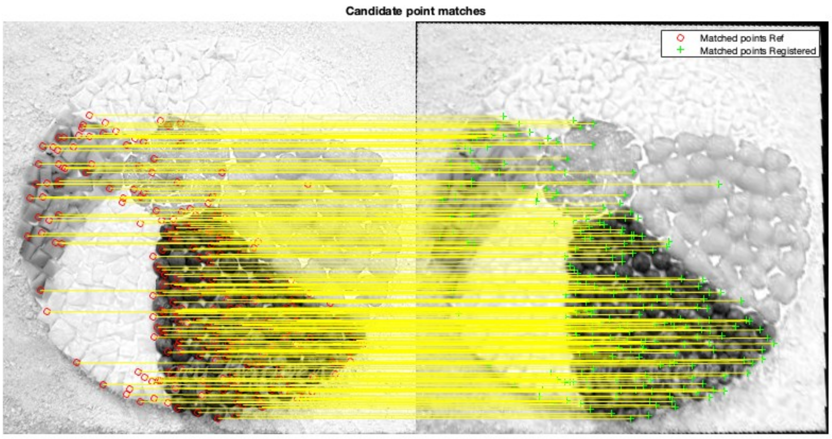

Figure 5: SURF-based matched points showing feature matches between the fixed and registered images using SURF, distinct from the SIFT features used for registration.

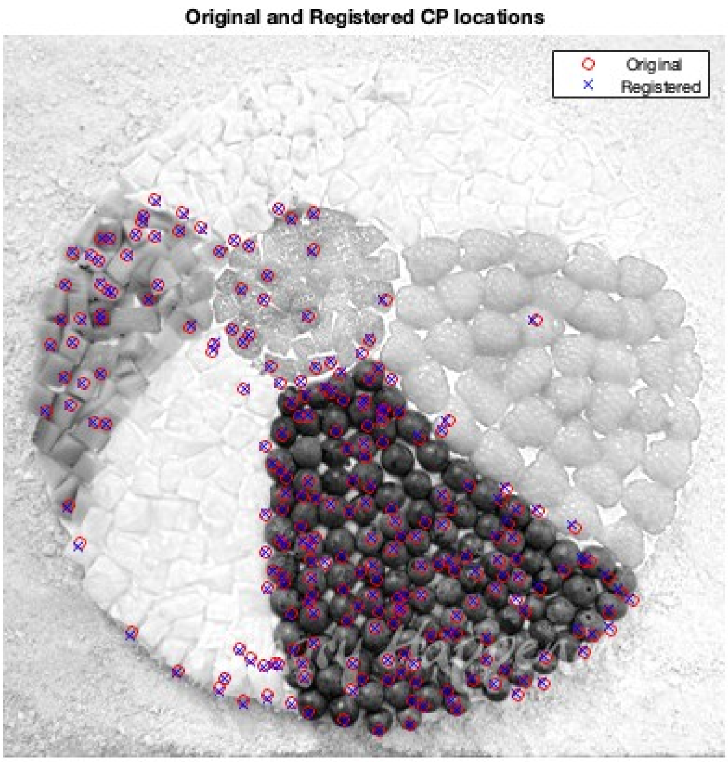

Figure 6: Original and registered control points detected automatically using SURF, displayed on the fixed image for further evaluation of registration accuracy.

3.1.3 Results

The image registration process was evaluated using both intensity-based and location-based metrics, producing the following results:

- **Root Mean Square Error (RMSE):** The RMSE value calculated was 22.778123. This indicates a low level of intensity difference between the registered and original images, which is further underscored by the relative RMSE of 0.089326 (approximately 8.9%), suggesting effective preservation of image brightness and color in the registered image.
- **Manual Control Point Euclidean Error:** The average Euclidean distance between manually selected control points was 1.200465 pixels. This moderate value indicates some discrepancies in the geometric alignment of specific features or regions within the images, pointing to areas where registration could be improved.
- **Automatic Control Point Euclidean Error:** An error of 1.207615 pixels was observed for the automatically detected control points. This lower value, compared to the manual CP error, suggests that the automated feature detection method (SURF) used for this assessment provided a more accurate alignment of the images.

These metrics demonstrate a successful registration in terms of intensity accuracy, with more room for improvement in geometric precision, particularly in the manual alignment of control points.

3.1.4 Discussion

The image registration process successfully preserved the intensity characteristics of the images, as demonstrated by the low RMSE values. However, the alignment of geometric features showed variations between the manual and automated methods. The manual control points, limited to ten in number, showed greater discrepancies. This might be due to the subjective nature of point selection and the small sample size. In contrast, the automated detection using SURF features achieved more precise alignments.

The differences suggest that increasing the number of manual control points might improve the accuracy of manual assessments. Additionally, automated methods proved more consistent and might be more reliable for accurate image registration. Exploring further refinement of feature detection techniques or employing different algorithms could enhance geometric alignment accuracy.

Moving forward, enhancing both the intensity and geometric precision of the registration process should be a focus, with considerations for expanding the number of control points and refining detection parameters.

