# Sunspot classification using artificial intelligence


## Eduard Plic
## Masaryk Grammar School


## Abstract


Sunspots, visible through telescopes or with the naked eye at sunset, are caused by the Sun's magnetic field. Studying these phenomena is crucial for predicting solar activity and understanding the Sun's cycle. My research focuses on automating the recognition, classification, and analysis of sunspots using hand-drawn observations from the Astronomical Institute of the Czech Academy of Sciences. I trained a convolutional neural network to label sunspots based on the McIntosh classification system, aiming to bridge deep learning with solar


## Sunspots

Sunspots are dark areas on the Sun caused by magnetic disturbances, consisting of a dark umbra and lighter penumbra. They are linked to solar flares and eruptions, which can impact Earth, causing auroras, aviation disruptions, and power grid failurest

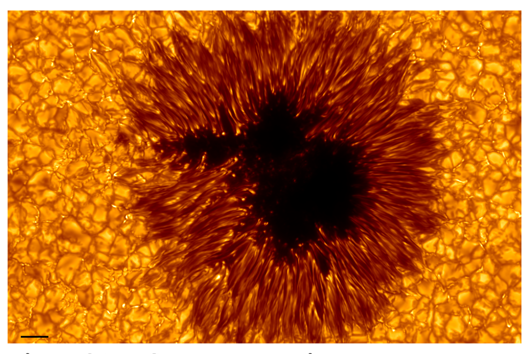

Fig. 01: Sunspot with observable umbra and penumbra

## Sunspot drawing

One of the earliest methods for capturing sunspots involved projecting the Sun's image onto paper. This simple technique has been used for centuries and is still relevant for improving solar predictions when satellite data is lacking. However, the number of sunspot observers has declined, and public awareness of these historical records is low.

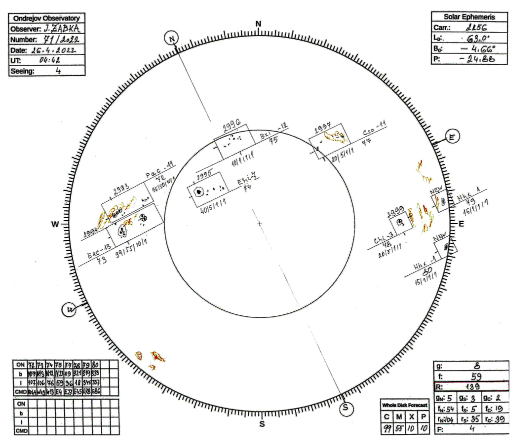

Fig. 02: Sunspot drawing from the Astronomical Institute of the Czech Academy of Sciences

## McIntosh classification

Classifying sunspots is crucial for understanding solar activity. I used the McIntosh classification, which relies on visible data and is accessible for amateur astronomers. Each sunspot group is labeled with three letters indicating size, properties of the largest sunspot, and distribution within the group, with different associations to potential solar eruptions.

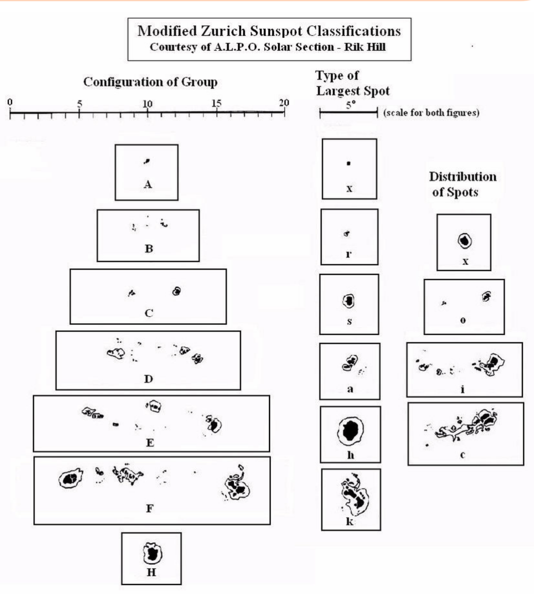


Fig. 03: Visualisation of each group of McIntosh classification system

## Neural networks

Neural networks, used in applications like large language models (LLMs) and image recognition, consist of neurons that compute values based on previous output. They generally consist of three types of layers: input, output, and hidden layers, enabling them to perform complex calculations. A convolutional neural network (CNN) is a type of neural network designed for processing images. CNNs use filters, or kernels, to analyze and extract features from images.

