Star Tracker without a Star Database

Stephen Scott
COMPENG 4TN4
Instructor: Seyed Mehdi Ayyoubzadeh

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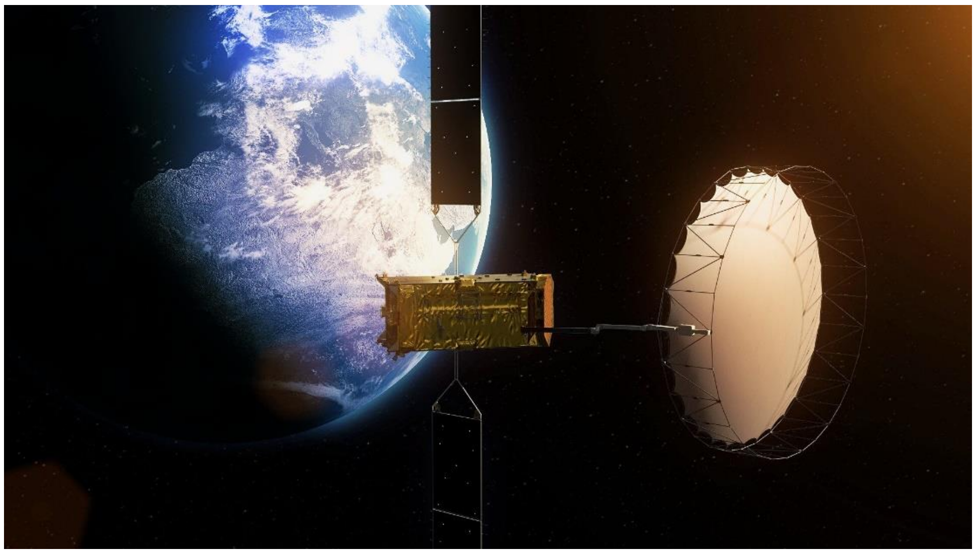
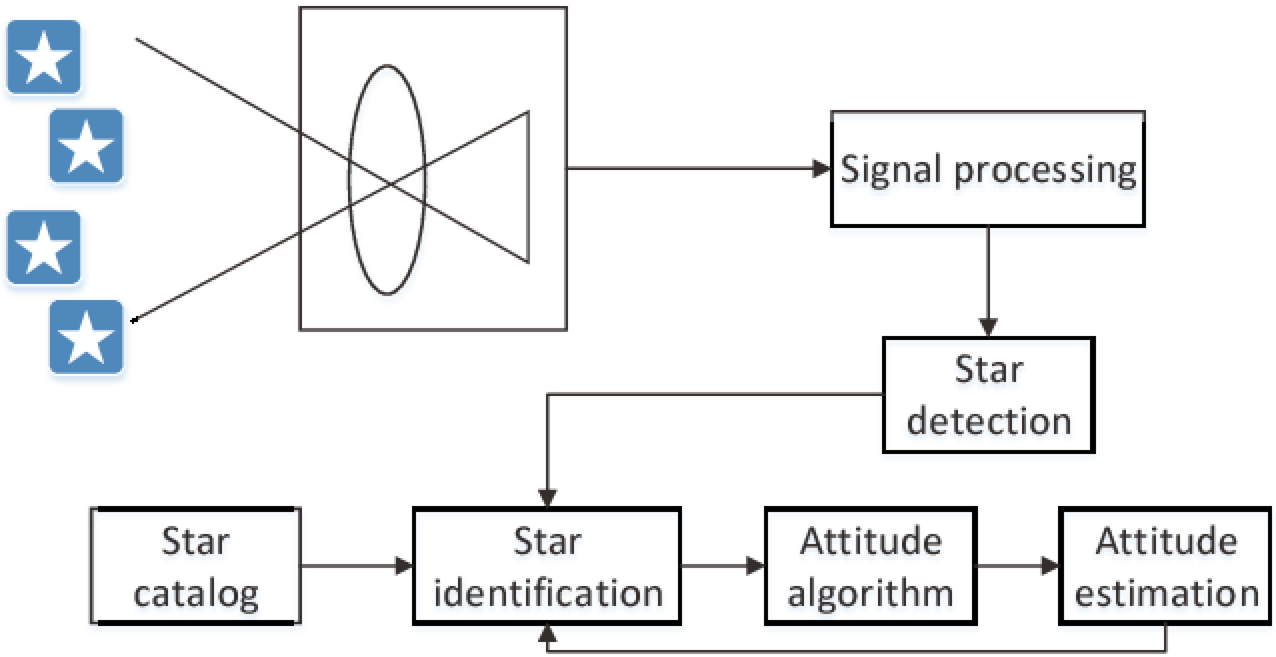
What is a star tracker?