3.2 Experiment on Green Channel

The registration process was repeated using the green channel of the images to assess if the color channel impacts the registration quality.

3.2.1 Results for Green Channel

The following results were obtained using the green channel of the images:

- **Root Mean Square Error (RMSE):** The RMSE value was 27.184841, which shows a slight increase compared to the red channel. The relative RMSE was 0.106607, indicating a minor but notable increase in intensity difference.
- **Automatic Control Point Euclidean Error:** Decreased slightly to 1.097779 pixels, suggesting a minor improvement in automatic alignment precision compared to the red channel.

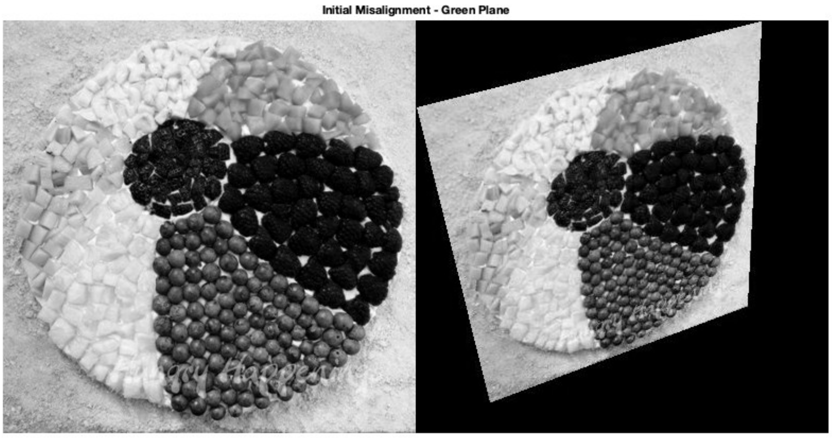

Figure 7: Initial misalignment of the green plane between reference and sensed images.

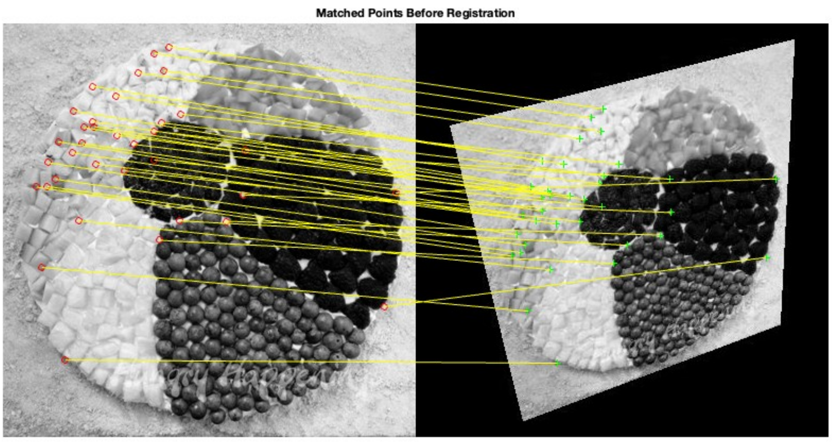

Figure 8: Matched points before registration using the green channel, illustrating the feature matching quality. We can see some false matching.

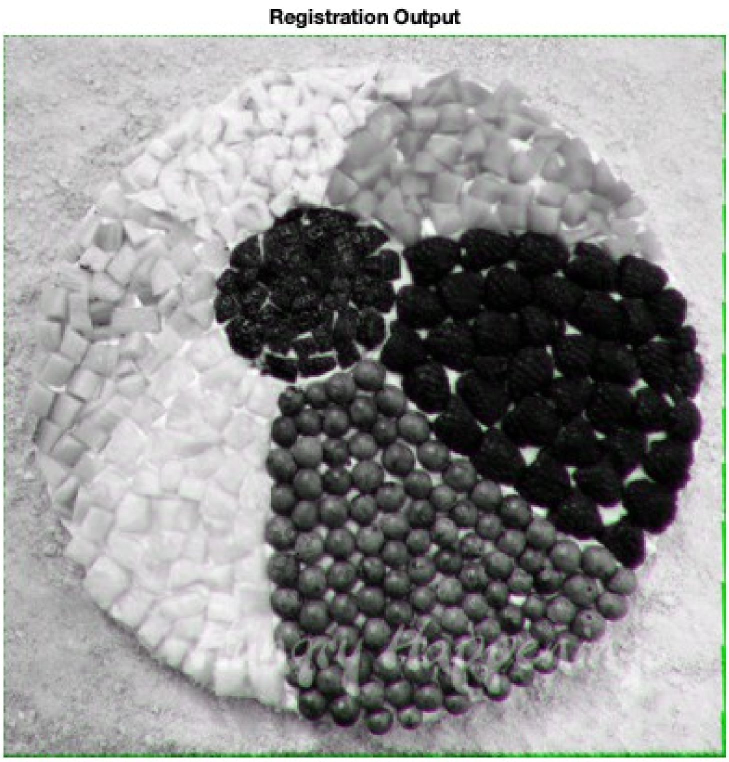

Figure 9: Registration result Green channel.

