AI in Solar Astronomy: Potential and Possibilities

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Abstract

Sunspots, observable 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 solar cycle. This 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. A convolutional neural network (CNN) was trained to label sunspots based on the McIntosht classification system, bridging deep learning with solar astronomy.

Methods

The preprocessing and classification of sunspot data were automated using Python. The initial dataset consisted of hand-drawn sunspot observations (Figure 1), which were prepared for machine learning through several adjustments (Figure 2 and 4). The processed images were then labeled according to the McIntosh classification system (Figure 3).

For model training, the dataset was divided into training, validation, and test sets in an 80-10-10 ratio (Figure 5). A Convolutional Neural Network (CNN) was used for sunspot classification, utilizing libraries such as Keras and TensorFlow. Model selection was based on the validation loss function, with the goal of minimizing this loss. Predictions were then run on the test set, and results were evaluated using accuracy metrics and a confusion matrix.

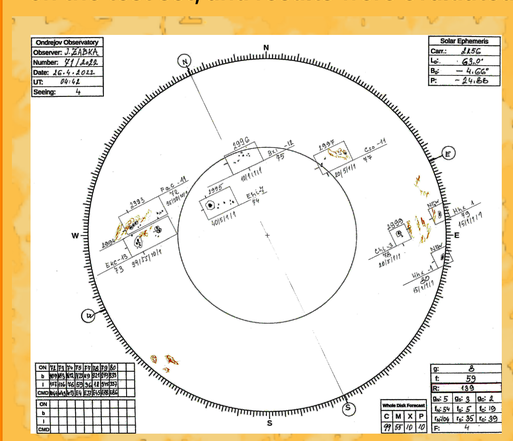

Figure 1: Original sunspot drawing from April 26, 2022, by the Astronomical Institute of the Czech Academy of Sciences.

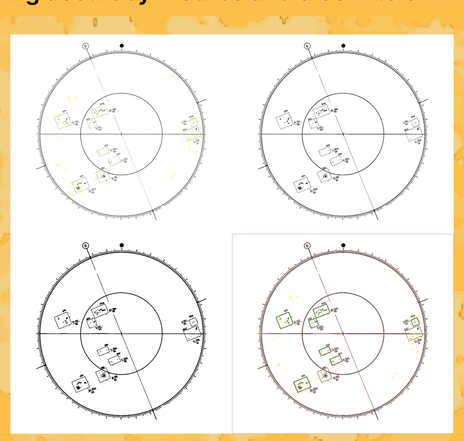

Figure 2: Preprocessing of sunspot drawing:
- Upper-left: Key area of the drawing
- Upper-right: Removed yellow filaments
- Lower-left: Enhanced contours using blur and black-and-white conversion
- Lower-right: Highlighted detected contours in green

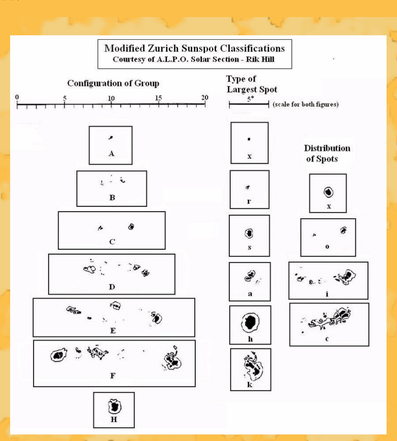

Figure 3: Visualization of each group in the McIntosh classification system. This system classifies sunspots using three letters to indicate size, the properties of the largest sunspot, and group distribution.

Figure 4: Preprocessing of individual sunspot groups: Upper-left: Extracted square area containing the sunspot; Upper-right: Removed surrounding areas based on the detected rectangle; Lower-left: Inverted colors to enhance machine learning performance; Lower-right: Visualization of labeling for supervised machine learning.

Figure 5: Visualization of dataset split into training, validation, and test groups.

Results

Several CNN models were trained to detect sunspots at varying levels of complexity, demonstrating the potential applications of AI in solar astronomy. Additionally, several pathways for future research in this field have been outlined.

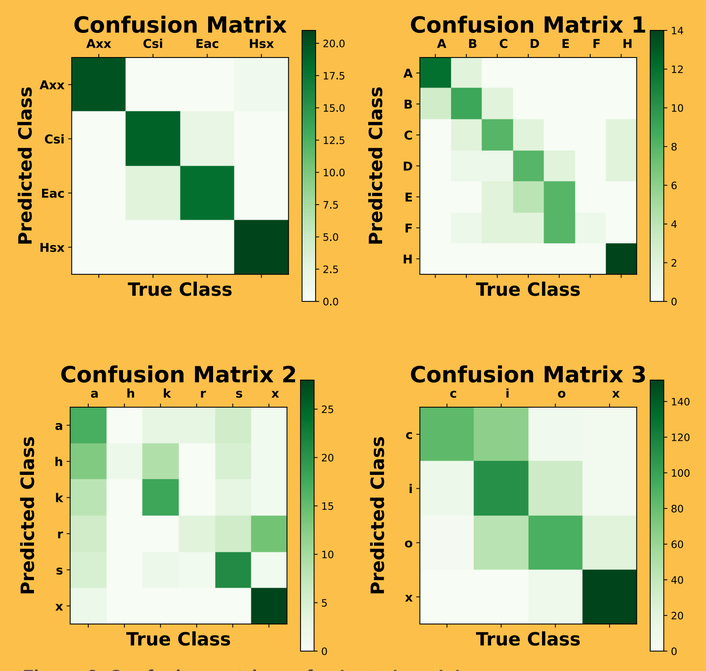

Figure 6: Confusion matrixes of selected models:
- Upper-left: Model for classification between 4 groups (93% accuracy)
- Upper-right: Model for predicting the first letter of the McIntosh classification (61% accuracy)
- Lower-left: Model for predicting the second letter of the McIntosh classification (50% accuracy)
- Lower-right: Model for predicting the third letter of the McIntosh classification (68% accuracy).

Future Possibilities

Future work could focus on developing more accurate models, improving sunspots detection, and incorporating data from additional observatories (Figure 7). Increasing model complexity with deeper layers and more neurons could enhance precision. Another direction is creating a tool for automatic sunspot classification to aid observatories and amateurs in verifying manual classifications.

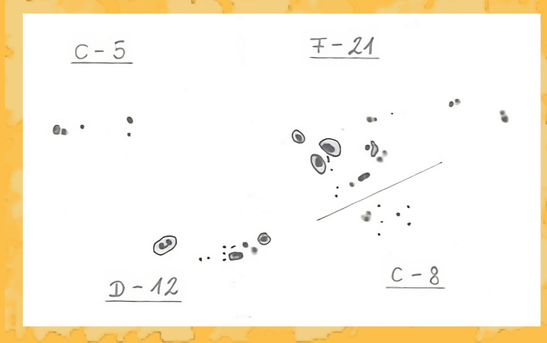

Figure 7: Two sunspot groups as drawn at Kanzelhöhe Solar Observatory, Austria. Both classified using the Zurich classification system.

Sources

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Acknowledgments:
Ing. Martin Bulín, M.Sc.
Martina Pavelková
RNDr. Miroslav Randa, Ph.D.
Lumír Honzík
Dr. Werner Pötzi

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