European Space Agency. Alphasat. 2013

- Camera system often found on satellites
- Expensive to implement effectively, not often used on low-budget nanosatellites

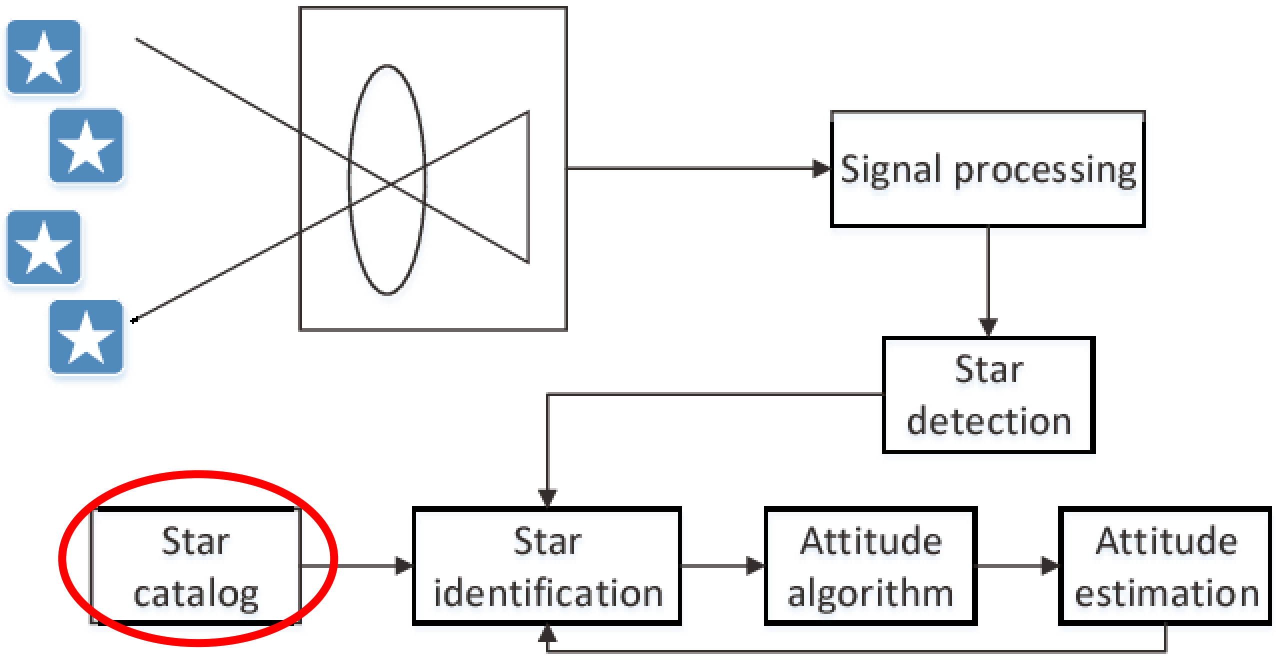
Why do satellite's need a star tracker?