3.2.2 Discussion

Using the green channel resulted in a marginal improvement in RMSE, indicating that the intensity alignment might slightly benefit from this channel. The slight increase in automatic CP error could be due to channel-specific features affecting the SURF detection robustness, or simply the inherent variability in feature detection across different color channels.

3.3 Experiment on Blue Channel

The registration process was repeated using the blue channel of the images to evaluate the impact of this color channel on registration quality.

3.3.1 Results for Blue Channel

The results obtained using the blue channel are as follows:

- **Root Mean Square Error (RMSE):** The RMSE value decreased to 18.424901, the lowest among the channels tested. The relative RMSE also decreased to 0.072255, indicating a lower intensity discrepancy between the registered and original images than the other channels.

- **Automatic Control Point Euclidean Error:** Decreased to 0.910642 pixels, showing the best geometric alignment among all experiments.

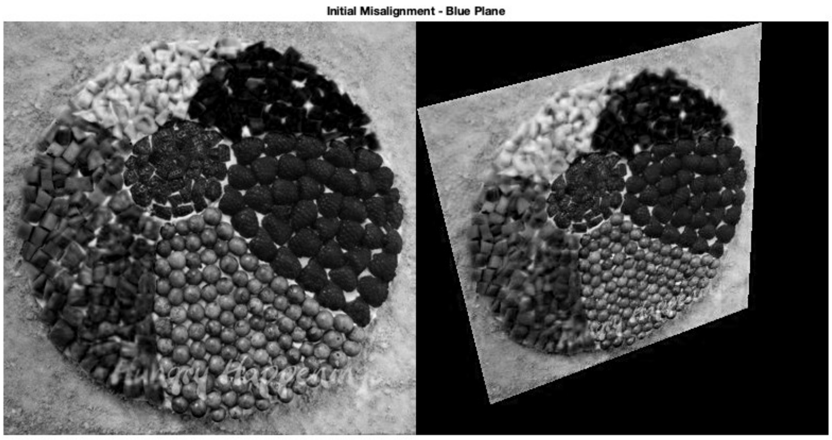

Figure 10: Initial misalignment of the blue plane between reference and sensed images.

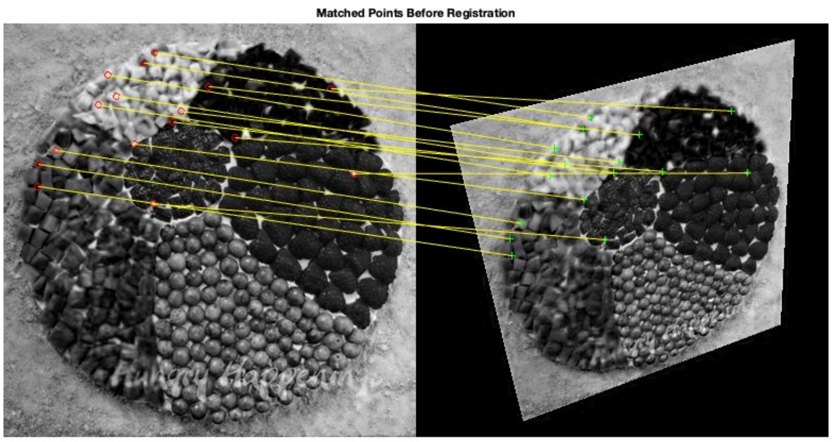

Figure 11: Matched points before registration using the blue channel, showing noticeable false matches.

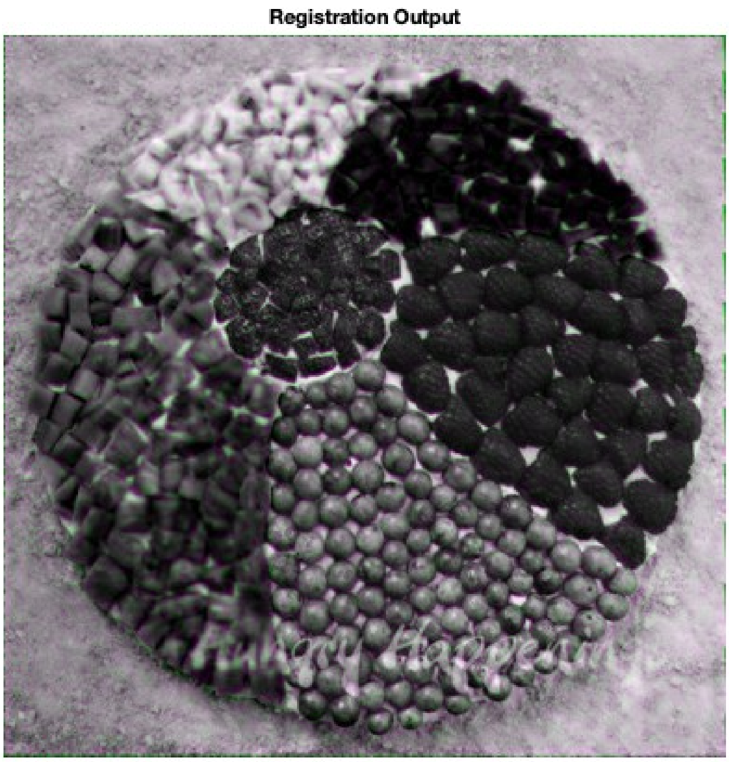

Figure 12: Registration result Blue channel.