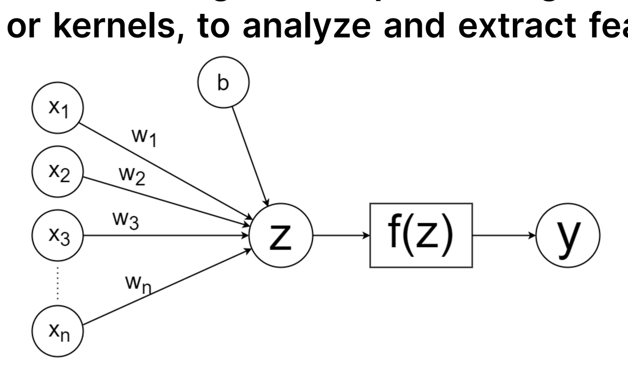


Fig. 04: Calculation of neuron value: A neuron's value $y$ is determined by applying an activation function $f(z)$ to the sum $z$ of the weighted inputs $xi$ plus a bias $b$.

## Metods - Preprocesing

The preprocessing was automatized via python. Having the sunspotdrawing, I adjust its size and contrast to improve the results of findingrectangels by library OpenCV.

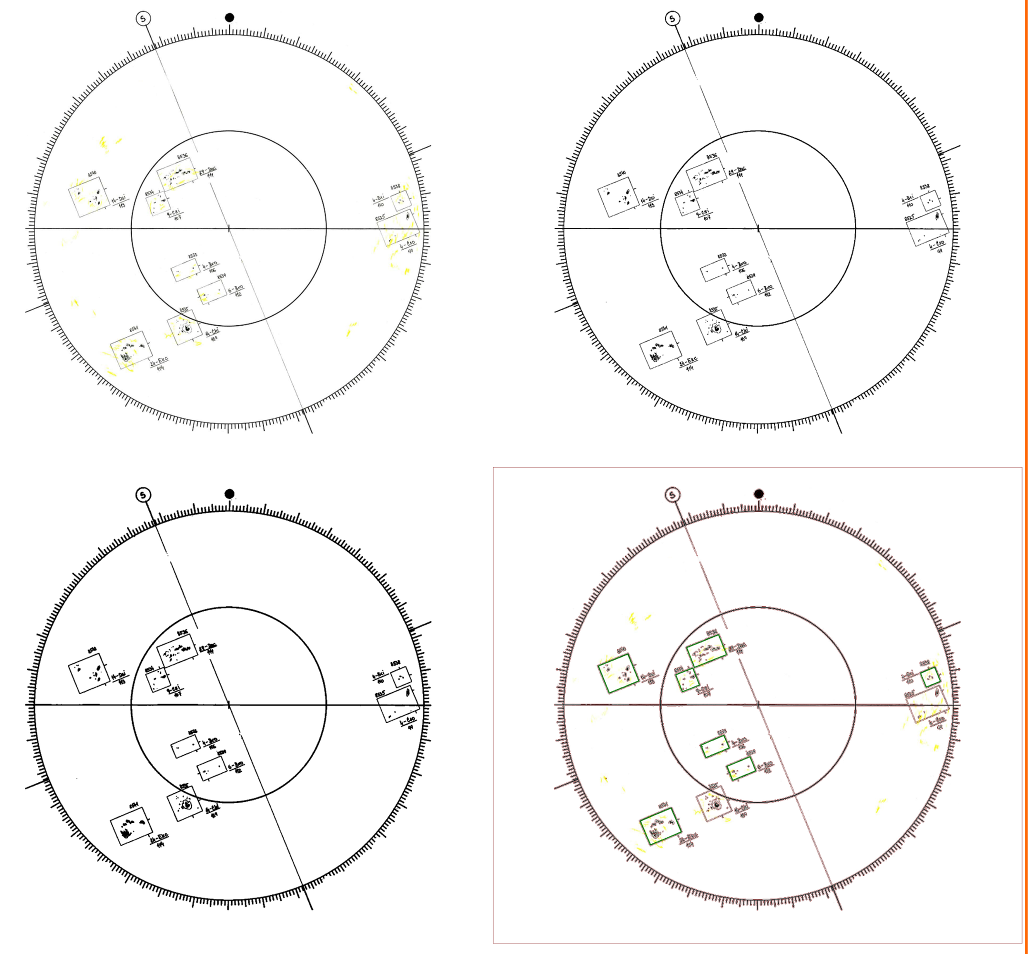

Fig. 05: Shown adjustments. [05a] Resized sunspot drawing, focusing on the area of interest. [05b] Removed yellow filaments. [05c] Enhanced contours by applying blurring and converting the image to black and white. [05d] Applied contour detection, with detected rectangles highlighted in green.