Jianan, Y. et al. "Pico-satellite attitude determination using a star tracker with compressive sensing". 2015

- Helps to stabilize the satellite (reduce pointing error)
- Used in trajectory control system

The issue with star trackers



Jianan, Y. et al. "Pico-satellite attitude determination using a star tracker with compressive sensing". 2015

- Star lookup is computationally expensive
- Expertise in subject is needed to implement effectively (not helpful to small missions like university CubeSats)

Related work

H. Yoon, Y. Lim, and H. Bang. New star-pattern identification using a correlation approach for spacecraft attitude determination. Journal of Spacecraft and Rockets, 48(1), 2011.

Correlation algorithm

- Compare image to on-board database and maximize cost function
- Stars as Gaussian distributions
- Correlate images in image space using heat map

T. Delabie, J.D. Schutter, and B. Vandenbussche. Highly efficient attitude-estimation algorithm for star trackers using optimal image matching. Journal of Guidance, Control, and Dynamics, 36(6), 2013.

Optimal image matching

- Match pairs of images optimally on top of each other
- Eliminates complex coordinate conversions
- Uses Euclidean squared distance

K.T. Kim and H. Bang. Reliable star pattern identification technique by using neural networks. The Journal of the Astronautical Sciences, 52:239–249, 2004.

Neural Network

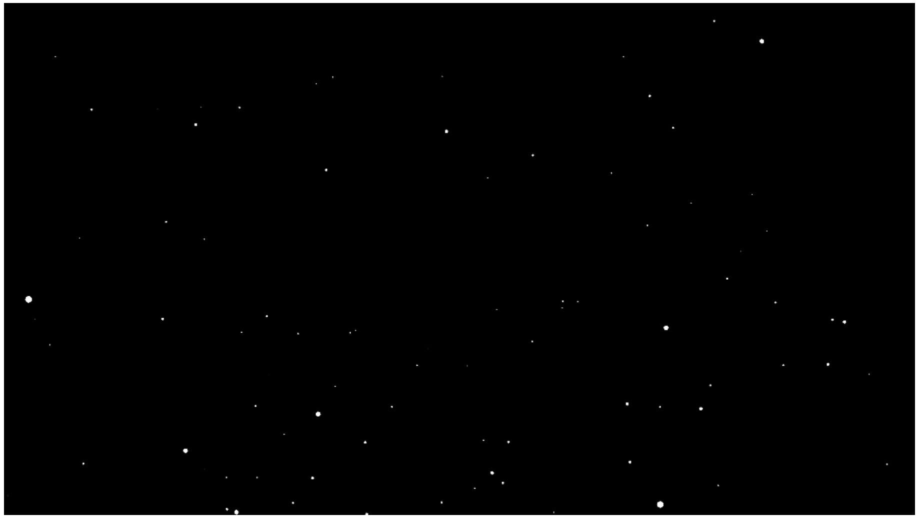
- Use neural network to maximize star lookup efficiency
- Group neighbouring stars together in database