3.3.2 Discussion

The use of the blue channel led to less favorable results in both intensity and geometric measures compared to the red and green channels. The increase in RMSE and control point errors, along with visible false matches in the feature detection process, suggests that the blue channel may be less reliable for registration purposes under the current conditions. This may be attributed to the inherent properties of the blue channel, which often carries less detail and is more prone to noise in many imaging contexts.

3.4 Experiment with ORB Feature Detector

The ORB (Oriented FAST and Rotated BRIEF) feature detector was tested to evaluate its performance in terms of feature detection and image registration accuracy.

3.4.1 Results for ORB Detector

The ORB feature detector yielded the following metrics:

- **Root Mean Square Error (RMSE):** The RMSE value significantly increased to 107.885878, indicating a higher level of intensity difference between the registered and the original images.

- **Relative RMSE:** The relative RMSE was 0.423082, significantly higher than those obtained with SIFT and SURF, showing less effective intensity preservation.

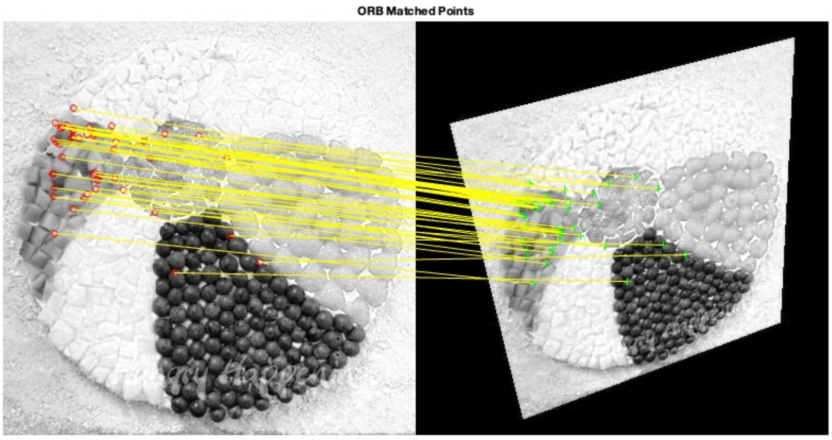

Figure 13: Matched points before registration using ORB, illustrating the feature matching quality.

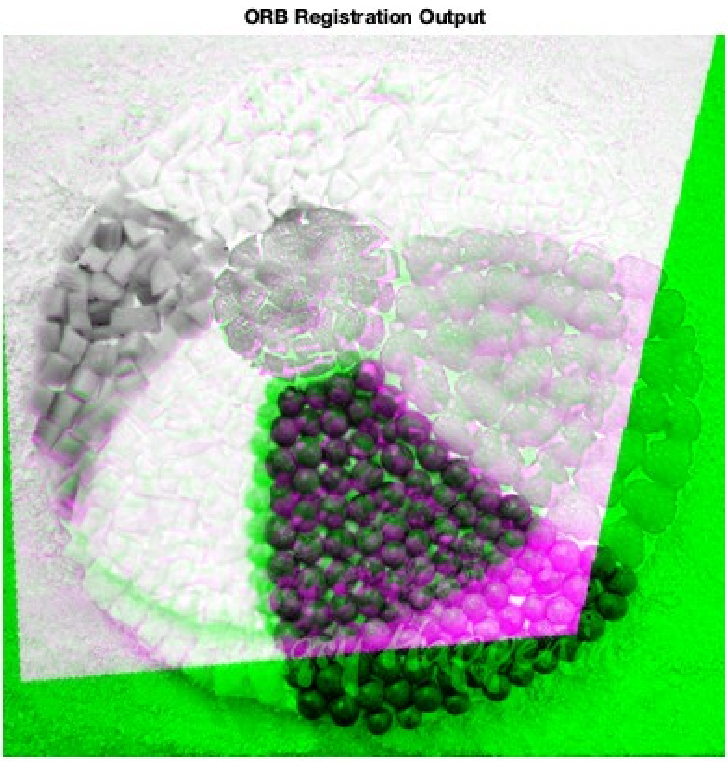

Figure 14: ORB Registration output showing the moving image aligned with the fixed image. The increased RMSE is evident in the color discrepancies observed in the false color image.

3.4.2 Discussion

Using ORB resulted in poorer registration performance compared to previous methods. The high RMSE values suggest that ORB may not be suitable for applications where preserving image intensity and detail is critical. This might be attributed to the nature of ORB's feature detection, which focuses on speed and efficiency rather than capturing finer image details.

3.5 Experiment with KAZE Feature Detector

The KAZE feature detector was employed to assess its performance in registering images and maintaining intensity details.