Next, I extracted the individual sunspot groups, removed the background, and inverted the colors.

Fig. 06: Preprocess of individual sunspot groups. [06a] Extracted the square area containing the sunspot. [06b] Removed surrounding areas based on the detected rectangle. [06c] Inverted the colors to enhance machine learning performance.

## Metods - CNN Training

The dataset preparation involved labeling the black-and-white sunspot images with their classifications from the McIntosh system. I then divided the dataset into training, validation, and test sets in an 80-10-10 ratio.

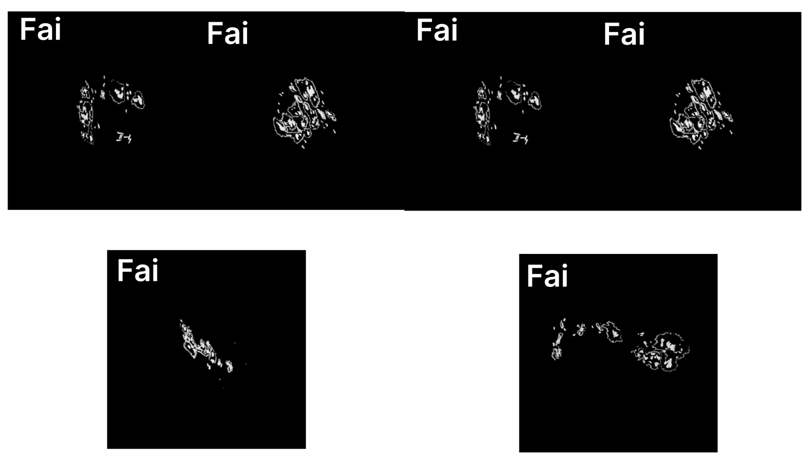


Fig. 07: Visualization of dataset split into training, validation, and test groups.

With this structure, I began training the CNN in Python using libraries like Keras and TensorFlow. I selected the final model based on the validation loss function, choosing the one where the loss was minimal.

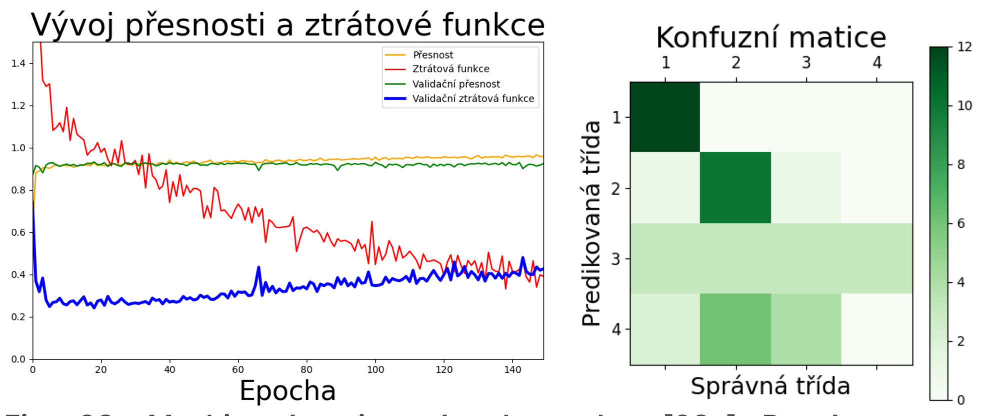


Fig. 08: Machine learning-related graphs. [08a] Development of precision and loss functions on training and validation data during model training. [08b] Example of a confusion matrix.

Once the model was trained, I ran predictions on the test set and evaluated its accuracy, not only in percentages but also using a confusion matrix.

## Ressults

I've trained several convolutional neural network (CNN) models capable of detecting sunspots at varying levels of complexity, showcasing the potential applications of AI in solar astronomy. Additionally, I have outlined several pathways for future research in this field.