The proposed method

1. Generate simulated star image dataset using open-source planetarium (Stellarium)

Original Image

Preprocessed Image

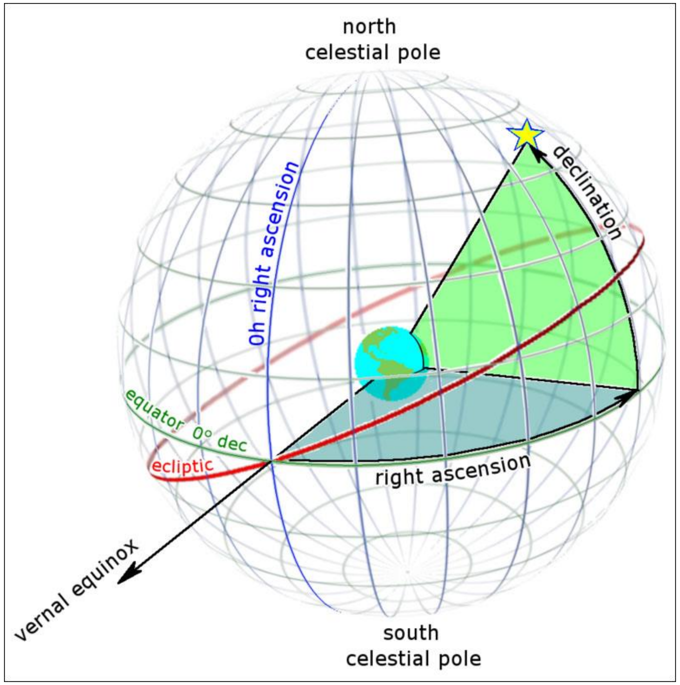


Stellarium 0.22.0. https://stellarium.org. 2022

- 2,592 images by incrementing right ascension/declination angles by 5 degrees
- Deep space objects, milky way, and other elements disabled in Stellarium
- Gaussian blurred with sigma = 2, binarized using Otsu optimal threshold