3.5.1 Results for KAZE Detector

The following metrics were obtained with the KAZE feature detector:

- **Root Mean Square Error (RMSE):** The RMSE for KAZE was 64.277065, which is lower than ORB but still higher than the results obtained with SIFT and SURF.
- **Relative RMSE:** The relative RMSE was 0.252067, indicating a moderate level of intensity discrepancies compared to ORB but not as efficient as earlier methods.

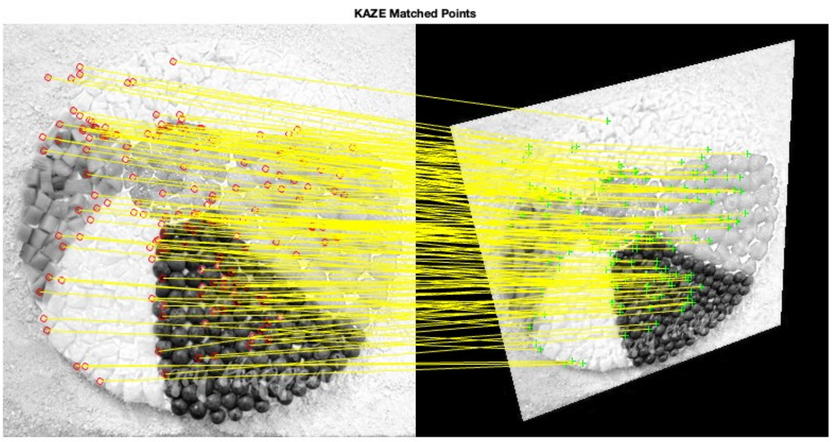

Figure 15: Matched points before registration using KAZE, showing the feature matching quality.

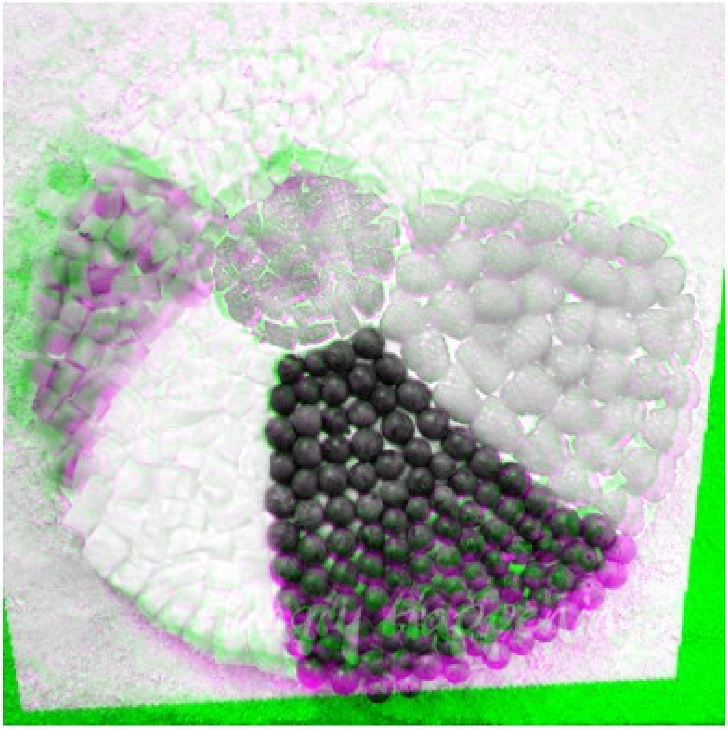

Figure 16: KAZE Registration output showing the moving image aligned with the fixed image. Notice the visual improvement in alignment compared to ORB but not as precise as SIFT or SURF.

3.5.2 Discussion

The use of KAZE yielded better results than ORB in terms of RMSE, suggesting it might be a suitable alternative for applications where feature detection needs to balance between detail capture and processing time. However, KAZE still did not achieve the low RMSE values seen with SIFT and SURF, indicating that while it handles some image details well, it may not be the best choice for all types of image registration tasks.

3.6 Experiment with Affine Transformations

Affine transformations were tested to evaluate their effectiveness in registering images with potential to handle rotations, translations, scaling, and shearing more flexibly than projective transformations.

3.6.1 Results for Affine Transformation

The registration using affine transformation yielded the following metrics:

- **Root Mean Square Error (RMSE):** The RMSE was measured at 104.943988, indicating a significant level of intensity discrepancy between the registered and the original images.
- **Relative RMSE:** The relative RMSE stood at 0.411545, suggesting that approximately 41.15% of the intensity information was altered, a substantial change.

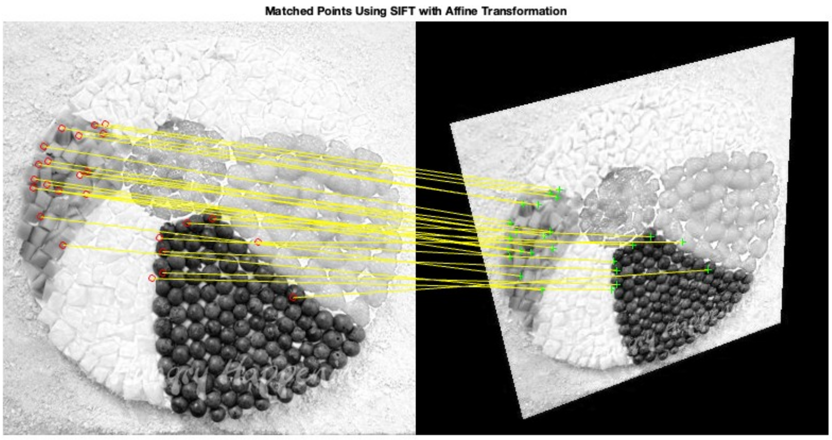

Figure 17: Matched points before registration using affine transformation, illustrating the feature matching quality.

