Competitive Constellation Detection Using Template Matching and Geometric Analysis

Team: Binary Stars

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Abstract

This paper presents a method for detecting constellations in astronomical sky images using template matching and geometric star pattern analysis. The proposed approach identifies valid star patches, rejects erroneous patches, and predicts the main constellation in a given sky image. The pipeline combines image preprocessing, multi-scale template matching, adaptive thresholding, and Procrustes-based geometric alignment to achieve robust constellation classification. Results demonstrate the effectiveness of the approach in handling variations in star brightness, patch scale, and background noise.

Preface

This work was completed as part of the Computer Vision course at NYU Tandon School of Engineering during the Fall 2025 semester. The project was designed to challenge us in astronomical image analysis, template matching, and geometric pattern recognition. We thank the course instructors and our peers for their guidance and valuable feedback.

Acknowledgements

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Introduction

Astronomy has long relied on visual observation and pattern recognition to identify constellations in the night sky. Modern computational approaches enable automatic detection and classification of constellations using digital sky images. In this project, we address the problem of identifying constellations from star field images, where patches of stars are extracted from sky images, and the algorithm must distinguish between valid and erroneous patches. Our goal is to produce accurate coordinates of valid star patches and predict the corresponding constellation.

Related Work

Previous work in astronomical image analysis has focused on template matching, feature extraction, and pattern recognition for star detection. Methods often employ:

- Thresholding and morphological operations for star localization.
- Template matching for identifying known patterns.
- Geometric alignment methods like Procrustes analysis to handle scale, translation, and rotation invariance.

This project builds on these techniques by combining multi-scale template matching with geometric ratio-based matching for robust constellation classification.

Dataset Description

The dataset consists of:

- **patterns/**: Reference constellation pattern images.
- **train/**: Labeled sky images with extracted patches for validation and testing.
- **validation/**: Unlabeled sky images for the main evaluation.

Each constellation folder contains one sky image (`.tif`) and multiple star patches (`.png`). Patches can be valid stars of the main constellation, stars from neighboring constellations, stars from different sky images, or non-existent stars, requiring the algorithm to carefully accept or reject each patch.

Methodology

Data Loading and Organization

Pattern and sky images are loaded dynamically into dictionaries:

- Pattern names mapped to images (`pattern_img_table`).
- Constellation folder names mapped to (sky image, list of patches) tuples (`constellation_table`).

Maximum patch counts are recorded for CSV output formatting.

Image Preprocessing

Sky and patch images are preprocessed to enhance star visibility:

1. Conversion to grayscale.
2. Normalization to 8-bit intensity values.
3. Contrast enhancement using CLAHE.
4. Top-hat morphological filtering to highlight bright stars.
5. Optional Gaussian sharpening.

These steps reduce background noise and standardize images for matching.

Patch Matching

Patches are matched to sky images using multi-scale template matching:

- Resized to multiple scales to account for variations.
- `cv2.matchTemplate` computes correlation scores.
- Adaptive thresholding accepts high-confidence matches and rejects low-confidence patches.

Accepted patches are recorded with their center coordinates; rejected patches are assigned `-1`.

Geometric Constellation Classification

Using accepted patch coordinates:

1. Construct a sky mask with circles at patch centers.
2. Extract star centroids.
3. Compute normalized inter-star distance ratios.
4. Match coordinates to pattern templates using distance ratios and Procrustes alignment.
5. Select the pattern with the lowest Procrustes disparity as the prediction.

CSV Output

Results are written into a CSV with:

- Sequential index.
- Folder name.
- Patch coordinates (x, y) or `-1`.
- Predicted constellation label.

Columns are padded with `-1` where necessary.

Experiments and Results

We applied the proposed pipeline to validation data. Our preprocessing and multi-scale template matching successfully detected valid patches. The geometric classification algorithm correctly aligned extracted star coordinates with reference patterns, producing accurate constellation predictions. Rejected patches were correctly assigned `-1`, preventing contamination of classification results.

Evaluation: Uploading the resulting `aaj6301_validation_results.csv` yielded a perfect score of **1.00** on 41% of the test set, demonstrating the accuracy of our patch detection and constellation classification.

Discussion

We note the following points about our approach:

- **Adaptive thresholding:** Balances sensitivity and false positives.
- **Multi-scale matching:** Handles star size variability.
- **Geometric matching:** Provides invariance to translation, rotation, and scale.
- **CSV padding:** Ensures compatibility with scoring scripts.

Limitations include computational cost for dense star fields and dependency on pattern completeness.

Conclusion

In this work, we present a pipeline for constellation detection. By combining preprocessing, template matching, adaptive thresholding, and geometric alignment, our system achieves robust patch detection and accurate constellation classification. The approach generalizes to unseen constellations without code modification. Uploading `aaj6301_validation_results.csv` yielded a perfect test score of **1.00** on 41% of the dataset, confirming the effectiveness of our method.

References

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