The proposed method

1. Generate simulated star image dataset using open-source planetarium (Stellarium)

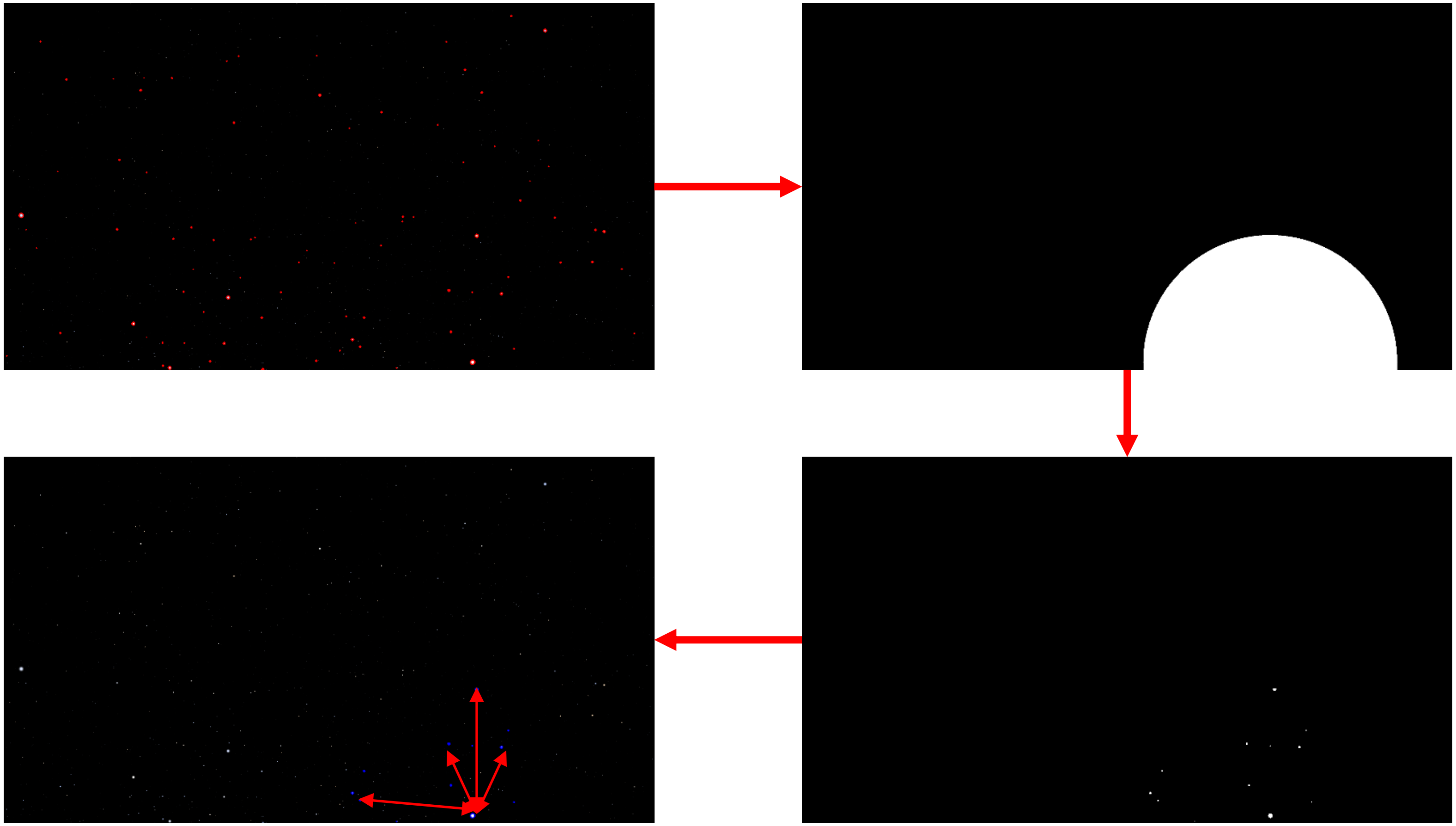


King, B. Right Ascension & Declination: Celestial Coordinates for Beginners. 2019

- Images were further classified into 4 regions based on RA and DEC
- North-East, North-West, South-East, and South-West