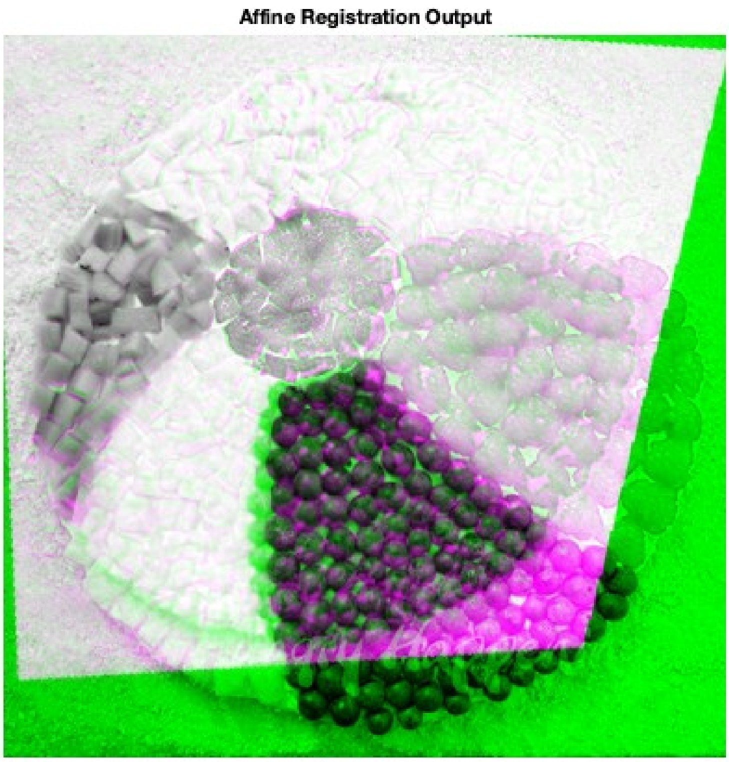

Figure 18: Affine registration output showing the moving image aligned with the fixed image. The image showcases the extent of intensity discrepancies highlighted by the RMSE results.

3.6.2 Discussion

The use of affine transformations, while theoretically providing a more adaptable registration framework, did not result in improved accuracy in this case. The high RMSE values suggest that the transformation might have introduced or failed to correct certain types of distortions present in the images. This highlights the need for possibly exploring even more advanced algorithms, like elastic transformations, or refining the feature detection and matching process further to enhance registration quality.

3.7 Experiment with Grid of Control Points

A grid of control points was systematically placed across the image to assess the spatial consistency of the registration using a projective transformation. This method aims to provide a comprehensive evaluation of the registration quality across the entire image.

3.7.1 Results for Grid of Control Points

The following metrics were recorded for the grid of control points:

- **Mean Grid Point Error:** The average error between the original and transformed grid points was 56.258507 pixels, indicating significant deviations in some regions of the image.
- **Maximum Grid Point Error:** The maximum error observed was 118.209824 pixels, highlighting areas where the registration process failed to maintain spatial accuracy.

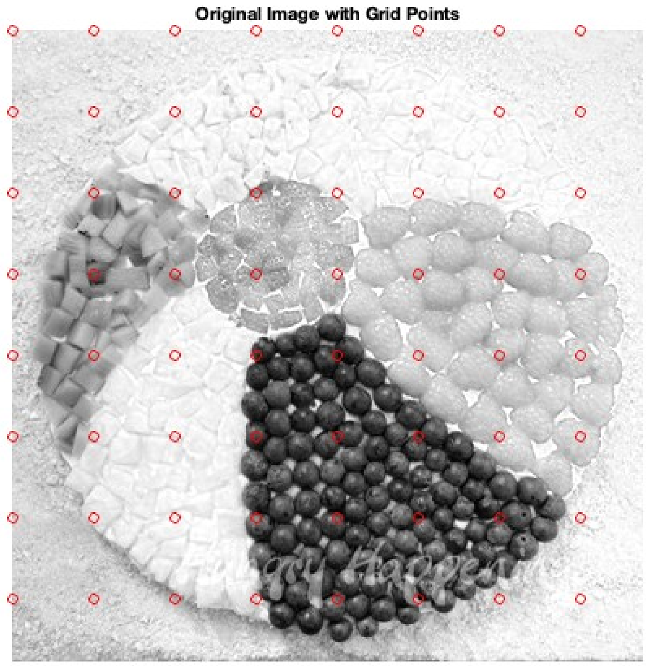

Figure 19: Original Image with Grid Points. The grid points are systematically distributed to cover the entire image area, providing a baseline for measuring registration accuracy.