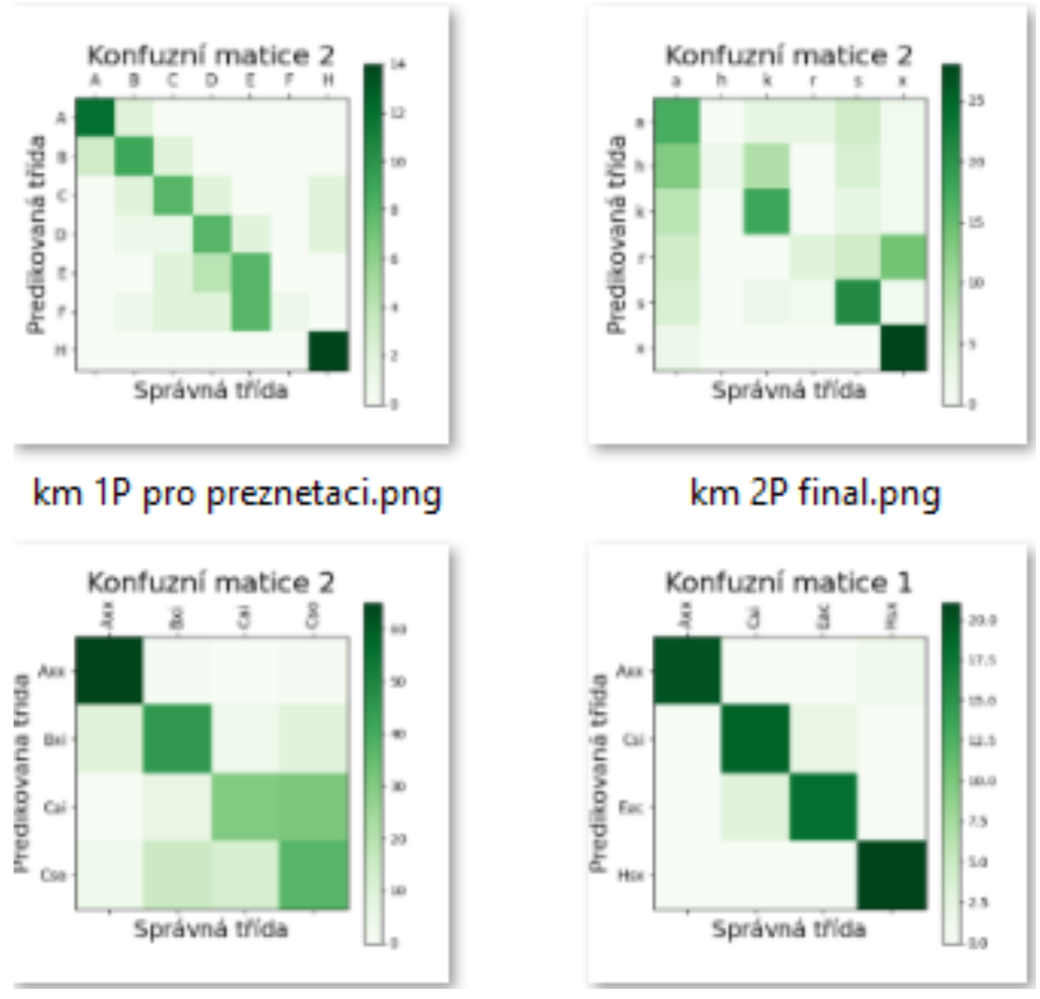


Fig. 09: Confusion matrices of selected models. [09a] Model for classification between 4 groups, with 96% accuracy. [09b] Model for predicting the first letter of the McIntosh classification, with 55% accuracy. [09c] Model for predicting the second letter of the McIntosh classification, with 55% accuracy. [09d] Model for predicting the third letter of the McIntosh classification, with 35% accuracy.

## Future

Future work could focus on developing more accurate models, improving spot detection, or incorporating data from additional observatories. Expanding model complexity with deeper layers and more neurons could also enhance precision. Another direction is creating a tool for automatic sunspot classification, aiding observatories in verifying manual classifications.

Fig. 10: Sunspot group as drawn at Kanzelhöhe Observatory, Germany.

## Sources


[1] Astronomická jednotka. In: Wikipedia: the free encyclopedia [online]. San Francisco (CA): Wikimedia Foundation, c2024 [cit. 2024-03-11]. Dostupné z: https://cs.wikipedia.org/w/index.php?title=Astronomick%C3%A1_jednotka&oldid=23683910

[2] Solar radius. In: Wikipedia: the free encyclopedia [online]. San Francisco (CA): Wikimedia Foundation, c2024 [cit. 2024-03-11]. Dostupné z: https://en.wikipedia.org/w/index.php?title=Solar_radius&oldid=1210839025

[3] Struktura Slunce. POZOROVÁNÍ SLUNCE [online]. [cit. 2024-03-12]. Dostupné z: https://pozorovanislunce.eu/slunce/struktura-slunce.html

[4] The Sun. In: Wikipedia: the free encyclopedia [online]. San Francisco (CA): Wikimedia Foundation, c2024 [cit. 2024-03-12]. Dostupné z: https://upload.wikimedia.org/wikipedia/commons/thumb/d/d4/Sun_poster.svg/1024px-Sun_poster.svg.png