The proposed method

2. Find largest contour, get 4 brightest stars in region around largest contour



Stellarium 0.22.0. https://stellarium.org. 2022

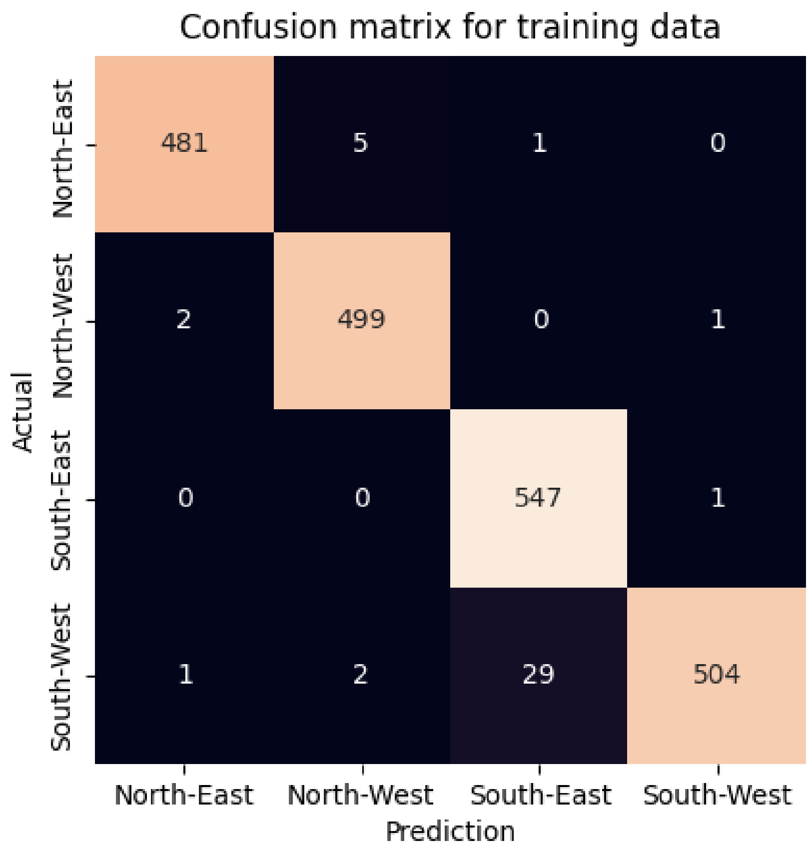
The proposed method

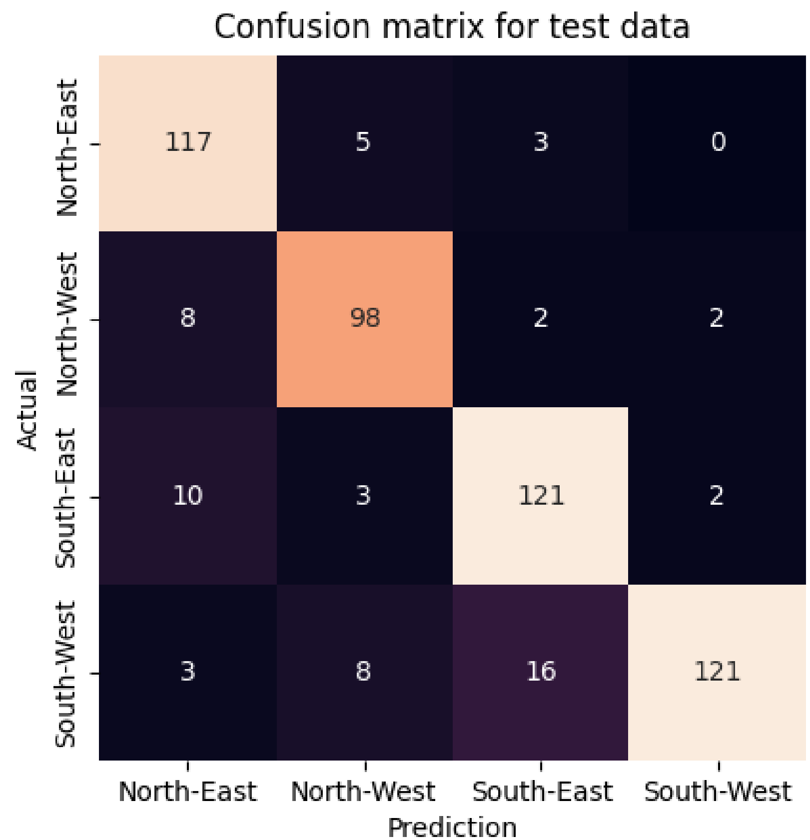
3. Train Support Vector Machine (SVM) using feature vector

Feature No.	Feature Description
1	Radius of brightest star (star 1)
2	# non-zero pixels around brightest star
3	Radius biggest star in local region (star 2)
4	Radius 2nd biggest star in local region (star 3)
5	Radius 3rd biggest star in local region (star 4)
6	Radius 4th biggest star in local region (star 5)
7	Euclidean distance stars 1:2
8	Euclidean distance stars 1:3
9	Euclidean distance stars 1:4
10	Euclidean distance stars 1:5
11	Euclidean distance stars 2:3
12	Euclidean distance stars 2:4
13	Euclidean distance stars 2:5
14	Euclidean distance stars 3:4
15	Euclidean distance stars 3:5
16	Euclidean distance stars 4:5

Matrix norm computed

The proposed method: Results



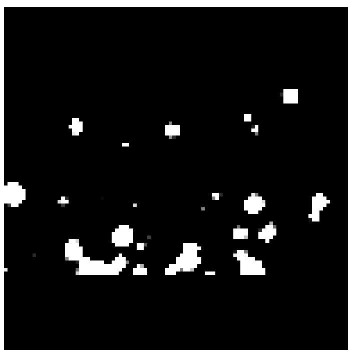


- Struggles with distinguishing between South-East/West skies
- 88.1% accuracy on the test set

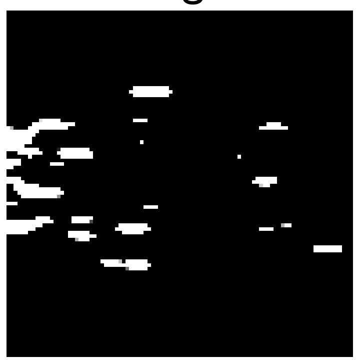
The alternate method

1. Downscale images to 96x96
2. Blur images with Gaussian blur (sigma = 40) to reduce sparsity
3. Augment the dataset with rotated images