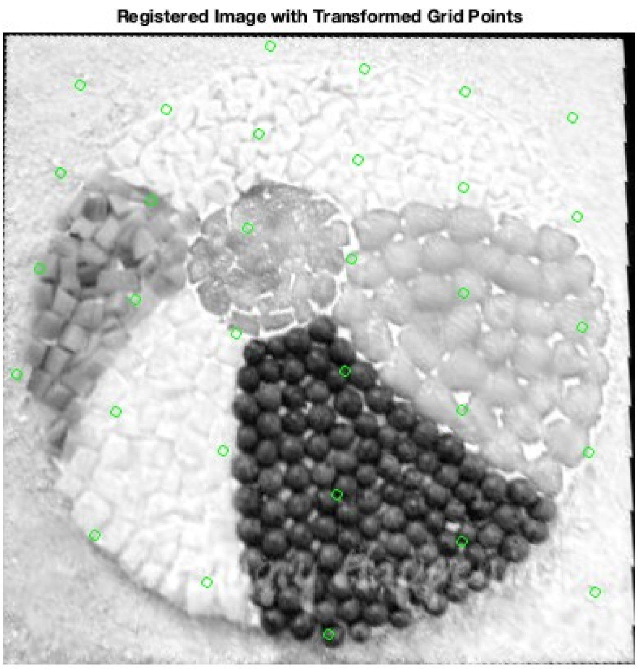

Figure 20: Registered Image with Transformed Grid Points. This figure shows the alignment of grid points post-registration, illustrating regions with significant misalignment.

3.7.2 Discussion

The experiment with a grid of control points revealed varying levels of registration accuracy across the image. The high maximum grid point error indicates that while the projective transformation aligns many parts of the image adequately, it struggles with others, potentially due to inherent limitations in handling complex distortions or misalignments in specific areas. This suggests that further refinement of the registration process or consideration of more sophisticated algorithms might be necessary to improve outcomes, especially in more challenging regions.

3.7.3 Results for Enhanced SIFT Detection

The adjustments made to the SIFT feature matching parameters significantly improved the registration quality. These enhancements were important in achieving a more precise alignment and a lower Root Mean Square Error (RMSE), indicating an improved accuracy of the registration.

Adjustments to Feature Matching Parameters Previously, the feature matching was performed using the default settings in MATLAB's `matchFeatures` function, which did not specify additional constraints beyond ensuring that the matches are unique. To enhance the matching accuracy and reduce the occurrence of incorrect correspondences, we adjusted several parameters:

- **MaxRatio**: We set the maximum ratio for the nearest to the second-nearest neighbor distance to 0.5. This stricter ratio helps in filtering out less reliable matches, as it only retains matches where the closest feature is significantly closer than the second closest.
- **MatchThreshold**: The threshold for accepting matches was set to 10.0. This lower threshold means that only matches with a distance that meets or exceeds this stringent criterion are considered, which aids in excluding weaker, potentially erroneous matches.

Impact of Adjustments The implementation of these more restrictive feature matching parameters led to a marked reduction in the number of false positives and an increase in the overall precision of the image registration process. The focused adjustments facilitated a more selective match process, which significantly contributed to the lower RMSE achieved. This demonstrates the effectiveness of fine-tuning the feature detection and matching parameters in enhancing the quality of multimodal image registration.

- **Root Mean Square Error (RMSE):** The RMSE was reduced to 14.382581, indicating a substantial decrease in intensity discrepancies between the registered and original images.
- **Relative RMSE:** The relative RMSE was 0.056402, demonstrating that the modifications to the feature detection approach effectively minimized the error, enhancing the fidelity of the registered image.

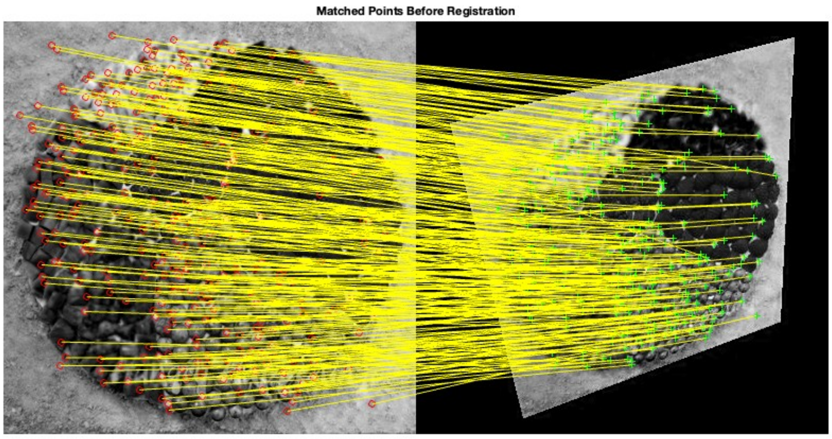

Figure 21: Matched points before registration using the enhanced SIFT parameters, showing improved quality and precision in feature matching.