0 degrees



90 degrees



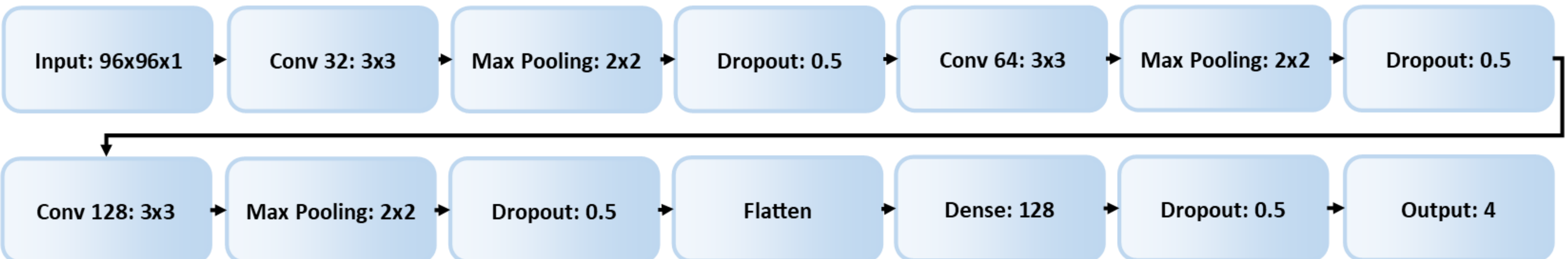
180 degrees

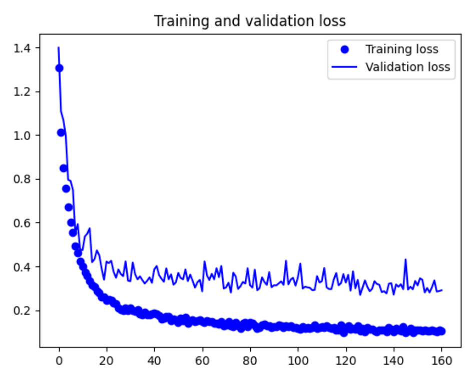
270 degrees

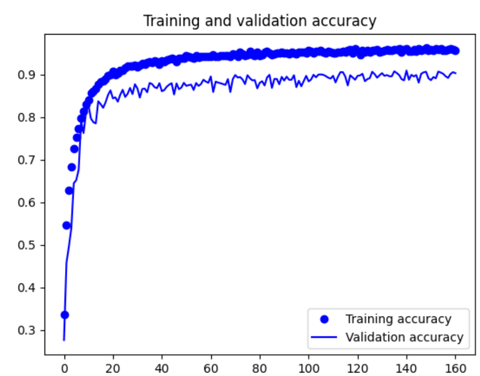
- Augmented dataset has 10,368 images

The alternate method

4. Train a Convolutional Neural Network on the augmented dataset

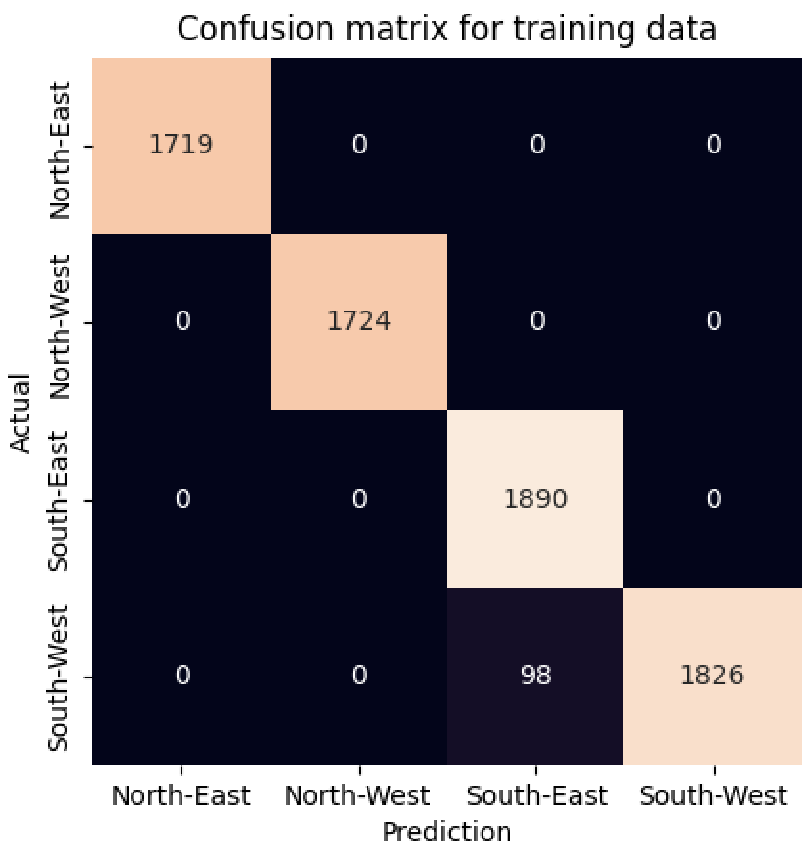


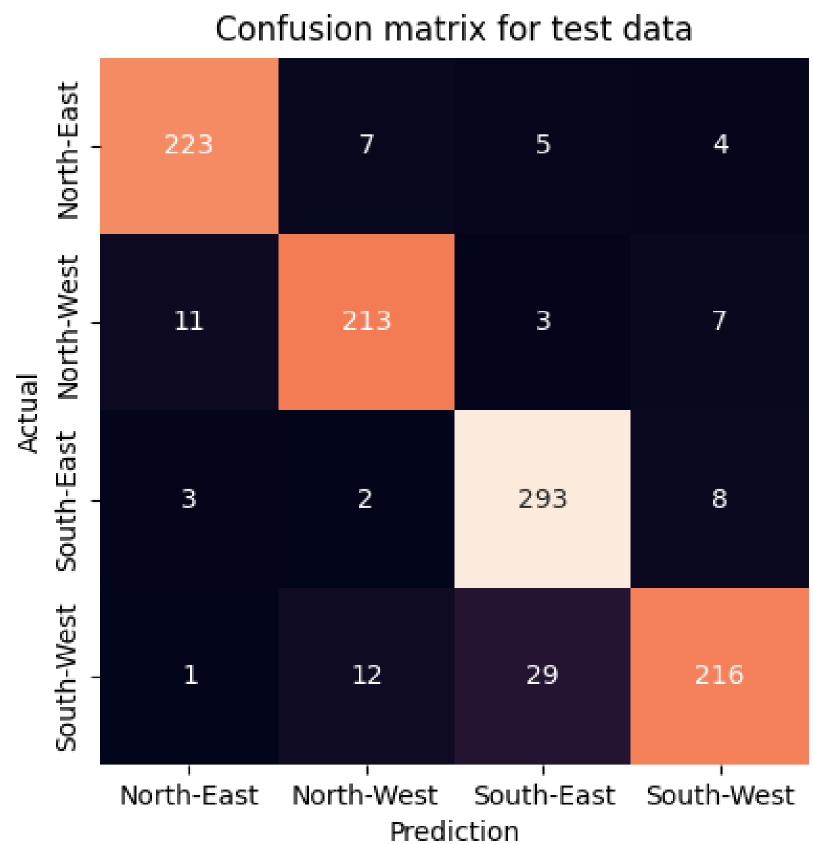




- Adam optimizer used with learning rate = 0.001
- Batch size = 32

The alternate method: Results





- Also struggles with distinguishing between South-East/West skies
- 91.1% accuracy on the test set