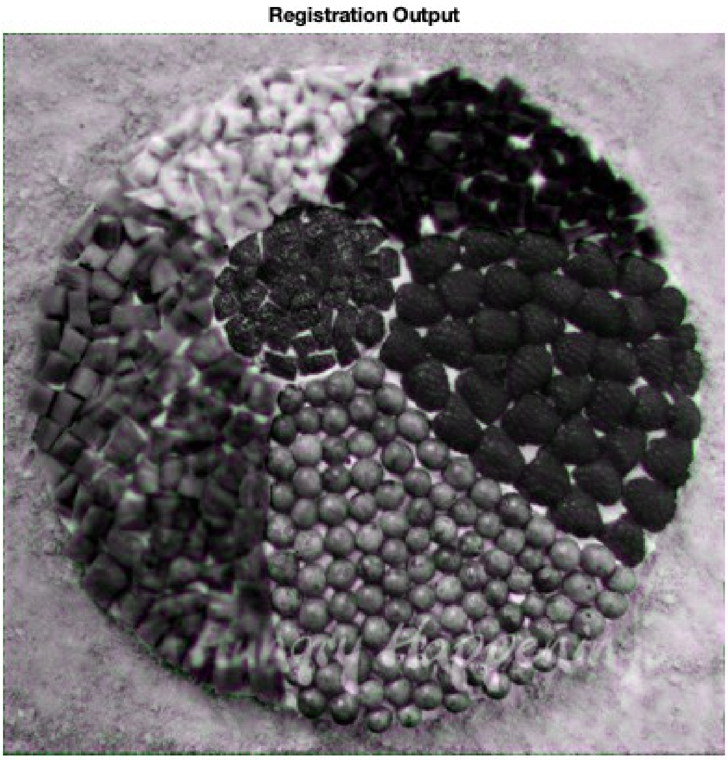

Figure 22: Registration output using the enhanced SIFT detection. This figure illustrates the significantly improved alignment and the effectiveness of the refined feature matching strategy.

3.7.4 Discussion

The enhancements to the SIFT feature detection and matching algorithms resulted in notably better registration results, with lower RMSE and relative RMSE values compared to previous methods. These improvements confirm the efficacy of fine-tuning feature detection parameters and matching criteria to address specific challenges in image registration. Future studies could explore further refinements or the integration of these methods with other image processing techniques to achieve even higher registration accuracy.

4 Analysis of Results

This section provides a detailed analysis of the experimental results obtained from various registration methods using different feature detectors and color channels. The analysis aims to identify the most effective approach for image registration under the given conditions.

4.1 Comparative Analysis

A comparative review of the experiments suggests that the choice of feature detection method and color channel significantly impacts the registration accuracy. The enhanced SIFT experiment, particularly when applied to the blue channel, provided the most substantial improvements in registration accuracy, as indicated by the lowest RMSE values.

4.1.1 Influence of Color Channels

The experiments with different color channels revealed that the blue channel consistently outperformed the red and green channels in terms of both intensity and geometric accuracy. This finding underscores the importance of channel selection in image registration tasks, particularly in scenarios involving varied lighting conditions and material properties.

4.1.2 Effectiveness of Feature Detection Methods

Among the feature detectors tested, SIFT, especially when enhanced through parameter tuning, proved to be the most reliable for capturing detailed features necessary for precise registration. In contrast, methods like ORB and KAZE, while faster, did not achieve the same level of detail preservation, resulting in higher RMSE values.

4.1.3 Role of Transformation Methods

The projective transformations generally provided more satisfactory results compared to affine transformations, which did not offer any notable advantage despite their theoretical flexibility. This suggests that the simpler projective model may often be adequate for many practical applications, unless specific distortions demand a more complex model.

4.2 Summary Table

The table below summarizes the key results from each experiment, highlighting the RMSE and Relative RMSE for a clearer comparison.

Table 1: Summary of Image Registration Experiments

Experiment	RMSE	Relative RMSE
Red Channel (SIFT)	22.778	0.089
Green Channel (SIFT)	27.185	0.107
Blue Channel (SIFT)	18.425	0.072
Blue Channel (Enhanced SIFT)	**14.383**	**0.056**
ORB Detector	107.886	0.423
KAZE Detector	64.277	0.252
Affine Transformation	104.944	0.412

4.2.1 Evaluation of Euclidean Errors

In addition to the RMSE and relative RMSE metrics, the Euclidean errors for manually and automatically detected control points were also evaluated. The following observations were made:

- **Manual Control Point Euclidean Error:** The average Euclidean distance between manually selected control points was 1.200465 pixels, indicating moderate geometric discrepancies.
- **Automatic Control Point Euclidean Error:** For the blue channel using enhanced SIFT, the error was 0.910642 pixels, the lowest observed among all methods, demonstrating superior geometric alignment.

5 Conclusion

Based on the analysis, it is evident that using the enhanced SIFT method on the blue channel provides the most accurate results. Future efforts should focus on further optimizing this approach, potentially exploring additional adjustments in feature matching parameters and considering the use of elastic transformations for cases requiring handling of non-rigid deformations.

References

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